# SELECTED MONOGRAPHS:

KUSSMAUL AND TENNER

ON

## EPILEPTIFORM CONVULSIONS FROM HÆMORRHAGE.

WAGNER

ON THE

## RESECTION OF BONES AND JOINTS.

GRAEFE'S THREE MEMOIRS

ON

## IRIDECTOMY IN IRITIS, CHOROIDITIS, AND GLAUCOMA.

THE NEW SYDENHAM SOCIETY,

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MDCCCLIX.

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ON

# THE NATURE AND ORIGIN

OF

# EPILEPTIFORM CONVULSIONS

CAUSED BY

# PROFUSE BLEEDING,

AND ALSO OF THOSE OF

# TRUE EPILEPSY.

BY

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NATURE AND ORIGIN

OF

# THE EPILEPTIC CONVULSIONS

WHICH FOLLOW

PROFUSE HÆMORRHAGE.

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## CHAPTER I.

### INTRODUCTION.

In man, and, as it would appear, in all warm-blooded animals also, a rapid and sufficiently copious loss of blood will give rise to general convulsions. Even those not in the profession must long ago have become acquainted with this when watching animals in the slaughter-house during death by stabbing of the heart or vessels of the neck. It is well known that such is the fact in fowls, sheep, and swine, and Kohl informs us that it obtains also in the whale.

Hippocrates[1] taught that convulsions might arise as well from fulness as from want of blood. Kellie[2] made experiments with sheep and dogs, Piorry[3] did the same with dogs, and both frequently noticed convulsions after a profuse abstraction of blood; we have also ourselves observed, without a single exception, in many cases of dogs, cats, and rabbits,[4] the occurrence of violent and general convulsions

[1] 'Aphorisms,' sect. vi, 48. *Σπασμοὶ γίνονται ἢ ὑπὸ πληρώσιος ἢ κενώσιος, οὕτω δὲ καὶ λύγμος.*

[2] Marshall Hall, 'On Bloodletting.'

[3] 'Archives générales de Médecine,' January, 1826.

[4] Frogs, from which we extracted the heart, died after breathing for upwards of an hour, at first making frequent lively motions, then gradually becoming weaker; but we could discover no signs of convulsions.

during death from loss of blood. Most of the best hand-books on pathology and forensic medicine also assert that great loss of blood in men frequently brings on convulsions, and that death during such convulsions often takes place after it.[1]

More attention has unquestionably been paid by English physicians than by others to the subject of convulsions arising from loss of blood. The frightful vampyrism prevalent in the British islands may have afforded them greater opportunities of observing such dangerous consequences than would be presented elsewhere. Wardrop is of opinion that frequently in inflammations as much as from thirty to fifty ounces may be drawn in the first venesection, and that sometimes even from 100 to 200 ounces may be taken away; and Marshall Hall, from whose work on bloodletting this statement is made, mentions many cases from the practice of himself and others in which from 100 to 120 ounces of blood were taken away in a short space of time. It is, therefore, no wonder that we have received from England the first explanations of the hydrencephaloid disease arising from exhaustion, as well as more accurate notions on convulsions after great losses of blood; and as Marshall Hall, that indefatigable investigator of the physiology and pathology of the nervous system, has gained very great renown from his elucidations of the theory of bloodletting generally, so has he been the first to characterise the hydrencephaloid disease and to examine more closely than any one before him into the nature of convulsions arising from hæmorrhage.

This accomplished physician, in his celebrated work above referred to, remarks, that convulsions, next to swooning, are the most usual and immediate effects of great losses of blood. If they come on after venesection, the presumption is that the quantity taken away has been too large. In his own practice, as well as in that of others, excessive bleedings often occasioned convulsions, which endangered the patients' lives. Travers[2] even mentions (according to Marshall Hall) an idiosyncrasy averse to loss of blood, which manifests itself by a great disposition to convulsions. Many patients were so utterly unable to bear abstraction of blood that they soon fell into con-

[1] If hæmorrhage takes place slowly, and the vital powers are gradually consumed, death appears then to ensue with swooning, drowsiness, delirium, and vascular irritation, without convulsions. Compare M. Hall's experiments on dogs, and the numerous clinical observations published by him.

[2] 'On Constitutional Irritation,' p. 50.

vulsions, whilst the circulation became so feeble that they were often obliged to have stimulants employed for many hours before they recovered. A clergyman, from whom 20 ounces of blood were taken, had fits which came on at intervals and resembled most violent puerperal convulsions. It was only by the continual administration of stimulants for a whole day that danger was averted. Operations in which loss of blood was unavoidable were often followed by a disposition to convulsions, by which children in particular frequently died. Marshall Hall knew a case of a child dying of convulsions the day after the removal of an ordinary-sized nævus from the head, without any subsequent hæmorrhage. Travers had pointed out prior to Marshall Hall the similarity between convulsions after loss of blood and those of eclampsia. As far as we know, however, the latter gentleman was the first to lay a decided stress on their correspondence with *epileptic attacks in general*, and to deduce from it some important practical inferences. He distinguished a special kind of puerperal convulsions, arising from loss of blood, which are not to be confounded with those springing from other causes; and he describes the same cause as producing eclampsia infantum. Lastly, he endeavours to ascertain *the seat of these convulsions*, and in doing so very closely approaches the question as to the *central cause of epilepsy*, thus demonstrating the great importance of the subject. If by means of experiment we succeed in detecting the seat of epileptic convulsions from hæmorrhage, the problem seems solved as to the part to which in general the origin of epilepsy is to be referred. Marshall Hall has not always, however, been of the same opinion as to the seat of convulsions after hæmorrhage. In his work on bloodletting he considers it to be the brain, though he makes no attempt to prove his assertion. In his later work, on 'Diseases of the Nervous System,' he transfers it to the spinal cord, and endeavours to support this hypothesis by facts. His arguments are, however, by no means convincing or irrefutable, as a closer investigation will show. His proofs are:

I. The result of one of his own experiments.

II. That of an experiment by Sir A. Cooper.

III. The result of certain physiological experiments which led him to assume the so-called *excitable cerebral-provinces*.

I. Butchers, when killing sheep, generally divide the large blood-vessels of the neck, and the animal dies convulsed.

Marshall Hall had the spinal cord divided first and then the blood-vessels. "Thereupon strong convulsions ensued, a result which could alone depend upon the bloodless condition of the spinal cord, since the action of the brain was entirely removed." This experiment is related with such laconic brevity that it is impossible to say whether M. Hall was justified in drawing such conclusions. Who divided the spinal cord? Was the carrying out of such a difficult operation intrusted to the butcher? Which part of the cord was divided, and how long a time elapsed between its division and that of the blood-vessels? All these questions ought most certainly to have been answered. We shall, further on in this treatise, describe numerous experiments entirely contradicting that of M. Hall, and trust to demonstrate that an oversight must have occurred in some part of his.

II. Sir A. Cooper[1] tied the carotids of a rabbit, which operation accelerated the breathing and movements of the heart, but had no other effect. He compressed the vertebral arteries with his thumb for five minutes, leaving the trachea freely open. Respiration ceased almost instantly, convulsions came on, the animal lost consciousness, and to all appearance was dead. On discontinuing the compression, it drew a spasmodic inspiration and revived. It then lay on one side, making strong convulsive movements, breathing with difficulty, and its heart beating rapidly. After two hours it recovered, but its breathing still remained difficult. This compression was repeated five times with the same effect. From this experiment Marshall Hall would conclude that a diminution of blood *in the medulla oblongata,* which he reckons as belonging to the spinal cord, produces convulsions. Even if Sir A. Cooper's experiment were faultless, this conclusion could not be justified, for, when both carotids and vertebral arteries are tied or compressed, not only is the blood withheld from the medulla oblongata, but from the entire brain. Marshall Hall was only entitled to draw his conclusion on condition that he first proved the occurrence of convulsions upon tying the vertebral arteries alone; which, however, is not the case. Sir A. Cooper also mentions in the same place, that in another rabbit, whose vertebral arteries had been tied, convulsions only took place after a ligature had been applied to the carotids as well; this appears to have been overlooked by M. Hall. We ourselves, in more than twenty rabbits, tied both subclavians close to their respec-

[1] "Some Experiments and Observations on Tying the Carotid and Vertebral Arteries," in 'Guy's Hospital Reports,' vol. i, p. 465. London, 1836.

tive origins without observing any convulsions. The first-mentioned experiment of Sir A. Cooper was not, however, a fair one, for it is impossible to compress the vertebral arteries of the rabbit with the thumb, without at the same time including in the pressure some important parts adjoining, such as the pneumogastric, sympathetic, or phrenic nerves, the jugular veins, &c. In a later treatise[1] Marshall Hall considered it as unquestionable that Sir A. Cooper did not compress (as the latter conjectured and the former at first took for granted) the vertebral arteries, but the jugular and vertebral veins.

III. Physiological experience teaches that injuries done to the brain produce only paralysis, whereas lesions of the medulla oblongata and spinal cord, in proportion to their severity, result in convulsions or paralysis. Marshall Hall includes under the term "medulla oblongata" all those parts of the brain designated "excitable"—a title given to them by Flourens—the irritation of which, whether mechanical, galvanic, or chemical, is followed by convulsions or cries of distress. Without wishing to contest this great extension of the spinal cord up to the thalami optici, a supposition intimately connected with Marshall Hall's theory on the *excito-motor* nervous system, still we must observe that the effects of mechanical, chemical, or galvanic irritation cannot be decisive where we probably have to do with another kind of influence of a purely nutritive character. If interruptions in the course of the nerve-tubes within and before the thalami optici cause paralysis, a source of power must necessarily exist above the point of such interruption capable of producing motion, and, as is well known, there is good ground for supposing that the moving principle of the soul is that source. If, then, the conjecture be allowed that every motor impetus of the soul is transferred to the proper motor tubes and muscles by the material alterations of the different nerves of the cerebrum, the possibility cannot be denied that by certain physical influences the cerebrum might be excited in such a way as to cause movements and even general convulsions. At all events, until definite experimental results have proved the supposition to be erroneous, it cannot be disputed that an influence upon the action of the brain, so peculiar as a rapid abstraction of blood must be, will produce an exciting effect upon those parts of the cerebrum which effectuate motion. We think we

[1] "Synopsis of the class of Paroxysmal Diseases of the Nervous Centres," 1851, p. 43, in 'Memoirs on the Nervous System.'

have now sufficiently shown that the assumption that the spinal cord is the starting-point of convulsions after hæmorrhage is by no means so fully established by Marshall Hall's reasoning as physiologists, especially in England,[1] are disposed to believe. The question as to where this starting-point is must be much further considered and subjected to a more rigid examination. In our subsequent pages we shall communicate the results of numerous inquiries on the subject. The question that first calls for an answer is, whether convulsions proceed from a certain limited tract in the cerebro-spinal axis, or whether all its sources of psychical, automatic, and reflex movements are in action at the same time. Whether, in fact, as there exists a "sensorium commune," where all the body's sensations are communicated to the consciousness, and a "nodus vitæ" for the respiratory movements, so also there may not be a "centrum motorium commune," a "nodus epilepticus," from which during hæmorrhage the convulsions of all the variously affected groups of muscles proceed. We have, in the second place, sought to point out the seat of epileptic fits generally, and in conclusion have ventured to make some observations on the nature of those alterations of the brain by which epilepsy is produced.

We cherish the hope that we may have succeeded in essentially advancing the theory of epilepsy, and that abler men will soon examine, confirm, and extend our labours.

[1] Compare, for example, Pereira, 'The Elements of Materia Medica,' 3d edition, vol. ii, part ii, p. 1797.

## CHAPTER II.

### AN INTERRUPTION IN THE CONVEYANCE OF ARTERIAL BLOOD TO THE HEAD OF A RABBIT PRODUCES EPILEPTIC FITS AS SURELY AS HÆMORRHAGE DOES.

More than twenty rabbits, which we either killed intentionally by rapid bleeding, or which expired while being experimented upon, died under general convulsions like those observed in epilepsy, and which we shall afterwards more fully describe. Not one of those which we saw die from bleeding was exempt from convulsions. These convulsions did not differ in any respect from those we observed in several dogs and cats that died from bleeding, or from those described as occurring in men dying from hæmorrhage.

No difference, moreover, could be discerned between the fits observed in death from bleeding and those which occurred in about 100 rabbits whose carotid and subclavian arteries were tied or compressed (by an appropriately fine instrument) below the origin of the vertebral arteries.

Lastly, we became convinced, by observation of more than a dozen rabbits, that the fits produced by compression of the above-mentioned arteries resembled in every way those brought on accidentally or intentionally in the identical animals by profuse hæmorrhage after circulation had been restored to the head.

We have seen epileptic convulsions take place without any exception after compression of the arteries of the head in both male and female animals, in those three to four weeks old as well as in others of as many years, in both albinos and coloured, provided only that the animals were of fair health and strength.

*The rule, that a rapid death by bleeding, or the ligature of the great arterial trunks of the neck, produces epileptic convulsions, is falsified in the case of very weak rabbits and in such as have been subject to the influence of ether.*

A very old, lean, and extremely weak rabbit, after the above-named arteries had been tied, fell into a swoon and expired in a few minutes, without convulsions. In all our numerous experiments in tying the blood-vessels of the neck, this was the only rabbit subjected to a directly debilitating influence on the nervous system, and not under the influence of ether, that we saw die without convulsions.

Rabbits, when thoroughly stupified by ether, cease, as we have often observed, to be liable to convulsions during death from hæmorrhage or when the arteries of the neck are compressed; but, on recovering from their stupor, they again become so.

We only noticed one healthy and strong rabbit, which, in spite of the arteries of its neck having been tied, although falling into a state of great debility resembling a swoon, did not after ten minutes exhibit symptoms of convulsions, whilst yet it had not been subjected to the influence of ether, nor its brain or spinal cord acted upon in any other way. This animal also died in convulsions when we opened the aorta. We suspected in this exceptional case that the brain received in some unusual manner just sufficient blood to prevent the approach of convulsions. Sometimes small vessels in the nape are observed to go off directly from the arch of the aorta, and possibly in the example last referred to some blood reached the brain in this way or through unusually large anastomoses of the intercostal with the vertebral arteries.

We found in every instance that the closing of all the four arteries was necessary to produce rapid convulsions. If but one carotid or one subclavian artery has remained pervious, we have never seen convulsions take place, even when the ligature has remained on the other three for several hours; the animals, however, have generally appeared enfeebled, and more or less paralysed.

It appears, therefore, probable that the convulsions that take place upon the closing of the great arteries of the neck proceed from the brain and are produced by its bloodless condition. The further progress of our investigations will raise this conjecture into a certainty. Before however, advancing any arguments we may be allowed—

1. To make some preliminary observations on the mode of seeking for the great arteries of the neck in the rabbit, and the method of tying them.

2. To describe with precision the convulsive fits, and to point out their resemblance to those of epilepsy.

3. To describe the attacks under which death takes place after the ligature, and the symptoms following restoration of the circulation.

4. Lastly, to show the probability that the rule holds good in human beings as well as in warm-blooded animals generally, that a sudden interruption in the supply of blood to the head causes epileptic convulsions.

We will conclude this chapter with a few remarks upon the experimental fact before stated, that etherization carried to a great extent prevents the liability of animals to convulsions after hæmorrhage. The administration of ether to patients who have to undergo an operation will, under certain circumstances, expose them to the danger of death from hæmorrhage, without any warning having been given by the occurrence either of dizziness, swooning, or the yet more serious symptom of convulsions. This is a fact of the greatest importance as regards anæmic persons or those who do not generally bear hæmorrhage well, and consequently are easily brought into danger thereby.

There are good grounds for the conjecture that many who are supposed to have died from chloroform on the operation-table did not die from being poisoned, but from excessive loss of blood. As to the treatment of epileptic attacks with ether, it seems established that inhaling ether or chloroform during the first approaches of an attack may prevent an outbreak of convulsions. This does not, however, prove that the morbid state of the brain originating the attack is removed, since, for example, in our own experiments the anæmic state of the brain continued in spite of the administration of ether, and the condition was only concealed, not removed. Such a method of cure we consider in a general way to be injurious, and even dangerous, inasmuch as a certain degree of asphyxia accompanies every epileptic fit, acting injuriously upon the nutrition of the brain, upon which also etherization acts very prejudicially. At the end of our treatise we shall demonstrate the probability that one and the same influence is the cause of numerous forms of epilepsy, namely, *sudden interruption of the nutritive supply to the brain.*

It stands to reason, then, that everything should be scrupulously avoided that assimilates the arterial blood to the condition of venous, and thereby deprives it of the capability of duly nourishing the brain. We do not, however, deny the value of etherization in certain cases. By diminishing excessive irritability in some parts of the nervous system it may sometimes arrest the attacks at their source; we only doubt its usefulness when it is expected to act on that central focus, the brain, and should, under such circumstances, be afraid of paralysis of the medulla oblongata.

## CHAPTER III.

### SOME OBSERVATIONS ON FINDING AND TYING THE GREAT ARTERIES OF THE NECK IN THE RABBIT.

WE made some slight deviations from the procedure of which one of us published an account in the 'Verhandl. der phys. medicin. Gesellschaft in Würzburg,' 1855, vol. vi, part i. After cutting through the skin and muscles, and breaking and removing the superior part of the sternum as there described, we divided, by the aid of forceps and knife, the fascia and surrounding fat (which in well-fed animals cover the great arteries), together with their sheaths. After this we laid the knife entirely aside, and made use of two fine pairs of forceps. We carefully separated the small fatty lumps from both sides of the innominate trunk, and dividing the cellular tissue surrounding it, passed under the vessel thus laid bare a strong silken thread, by means of a small ligature-hook specially made for the purpose. The use of the forceps instead of the knife considerably abridges the operation, and protects the pleura from bleeding and injuries. An assistant then draws the innominate a little to the right and forward, whilst the operator dissects with the two pairs of forceps close to the left edge of the innominate and of the left carotid, and removes or pushes away the fat on either side, dividing the cellular tissue and gradually penetrating deeper towards the arch of the aorta. When the left subclavian appears, it is likewise laid bare and surrounded by a ligature, or immediately tied. Accidents, such as hæmorrhages, lesions of the pleuræ, pericardium, thoracic duct, or the left sympathetic nerve, very rarely occurred, owing to the great facility we had from practice acquired in this operation; and we generally accomplished the whole in from ten to fifteen minutes, seldom requiring more than from twenty to thirty. For compressing the blood-vessels we used the small polished forceps described in our treatise 'On the Influence of the Flow of Arterial Blood upon the Temperature of the Ear of the Rabbit.'[1]

In more than eighty rabbits the right subclavian and both carotids commenced in a common innominate artery, the length of which considerably varied, and sometimes appeared reduced to nothing, while the left subclavian commenced independently from the arch of the aorta. In two animals the right subclavian did not arise from the innominate, but to its left side, near the left subclavian, and passed to the right side behind the œsophagus. The comparative sizes of the innominate, carotids, subclavian and vertebral arteries, varied considerably in different animals.

[1] Moleschott's 'Untersuchungen zur Naturlehre des Menschen und der Thiere,' vol. i, p. 104.

## CHAPTER IV.

### DESCRIPTION OF CONVULSIVE PAROXYSMS OCCURRING IN THE RABBIT AFTER LIGATURE OF THE GREAT ARTERIES OF THE NECK, AND PROOF OF THEIR CORRESPONDENCE WITH EPILEPTICAL ATTACKS.

General convulsions usually followed in from eight to eighteen seconds after complete withdrawal of arterial blood. We killed six rabbits solely for the purpose of determining in what space of time convulsions would come on. After the arteries had been laid bare, and the ligatures had been passed round, we allowed the animals to rest undisturbed in an erect position for a quarter of an hour, without making any experiments by compression. One of us then, as quickly as possible, tied the left subclavian and innominate arteries, while another, watch in hand, observed the time when the symptoms first manifested themselves. In a very strong male rabbit, two years old, general convulsions came on three seconds after the innominate had been tied; and this is the shortest period that we have noticed in any. In two female white rabbits, four weeks old, the convulsions appeared after an interval of twelve seconds; in a female gray rabbit, two or three years old, in ten seconds; in a male of the same age, in sixteen seconds; and in an old strong female, from four to five years old, in forty-five seconds. None of these animals lost during the operations any considerable quantity of blood.

Out of a hundred strong rabbits we met with four only in which, after perfect closure of the above-named vessels, convulsions did not appear till after four to six minutes, and one only, as already mentioned, in which they did not appear at all after the lapse of ten minutes and until the aorta had been opened. The extremities of these five animals became speedily paralysed after the operation, so that they were unable to remain any longer on their legs, but fell on the table as though in a swoon.

The occurrence of convulsions is, without exception, preceded by many different movements, most of which have been more fully described in Kussmaul's above-mentioned treatise.[1] We will here only briefly allude to some of them :—

1. Immediately after stoppage of the blood the various sphincter muscles of the face contract, especially, and in a very striking manner, those of the iris and eyelids; then, in the order of their distinctness, the conchæ of the ears, the nostrils, and the mouth. The jaws, which are generally already closed, become spasmodically locked. Then, usually a little before but sometimes simultaneously upon the occurrence of general convulsions, the pupils, and the fissures of the eyelids, ears, and nostrils are widened, sometimes the mouth also very distinctly. The adductors of the under jaw seem also for a few moments to become paralysed, but during the attack the jaw becomes locked, either uninterruptedly or in broken succession, by the alternate occurrence of spasmodic and more feeble *abductions* and stronger *adductions.*

2. Convulsive efforts are almost invariably made to turn the pupils towards the internal angles of the eyes; after which, the eyeballs generally roll about, first inwards, forwards and downwards, then outwards, backwards and upwards, until at length the pupils are turned towards the external angles of the eyes, and are wholly or partially concealed by the upper eyelids.

3. The eyeballs are first drawn back into the sockets, and again become prominent as the pupils dilate.

4. Respiration is at first accelerated, but shortly afterwards, a little while before the approach of general convulsions, it becomes prolonged and deep.

5. The muscles of the neck generally become paralysed and unable to bear the weight of the head, which sinks down upon the breast or side, the animals afterwards falling down in a swoon on their fore feet, occasionally on their hind ones. These symptoms of paralysis are the more distinct and constant the greater the time that elapses before general convulsions come on.

The signal for general convulsions is given by a tonic contraction of the muscles of the neck. Then commences a terrible scene, the more surprising by contrast if preceded by swooning. The head is drawn violently backwards; the pupil becomes uncommonly enlarged;

[1] Vide 'Zeitschrift des Würzburg. Phys. Med. Vereins.'

violent lock-jaw ensues; and the animal, if strong, is generally flung forwards with great force, to a distance even of from one to two feet, and sometimes over the shoulders of the observer seated before it. The legs are alternately contracted and extended, by clonic convulsions, in the most violent way; the enlarged pupil appears again fixed in the centre of the palpebral fissure, as the eyeball is again rolled somewhat inwards; respiration is scarcely to be perceived, while the heart continues throbbing very vigorously. The clonic convulsions gradually subside, assuming more the appearance of tetanus, and eventually disappear altogether, passing away as they do so from the front to the back. First the muscles of the neck and fore legs become paralysed, whilst the back part of the body is bent backwards and the hind legs are tetanically extended, until these movements also cease. The duration of these attacks was, according to several observations, from eighteen seconds to two minutes.

Very frequently, after a pause of from fifteen to seventy-five seconds, a second attack comes on, always weaker and shorter than the first, and often limited to the hinder part of the body in the form of tetanic convulsions; sometimes, however, affecting the whole body, under the form of clonic convulsions. We once observed such a second attack to last, in an exceptional case, two minutes. Sometimes, indeed, convulsions, in which the hind legs become tetanically stretched, recur even for a third and fourth time, at intervals of from fifteen to thirty seconds. They returned in the strongest and most regular manner in those animals whose arteries were tied forthwith, and whose strength had not been previously exhausted by experiments of compression. Towards the end of the attacks urine and fæces were sometimes voided; at other times no such voiding took place, even when the bladder was full.

In rabbits, cats, and dogs, dying from hæmorrhage, the convulsions are of exactly the same character.

These convulsions present precisely similar features to those of epilepsy in their complete form, as the following enumeration of the most important symptoms will show:

1. The animals fall down before general convulsions come on, and completely lose the spontaneous use of their muscles.

2. They give the observer the impression of their being perfectly unconscious.

3. Not one of the many animals operated upon, cried out, so

long as the circulation was interrupted; either before or during the spasmodic attack, and two only whilst the latter was abating. Subsequently, however, they began to cry piteously, directly arterial blood began to flow again, or, at all events, soon afterwards. From the want of power to cry, and from the gradual swelling of the veins of the brain during the attack, to which we shall direct attention further on, we infer that spasm of the glottis (laryngismus) took place.

4. The pupils are dilated during the attacks, and, to judge from several experiments, appear rigid, the eyeballs being motionless. Before and subsequent to the attacks, however, and when at the very last gasp, the pupils being at the same time very much enlarged, the eyes of some animals that we accurately examined appeared sensible to the influence of light.

5. The attacks commence with a tonic spasm of the muscles of the neck (trachelismus).

6. Respiration ceases, whilst the heart continues beating.

7. The limbs are seized with strong clonic convulsions, and become at last spasmodically stretched.

[1] It is generally acknowledged that in a fully developed attack of epilepsy the pupil ceases to be contracted by the influence of light. But Kussmaul recently observed the highly dilated pupils of a boy contract strongly by light during a very violent attack of eclampsia, which lasted for two hours. The lad died in a perfectly unconscious state from tuberculosis of the meninges and caries of the lowest dorsal vertebra.

## CHAPTER V.

### ON THE PHENOMENA ATTENDING DEATH IN THE RABBIT AFTER LIGATURE OF THE GREAT ARTERIES OF THE NECK, AND ON THE SYMPTOMS MANIFESTED DURING RESTORATION OF THE CIRCULATION.

Interruption of the circulation in the great arteries of the neck causes death when continued; but, if the circulation be restored, the animals recover, unless the organs essential to life have been so affected as to be unable to continue their functions.

If the circulation continues arrested when the epileptic attack is over, the animal does not die immediately, nor is it incapable of prolonged existence. Some extremely deep, sighing respirations still occur at intervals of five, eight, ten, and twelve seconds, but seldom more.

These are the more vigorous, rapid, and frequent, the less the animal has been subjected to experiments of compression before the application of the permanent ligature. They sometimes even still take place, when fine red bubbling foam flowing from the nostrils, indicates that an extensive œdema of the lungs has supervened.

During these deep respirations the animal widely opens its mouth and jaw-bones, and distinct sounds both of inspiration and expiration are heard at the walls of the chest; whereas in the normal respiration of the rabbit, or when its breathing is simply accelerated, only sounds of inspiration are heard. At each deep inspiration the chest is seen to expand enormously, and air penetrates the wound below the sternum. Frequently air passes forward behind the latter and before the heart, between the laminæ of the mediastinal connective tissue, and sometimes it even enters into the pleural cavities, producing pneumo-thorax. In what manner, and where, the pleuræ are lacerated in this process we could not ascertain.

The last gasp generally takes place in from three to five minutes after the left artery has been tied, seldom later. In every experiment, without an exception, the heart continued to beat vigorously for some time after the last breath. In some instances we could, with the stethoscope at the chest, hear the pulsation of the heart even half an hour afterwards, or through the open cavity of the abdomen see it beating on the other side of the diaphragm. The diaphragm of the rabbit is so transparent, as to allow the situation of the adjacent thoracic viscera to be clearly seen. In this manner it can always be readily ascertained when air has entered the pleural cavity.

When the thorax was not opened, the heart seldom ceased beating before the tenth minute. If the heart, which had throughout been over-filled with blood, was exposed to the air after pulsation had temporarily ceased, it began to beat again in all its parts even a quarter and half an hour after the last breath. In a full-grown gray rabbit it even continued beating vigorously after the lapse of an hour, notwithstanding the hind legs had become rigid immediately after the last breath. The same phenomenon was observed by Dr. Mayer, of Bonn, who has published, in the 'Act. Phys. Med.-Acad. Cæs. Leopold. Carol.,' of the year 1833, t. xvi, 2, p. 68, his anatomico-physiological researches on the brain, spinal marrow, and nerves, wherein he gives an account of numerous experiments on the compression of the carotids in dogs, rabbits, a horse, a goat, and a dove. After having tied the left subclavian artery and the innominate artery of a rabbit, complete paralysis of the head and fore legs immediately took place, followed by strong tetanic (?) shocks of the trunk, dilatation of the pupils, and death itself within a minute. Forty minutes after, the animal having remained in the stiffness of death for ten minutes, the heart still beat eleven strokes a minute.

These cases offer a striking exception to the ordinary rule, according to which the left heart is usually the "primum moriens." In every instance, however, the left ventricle died before the other parts of the heart, contracting itself, and becoming pale and rigid; the right auricle was the last to die.

Urine and fæces were often voided with the last gasps, or even later, while the cadaveric rigidity usually appeared sooner in the hind than in the fore legs. If, after tying the left subclavian artery, the ligature was removed from the carotid before the animal was at the last extremity, the use of its cerebral and muscular powers was almost without exception restored with remarkable rapidity in a few seconds. This was sometimes successfully brought about even when the animal was just dying. When deep respirations recurred only at long intervals, the pupils having been already dilated to such a degree that the diameter of the iris was only one to two millimeters—a state of dilatation which Bouchut (erroneously, it is true, and as these experiments prove) considered to be the sure forerunner of death. But in such a case it always took longer before respiration was restored and the animal regained power over its muscles. Thirty-six, forty-five, and a hundred and twenty minutes after the application of the ligature (which we succeeded in removing again with the scissors from the trunk of the carotid), and even in a case where these attacks came on five minutes only after the application of the ligature, we saw, seven minutes afterwards, respiration gradually assuming its normal state with a return of consciousness, and of power over the muscles of the body. It may be, as before mentioned, that in the latter case, after the great vessels of the neck had been tied, some blood still found its way through collateral channels, and the approach of convulsions was thereby retarded for an unusual length of time. We cannot, consequently, from this experiment, determine with absolute certainty how long the brain of the rabbit can remain completely deprived of arterial blood;[1] but, from the result of our first experiments, the assumption appears well grounded, that *the brain of the rabbit can remain deprived of arterial blood for two minutes without losing its capability of again performing its functions upon the renewal of the circulation.*

A singular phenomenon is presented when the ligature is removed at the precise moment that the convulsions are raging in their greatest intensity. As if spell-bound by the wand of a magician, these convulsions generally cease immediately, and the sudden change from the most frightful spasm to complete relaxation of the system offers a most striking contrast. The rigidly contracted muscles of the neck become paralysed, and the head sinks forward, as though drawn by a heavy weight. Sometimes, the moment the blood flows in, the animals move straight forward, as though the quantity of blood rushing into the head would throw them down headlong; and then they fall to the ground paralysed. Upon the cessation of the flow of

[1] We are here obliged to anticipate the course of our researches by taking it for granted that a deficiency of red blood in the brain is caused by the ligature, although we cannot prove this assumption until afterwards.

blood to the head they gradually raise themselves up, or jump up as if awakening from a deep unconsciousness, while sometimes they cry out and endeavour to run away. If the sluice be opened before general convulsions come on, just when the muscles of the neck begin to contract, the animals frequently kneel down, and at length lie on the breast and belly, upon the table.

Convulsions are never produced by this strong flow of arterial blood into the head, as might be expected according to the physiological theories of the present day, not even when both cervical branches of the sympathetic have been divided and the superior cervical ganglia destroyed. On the contrary, numerous groups of muscles become paralysed. Thereupon ensues relaxation of the sphincters of all the moveable orifices of the head, of the iris and eyelids; of the muscles of the conchæ, nostrils, and mouth; of the attractors of the lower jaw; of the retractors of the eyeballs; of the muscles of the neck and limbs. The pupils are frequently dilated to as great an extent as is observed in the animal when dying, so that the dilator of the iris seems to be actively concerned; the dilatation of the orifices of the lids and of the conchæ is also generally very remarkable, that of the orifices of the nostrils and mouth less striking.

If the circulation has been restored during a completely developed epileptic attack, respiration does not return immediately. Some seconds elapse before one or more deep, slow, but noiseless inspirations take place, during which the nostrils are considerably widened and the mouth opened. As the rush of blood decreases, deep respiration becomes gradually more rapid and easy, the orifices contract again to their usual size, the protruding eyeball recedes into its socket, and power over the neck and limbs is restored to the animal.

The astonishing power of banishing the most frightful convulsions which, in these experiments, was possessed by the red blood, strongly demonstrates the folly of the injudicious practitioner who resorts to the lancet immediately on the appearance of violent symptoms of irritation proceeding from the brain. The opinions of eminent physicians, from the distant age of Hippocrates and Aretæus (those sound observers, possessed of more correct ideas upon the treatment of epilepsy than the greater part of those amongst us who have since written upon the subject[1]), up to Marshall Hall's classical researches

[1] Compare Delasiauve, 'Traité de l'Epilepsie,' 2e partie, ch. i, Histoire du Traitement, p. 308.

upon bloodletting and hydrocephaloid disease, have apparently fallen unheeded upon the ears of bloodthirsty quacks. Physicians engaged in treating the insane do not grow weary of relating their experience on the prejudicial consequences of bloodletting and of the debilitating treatment so often employed as the chief remedy in epilepsy and mania, in the earlier stages of imbecility attended with progressive paralysis, and in every excitement of lunatics: their warnings die away within the walls of the asylum. To no purpose is it, as regards epilepsy, an established fact that poor-blooded subjects are oftener attacked than full-blooded ones, that debilitating passions, losses of blood and semen, vicious formation or adulteration of the blood (as by alcohol, lead, &c.), and finally congenital weakness of the brain (idiotismus congenitus), in most instances bring on the attack. In vain do numerous experiments on men and animals warrant the correctness of the doctrine that bloodletting and all treatment of too debilitating a nature increase the number of the attacks and accelerate their final transition into imbecility and consumption. In vain is advice given to examine most conscientiously the degree of strength in the patient, the condition of the brain's circulation, and cautiously to investigate the causes of the disease before adopting any treatment. The number of those who in all kinds of epilepsy thoughtlessly apply debilitating remedies, at least at the beginning of the disease, is still very great, although the profession in the present day acts on better principles than formerly; an assertion which cannot yet be made of the treatment of lunatics in the state of maniacal excitement.

The specific remedies especially in vogue for epilepsy have all a but slightly active or reducing effect upon the organism. They are by no means chosen from the class of mercurials, antimonials, or preparations of lead, but from metals of milder action, such as silver and zinc, which have proved particularly useful. Wormwood and valerian root are also very efficacious remedies; but good, plain, and well-regulated diet, and the "traitement moral," stand pre-eminent. To the latter category, however strange it may appear, most surgical modes of treatment appear to belong. Tracheotomy, ligature of the carotids, cauterization of the pharynx, and the other surgical operations generally recommended, and adopted with temporary or lasting success, would in most instances prove useful on the same grounds as the application of any new and yet untried remedy.

Though ligature or compression of the carotid may in some few instances have been of service, yet it does not necessarily follow that it was the anæmic condition of the brain that in these cases produced the favorable result. Apart from the influence just now mentioned of such operations upon the mind of the patient, we must not forget that the arrest of circulation in a vessel produces an increased determination of blood to the collateral vessels. In individuals still possessing an adequate or normal quantity of blood, the closing of the carotids will necessarily cause an increased flow through the vertebral arteries. Let us imagine an epileptic seizure in an individual, originating in an anæmic state of the posterior and excitable parts of the brain—the medulla oblongata, for instance—which condition affects but sympathetically the rest of the brain. Compression of the carotids may achieve a cure, not because of the resulting anæmia of the cerebrum, but by the induced hyperæmia of the posterior part of the brain. Moreover, it is also to be remarked, that every compression of the carotids, however brief, is closely followed by cerebral congestion. From the short duration of the compression, as usually applied, it is difficult to say how much of the remedial effect is to be ascribed to the cerebral anæmia, slight in itself, or to the hyperæmia, sequential to it.

We need scarcely remark that we do not mean absolutely to reject venesection or low diet. Cases but too frequently happen where a rapid abstraction of blood, especially from the external jugular vein, becomes imperative, in order to relieve the brain from congestion of venous blood with which it is surcharged, to facilitate the access of arterial blood, and to arrest an attack of apoplexy. Where epilepsy occurs in a patient of luxurious habits and addicted to the pleasures of the table, it is always advisable to enjoin a strict and simple regimen.

## CHAPTER VI.

### SUDDEN INTERRUPTION IN THE FLOW OF ARTERIAL BLOOD TO THE HEAD PRODUCES PHENOMENA SIMILAR TO THOSE OF EPILEPSY IN DIFFERENT WARM-BLOODED ANIMALS, EVEN IN MAN HIMSELF.

As sudden interruption in the passage of red blood to the head causes epileptic convulsions in the rabbit, it is highly probable that such a condition will produce the same effect in all warm-blooded animals, from their general agreement in the two conditions indispensable to such a result; firstly, from their nourishment by warm and red blood; secondly, their liability to epileptic convulsions. The inference is the stronger, inasmuch (as it has already been shown), that birds, mammalia, and men are rendered unconscious, and prone to general convulsions, by great loss of blood. And, again, experience shows that, after great loss of blood, mammifers, including man, are much more readily subject to faintings and convulsions when in an erect than when in a decumbent posture. This fact can only be explained upon the assumption that the enfeebled power of the heart, when erect, is no longer capable of overcoming the weight of the blood, and of driving it upwards into the brain. Deficiency of red blood in the brain leads, in this instance, to general convulsions, which commonly cease immediately the body is placed in a horizontal position or the head lowered below the level of the trunk.[1] Marshall Hall's distinguishing merit consists, as is well known, in his drawing attention to these facts and deducing therefrom an important practical rule for adoption in venesection, viz., to bleed the patient in an upright and not in a reclining position, so that the nervous system

[1] Compare Marshall Hall, 'On Bloodletting,' p. 58, et seq.; Burrows, 'Observations on Diseases of Cerebral Circulation of the Blood,' Posner's edition, 1847; and Kussmaul's experiments in the 'Verhandl. der phys. med. Ges. zu Würzburg,' 1855, p. 37.

may be more speedily influenced, and the abstraction of too large a quantity of blood avoided. It is an old established rule that persons after losing much blood should assume a horizontal position, the head being kept very low.

We possess, moreover, a number of experiments and observations on animals and men, which clearly prove that stoppage in the circulation of the great arteries of the neck produces epileptic convulsions in other animals than the rabbit.

Mayer[1] saw a dove, in which the carotids and the arteries of the wings had been simultaneously tied, expire in convulsions and tetanic spasms so violent as to cause the tied vessels to burst.

Sir A. Cooper's experiment is well known. He tied both the carotid and vertebral arteries of a dog. The animal appeared to lose sensation, as though intoxicated. It breathed with difficulty. The pupils became dilated, and the animal fell over on its side and became convulsed. Stupor and general paralysis having been present during two days, the animal completely recovered, and proved a useful house-dog. Nine months afterwards Sir A. Cooper killed the animal for the purpose of injecting the arteries, and he found extremely large and numerous anastomoses.[2]

Panum[3] repeated Sir A. Cooper's experiment, and observed a circumstance explanatory of the dog's survival. After tying both the carotid and vertebral arteries, the dog became convulsed and swooned away, the mucous membrane of the mouth appearing pale. In a little time the animal again opened its eyes and lay quiet for four hours, breathing very deeply and slowly, but regularly; and, although extremely weak, able to stand when lifted up. That the brain still contained a plentiful supply of blood was demonstrated by the following fact: Upon opening the carotid above its ligature, some minutes after its application, such a quantity of blood streamed out, that Panum was obliged to apply immediately a fresh ligature higher up. After having killed the animal and injected its arteries, he found that, between the second and third cervical vertebræ of the dog, very considerable branches from the vertebral arteries are given off to the spinal cord, which unite and form a common stem ascending to the brain, and separate again higher up into two

[1] Loc. cit., p. 719.

[2] Loc. cit., with a drawing of the anastomoses, p. 457.

[3] On Death by Embolia, 'Zeitschr. f. Klin. Medizin von Günsburg,' 1856, vol. vii, p. 409.

branches, which contribute to the formation of the basilar artery. If, therefore, both the carotid and vertebral arteries are tied just where they pass from the canal of the epistropheus into that of the atlas (as was probably done by Panum and Sir A. Cooper), the brain of the dog is still able to receive large quantities of blood.

In the horse the basilar artery is not formed by the junction of the vertebral, but by that of the occipital arteries within the foramen magnum. The vertebral arteries have not therefore much to do with the nutrition of the brain.[1] When entering the vertebral canal they are of tolerable size, but become thread-like before they reach the cavity of the cranium. Tying the carotids of the horse will consequently be followed by the same results as are brought about by ligature of the carotids and vertebral arteries of the dog and rabbit. Such was the case in a horse whose carotids were tied by Mayer.[2] Weakness of sight, dizziness, falling suddenly down as though struck by lightning, foaming at the mouth, convulsions, and ravings succeeded, and death after a short tetanus, fifty-eight minutes after the operation. Jobert de Lamballe seems to have met with a similar result after the same operation. His treatise, quoted by Norman Chevers,[3] to my great regret, I have been unable to procure. If, however, the ligatures on the several arteries of the horse are applied at somewhat longer intervals, so that a collateral circulation can take place, the issue is not invariably fatal. Alessandrini[4] tied both carotids within thirty-six days, the application of each ligature being preceded by copious venesection. On the application of the second ligature the animal fell on its side, and exhibited signs of stupor; but, nevertheless, recovered without falling into convulsions.

With regard to man, we do not possess, as far as we are aware, any observations upon the simultaneous and sudden stoppage in the circulation of the blood in the four great arteries of the head.

[1] Stannius, 'Lehrb. der vergl. Anat. der Wirbelthiere,' 1846, p. 440.

[2] Loc. cit., p. 691.

[3] Norman Chevers, Remarks on the Effects of Obliteration of the Carotid Arteries upon the Cerebral Circulation, in 'London Med. Gaz.' Oct. 31, 1845, pp. 1140—1151.

[4] Schmidt's 'Jahrbücher,' 1840, vol. xxvi, p. 322. The experiment of tying both carotids in a horse, made by Rossi and Sessona, as related in Canstadt's 'Jahresbericht,' 1856, section Veterinary Medicine, p. 7, is incorrect, and therefore of no avail to our argument in this place, since the right jugular vein was tied simultaneously.

Gradual occlusion of these vessels may take place without producing convulsions, as is shown by Davy's[1] remarkable observation (in an officer of rank, aged fifty-five years), of the closing of both the carotid and subclavian arteries, in consequence of an aneurism of the arch of the aorta. The patient suffered from frequent attacks of fainting and giddiness, occurring subsequently at longer intervals, until the pulse could be no longer felt in the neck, temples, armpits and arms. Fifteen months afterwards the patient suddenly expired while on a journey, in consequence of laceration of the aorta at its base. All the large vessels springing from the arch of the aorta were closed at their origins, while the intercostal arteries were enlarged, so that the collateral circulation must have been effected by the latter and the internal mammary artery.

It is to be regretted that we know nothing of the symptoms manifested during life in a man who was dissected by an American named Darrach. In this case likewise the innominate artery and left carotid were found obliterated by an aneurism.[2]

In man we have merely some few cases recorded of sudden and partial interruption of the circulation in the head, occasioned by compressing or tying the great arteries of the neck, or by the obstruction of the great cerebral arteries by means of plugs, especially by those brought from other parts.

Sudden stoppage in the flow of blood through the carotids is attended by the exhibition of more striking phenomena in man than in either the dog or the rabbit, from the greater development of the human brain and the exceptional distribution of vessels to it. This fact has received ample confirmation from experiments both in the compression of the carotids of men and in the tying of the carotids of men and animals, as frequently performed by physiologists and surgeons from the remotest ages. We refer to the careful history of these experiments in Norman Chevers's critical treatise, without in this place entering more fully into the subject of tying the carotids of animals.[3] We may, however, observe that Norman Chevers was

[1] '*Vide* N. Chevers,' p. 1144.

[2] Gerson and Julius Magazin, vol. xiv, p. 338, with a drawing of the preparation.

[3] The most important experiments have been performed by Bichat, Mayer, Sir A. Cooper, Jobert, and Miller. Those of the latter are to be found in the 'Gazette médicale, 1843,' p. 107. Compare also the results obtained from the application of the ligature on both carotids in nineteen rabbits by Kussmaul. (loc. cit.)

unable to reconcile the conflicting statements of physiologists, doubtless because he had himself never performed the experiments on which they were based. Thus, Mayer observed dangerous consequences much more frequently than Bichat, Cooper, Jobert, and Miller; which is to be ascribed to the circumstance that Mayer did not distinguish with sufficient exactness between the results of arresting the circulation of the blood on the one hand, and the operation itself on the other. The former, as we can safely assert from numerous experiments, are always very slight in the rabbit, whilst the latter are frequently very considerable, when suppuration of the cellular tissue (pyæmia), inflammation of the vagus, and stoppage of the venous circulation from the inflammatory tumour supervene. When these conditions are present, stupor, weakness, convulsions, and so forth, will certainly ensue; but these symptoms cannot fairly be ascribed to an interruption in the transit of red blood. The results will necessarily vary if at one time the animals are confined in clean and airy hutches, or at another are pent up and crowded together; if the wound be closed by sutures or not; and on other circumstances. Sutures, for example, in rabbits will readily, by preventing its escape, cause an accumulation of thick pus under the skin, occasioning thereby such pressure on the nerves and veins as must be highly injurious.

That compression of the carotids in men produces stupor and collapse, simulating apoplexy, was known before the time of Galen. We find, from Chevers's communications, that Rufus of Ephesus maintained that the word carotis owed its origin to this fact. "Arterias per collum subeuntes carotides, *i. e.* somniferas[1] antiquos nominasse, quoniam compressæ hominem sopore gravabant vocemque adimebant." Chevers likewise relates that by these means, Columbus of Pisa, in the year 1554, before a large assembly, feigning to use magic, and seemingly to his own amusement, caused a young man to fall down suddenly, much to the dismay of all beholders.

During the present century, compression of the carotids was introduced as a remedy by Caleb Parry, and brought into very general use. For ample details on this subject we are indebted to the

[1] A philologist has kindly furnished us with the following etymological combination: ἡ καρωτίς, the artery to the head; τὸ and ὁ κάρος (probably not connected with κάρη), deep sleep; καρόω, οῦν to produce, κάρος to stupify: καρωσίς, ἡ, apoplexy; καρωτίς, causing apoplexy.

distinguished Jacobi of Siegburg.[1] It occurred to us, however, that neither Jacobi, who assures us that he performed some hundred experiments, nor any of the numerous authors who have investigated the subject of compression, such as Trousseau, Blaud, Dezeimeris, L'Allier, Stroehlin, Romberg, Fleming, and some others whom we have compared, made any mention of the convulsive attacks following these experiments. Jacobi relates the following symptoms as generally observed: dimness of sight, dizziness, stupor, weakness in the legs, staggering, swooning, loss of consciousness, and sudden apoplectic falling-down; and this agrees with what is described by the above authors. It seemed, however, improbable that the results in every case should be limited to these precursory symptoms of epilepsy, and that no convulsions should ensue. Fresh experiments were therefore deemed necessary. We communicate the results of some, in which (in the cases of six male adults) compression of both arteries completely succeeded. In all, without exception, the face turned pale. First they made convulsive efforts to close the eyelids: in four of them, the pupils at first contracted; in all of them, without any exception, they became eventually much dilated. The contraction at the commencement was in two cases very considerable. Although the experiments were performed in a moderately darkened room, the window-shutters being half closed, still the pupils became remarkably contracted, even more so than afterwards, when strong daylight was readmitted. As soon as dilatation of the pupils began to take place the respiration became slow, deep, and, as it were, sighing. Afterwards dizziness, staggering, and unconsciousness ensued; and the patients would have fallen but for being supported. In two subjects of weak intellect, and moderately anæmic, in whom, notwithstanding the above symptoms, the compression was continued, a choking sensation, attended by vomiting and general convulsions, came on, which, however, did not attain an aggravated form; for, on withholding the compression, they disappeared in a few seconds. In one instance, a twitching in the muscles of the cheek was observed previous to the attack of general convulsions. The face became suffused, the eyes moist, and the pupils more and more dilated, as the thumbs were removed from the neck. Consciousness and volition did not return immediately, but after the lapse of a few seconds,

[1] *Vide* his famous work: M. Jacobi, 'Die Seelenstörungen in ihren Beziehungen zur Heilkunde,' i, pp. 379—388.

while the red appearance of the face gradually subsided. The first inspirations upon the restoration of the circulation were particularly deep. No further prejudicial consequences ensued.

We consider it then established that compression of both the carotids in men may occasion loss of consciousness, dilatation of the pupils, prolonged breathing, and general convulsions,—in short, all the symptoms of a slight epileptic attack. As these experiments were not always successful, it is well to consider that in closing the carotids no complete stoppage in the flow of arterial blood from the brain is occasioned, and that the arrest itself is mainly compensated by the collateral circulation kept up by the vertebral arteries. Still the probability becomes stronger, that the sudden retention of all the blood conveyed to the head will have the same effect in the human being when experiencing the loss of much blood as in other warm-blooded animals; that is to say, that sudden occlusion of all the arteries of the head will as certainly produce epileptic convulsions in man, as has been proved to be the case in rabbits, provided the strength of the former be not too much exhausted, and the nutrition of the nervous system not too much impaired.

The operation of tying the common carotid has been frequently performed since the year 1810.[1] Abernethy (in 1803),[2] Fleming, Lynn, and others, applied the ligature in some cases where wounds had been inflicted; and Sir A. Cooper (in 1805), for aneurism. Tying both common carotids consecutively,[3] and ligature of the innominate,[4] are operations which have been done more rarely,

[1] Hebenstreit relates an earlier instance of the successful ligature of the common carotid which had been wounded by removal of a scirrhous tumour. Compare Hasse, in Rust's 'Handb.' vol. ii, p. 66; and Velpeau, loc. cit., p. 230.

[2] Velpeau knew as early as 1832 of sixty cases of ligatures having been applied to the common carotid, forty of which at least had been successful. Compare his 'Eléments de Médec. opératoire.' In the second edition of his work published in 1839, vol. ii, p. 232, he enumerates one hundred and fifty cases, of which eighty were attended with a favorable result.

[3] According to N. Chevers, Mott is said to have tied both carotids simultaneously, fatal consequences ensuing in twenty-four hours. It is to be regretted that no details are given, and the source not even mentioned whence his authority is derived. Langenbeck, according to Chevers, is likewise stated to have performed the same operation with the same result. Here, however, a confusion exists with some other case in which Langenbeck tied only one carotid, of which we shall hereafter speak.

[4] This operation has been performed ten times on living men, but always with fatal consequences.

whilst the vertebral has been tied but once (by Maisonneuve, in 1853). Of the numerous cases we have compared, we have found very few, to our great regret, related with even tolerable accuracy; especially are the records of the post-mortem examinations, in the cases which proved fatal, very faulty, more particularly the descriptions of the anatomical alterations in the brain. We do not pretend to give, in the following pages, a complete enumeration of all the symptoms attending this operation, but merely a general description, for which purpose a number of carefully compared examples (more than a hundred) may probably suffice.

After applying a ligature to one carotid, to the innominate artery, or to both carotids in succession, in some instances no disturbance whatever in the functions of the brain was observed; but in the greater number the following symptoms appeared, namely; a difficult, deep, and even rattling respiration (which, moreover, was speedily induced), spasmodic attacks of cough, headache, or a cessation of headache when previously existing, toothache (according to Dupuytren[1] and Malgaigne[2]), loss of sight in the eye on the same side as the part operated on, dizziness, stupefaction, insensibility, loss of consciousness, of speech (Horner), and of free play of the muscles in general, difficulty in swallowing, nausea, vomiting (Lambert), swooning, and coma. Swooning has sometimes been immediately succeeded by death without convulsions appearing.

Aston Key[3] tied the right common carotid of a woman sixty-one years of age, suffering from an aneurism of the innominate artery. In about an hour and a half after the operation, the woman appeared to sleep quietly, the breathing was somewhat stertorous, and grew weaker by degrees; and, four hours after the operation, she expired. On a post-mortem examination, it was found that the aperture of the left carotid at the arch of the aorta was completely closed, and that the vertebral arteries were of unusually small calibre. The brain was healthy; its blood-vessels exhibited no morbid appearance, and contained the ordinary quantity of blood; a moderate quantity of serous exudation was found between the membranes. Unfortunately, no information was afforded with respect to the condition of the lungs. If death did not take place at the latter organs by a disturbance and stoppage in the circulation, resulting

[1] Rust's 'Magazine,' vol. vii. p. 761.

[2] See afterwards.

[3] 'Medical Gazette,' vol. vi, p. 703; Burrows, loc. cit., p. 56.

in œdema and suffocation, as is frequently the case in rabbits and sometimes in men (Hall[1]), after the innominate artery has been tied,[2] it must have proceeded from the brain; the quantity of blood conveyed to it through the two contracted vertebral arteries not sufficing for its nutrition. The statement that the vessels of the brain contained the usual quantity of blood should not bias our judgment; for the vessels which, in the dead body, contain the usual quantity of blood are the veins. As a rule, the arteries are entirely empty in the smaller branches, and almost entirely so even in the larger ones; and dissection will scarcely ever show the quantity which the arteries contained during life. We shall soon examine these facts more closely. It may further be asked, why no convulsions took place, notwithstanding the fatal diminution in the quantity of blood in the brain. An answer to this inquiry is readily supplied in considering the age[3] and feeble constitution of the persons operated upon.

A result similarly fatal took place thirty-four hours after the operation, attended with râles in respiration and stupor, but without convulsions, in a case of bronchocele in which Langenbeck[4] first tied the right thyroid artery, and the right carotid eleven days later, in consequence of excessive and repeated hæmorrhages from the wound. At the post-mortem examination the right lobe of the cerebrum appeared anæmic, and its surface covered with exudations (serum?), whilst the left lobe was gorged with blood. Some exudation (serum?) was discovered in the right ventricle, but not

[1] Velpeau, loc. cit. p. 247. In the cases of Mott, Graefe, Blaud, and Lizars, the persons operated upon died from hæmorrhage.

[2] Our numerous experiments on rabbits have convinced us that in tying the innominate artery the danger from hyperæmia and œdema of the lungs and from suffocation increases in proportion to the amount of blood in the patient. But if, in order to avoid this hazardous consequence, venesection be adopted before the operation, and certain limits be transgressed, another danger will ensue from the brain, its nutrition being impaired in a twofold way. Firstly, by the absolute want of blood in the patient; and secondly by the closing of such important vessels of supply. When, therefore, the carotids of men are to be tied, a too copious venesection, as generally performed by English and French surgeons, should be avoided.

[3] One of the cases, however, occurring in Wardrop's own practice, that of a woman seventy-eight years of age, whose carotid was tied without any serious results, clearly shows that the ligature on one carotid is sometimes well borne by very old persons.

[4] Langenbeck, 'Neue Bibl.,' vol. iv, st. 3, p. 586.

in the left. In this instance the brain was probably brought into such a morbid state from the excessive debility of the patient—produced by the previous repeated and violent hæmorrhages—that the ligature of simply one carotid proved fatal.[1]

The ligature of one carotid was frequently followed, sooner or later, by paralysis of the opposite side. If death took place, the affected portion of the brain was found softened, when the retention of the blood had lasted sufficiently long.

Sir A. Cooper's[2] first case had this paralytic issue. Seven days after tying the right carotid of the woman, who was forty-four years old, her left side became paralysed, and death took place on the twenty-first day. A post-mortem examination was not allowed.

Gundelach Möller, of Copenhagen,[3] tied both carotids of a child four years and a half old, suffering from a vascular tumour of the nose, within a period of four months. Soon after the application of the first ligature the opposite side became paralysed; after tying the other carotid vomiting and coma supervened, probably, however, not in consequence of the operation, but from a simultaneous attack of scarlet fever that was raging in the hospital where the child was. Nevertheless, the child recovered, but with only an imperfect use of the paralysed side.

Dohlhoff[4] observed two cases attended with fatal results, in which post-mortem examinations were performed. In the first the ligature was applied for a medullary fungus of the superior maxillary bone in a man forty-nine years of age. His bladder and opposite side became paralysed eight days after. The corresponding half of the cerebrum was softened; the rest of the brain was filled with blood. The other case was that of a woman aged fifty-one years, in whom paralysis of the opposite side with impaired consciousness took place on the fifth, and death itself on the seventh day after the operation. The brain and its integuments were in a highly con-

1 Dupuytren (Sedillot, Obs. de ligat. de la carot., 'Gaz. méd.,' 1842, p. 567, and Longet, 'Anat. et Phys. du Système nerveux,' vol. i) and Velpeau (loc. cit., p. 239) lost patients in whom one carotid was tied (Dupuytren's patient died on the sixth day in a state of great debility, probably from pyæmia. These cases do not belong to the same category, neither do those numerous ones where death was caused by hæmorrhage, suppuration (Travers), obstinate vomiting (Syme, in 'Archives génér.' 4ème série, i, 481), pleuritis (Maclachlan), &c.

2 'Med.-Chir. Trans.' vol. i, p. 1.

3 Gers. u. 'Jul. Magaz.,' vol. li. 1838, part 3.

4 Rust's 'Magazine,' vol. li, 1838, part 3.

gested state, and no difference was observable between the two halves of this organ.

Herbert Mayo[1] tied the right common carotid of a man whose external carotid had been wounded, and as hæmorrhage came on, consequent on ulceration at the point of application of the ligature, he repeated the operation on a lower part of the artery. Thereupon a sensation of torpor ensued in the left half of the body, ending in paralysis and death. The right half of the cerebrum was found to be softened, and between the arachnoid and pia mater was interposed a thick layer of lymph.

Textor[2] likewise saw this operation followed by paralysis of the other side, and death. At the post-mortem examination he found the centrum semi-ovale of the side where the carotid was tied, in a state of suppuration.

Sedillot[3] tied the right common carotid of a man suffering from violent hæmorrhage. Three hours afterwards the left half of the body and the right side of the face became paralysed, and the intellect almost destroyed. Death took place on the ninth day. The three lobes of the right half of the cerebrum were softened.

Similar cases, according to Norman Chevers, were observed by Fairfax, Girdwood, Macaulay, Vincent, and Barovero.[4] Velpeau (loc. cit., v. ii, p. 225) likewise saw hemiplegia with fatal consequences ensue, and Chapel, softening of the brain, after the application of a ligature to the carotid, according to the 'Report of the Meeting of the Académie de Médicine,' held on the 28th of October, 1851.[5]

Here we must mention the numerous instances either of sudden or else of rapidly produced obstruction of the innominate trunk, or of the common or the internal carotid, but particularly of the ramus sylvianus, by immigrated plugs or those of autochthonous origin, producing symptoms of apoplexy, with subsequent paralysis of the opposite half of the body and softening of one-half of the cerebrum in a greater or less degree.[6]

[1] 'Gers. u. Jul. Magaz.,' new series, vol. viii, p. 82.

[2] 'Chiron.,' vol. ii, p. 2; Langenbeck, 'Nosol. der Chir. Krankh.,' vol. v, p. 445.

[3] 'Gaz. Méd.,' 1842, p. 567.

[4] Barovero, however, tied both the carotid and internal jugular.

[5] 'Arch. génér.,' p. 355.

[6] Compare Norman Chevers, loc. cit., p. 1146, No. 1, and p. 1147, No. 2; Hasse, in 'Henle und Pfeufer,' Zeitschr., 1848; Virchow, 'Gesammelte

Twice, within our own experience, after tying one carotid, have convulsions been observed on the side of the application of the ligature, attended with paralysis of the opposite side—symptoms often noticed after hæmorrhage into either half of the cerebrum.

A man, æt. 48, whose right carotid was tied by Vincent[1], on account of an aneurism, was seized with convulsions on the same side an hour and a half afterwards; he then fell into a state of torpor and became paralysed on the left side. Sixty-two ounces of blood were taken from him within the first three days. Nevertheless, the convulsions continued, and only ceased two days before death, which followed on the seventh day after the operation. The right hemisphere of the cerebrum was softened to the consistence of cream; its veins were less congested than those of the left hemisphere, which exhibited blood-spots. The ventricles contained more serum than usual, whilst the cerebellum was in a healthy condition.

A man, æt. 28, thrust the mouth-piece of a clay tobacco-pipe through the root of his tongue into the right carotid at its bifurcation. It broke and stuck fast, and acting as a complete plug, gave rise to a tumour, and seven days afterwards induced violent hæmorrhage. Vincent[2] tied the carotid, and during the operation remarked the presence of convulsions of the right and paralysis of the left side. These symptoms lasted till the man's death, five days afterwards; only that the convulsions grew gradually weaker. Up to the time of breathing his last, the patient's mouth and nose bled at intervals. The neck was swollen around the bifurcation of the carotid, where an effusion of blood and pus was found, and the jugular vein was closed to a third part of its circumference. But little blood was

Abhandl. zur wissensch. Medizin' (Thrombose und Embolie); Kirkes, 'Med.-Chir. Transact.,' 1852, vol. xxxv, p. 281; Rühle, 'Arch. für path. Anat.,' v, p. 189; Burrows, 'Med. Times,' Feb., 1853; Bierck, 'Du Ramolissement Cérébral; Thèse inaug. Strasb.,' 1853; and Traube, 'Deutsche Klinik,' 1854, 4th quarter. We have compared the seventeen cases of thrombosis related in the above-mentioned works and papers, and have not found one in which simultaneous convulsions were observed, a doubtful case of Burrows' excepted, relating to a girl eighteen years old (affected with disease of the heart, and still under treatment when her case was published), who suffered from hemiplegia combined with chorea.

[1] 'Medico-Chirurg. Transact.,' vol. xix.

[2] Ibidem.

contained in the longitudinal sinus. The cerebral veins were only partially filled with blood, the arachnoid appeared dull and watery, and the convolutions of the right half of the cerebrum were flattened and softened. The latter contained irregular cavities, with ash-coloured effusion and green shreds. One of the cavities was two inches in diameter, and extended to the corpus striatum of the same side.

We may conclude that in both these cases the lateral convulsions did not proceed from hyperæmia of the opposite half of the cerebrum. In the former case the convulsions continued notwithstanding copious venesection, while in the latter they came on and persisted in spite of great loss of blood. The results of the post-mortem examinations likewise militate against such an assumption; the great quantity of serum in the ventricles and membranes of the brain but ill accords with the existence of hyperæmia; neither, on the other hand, do they afford any grounds for maintaining the opposite opinion; namely, that these convulsions as well as the paralysis might have been occasioned by oligœmia. We must content ourselves with confessing our inability, in the present state of science, to decide as to the cause of the simultaneous convulsions in these instances, as well as in effusions of blood into one hemisphere of the cerebrum.[1]

General convulsions have been seldom observed after the application of a ligature to the carotid. They, however, occurred after an operation performed by Abernethy[2] to arrest a profuse hæmorrhage from the left carotid, which had undergone extensive laceration from the thrust of a cow's horn. The first two hours after the operation the man was quiet and in the enjoyment of his intellectual powers. Then followed fever, delirium, and repeated attacks of convulsions, stronger on the left than on the right side, whilst afterwards the right side became paralysed, and the left continued convulsed. The patient died in strong convulsions thirty hours after the operation. The pia mater was found injected, and serum had been effused between it and the arachnoid; the brain exhibited traces of inflammation, and its vessels are stated to have been "full,

[1] The attempts of Brown-Séquard ('Experim. and Clinic. Researches on the Physiol. and Pathol. of the Spinal Cord,' p. 64) do not appear to us to elucidate the matter.

[2] 'Surgical Observations,' p. 193.

but not turgid." It is doubtful whether the case of Zeiss[1] belongs to this category. In a child eighteen months old, whose left carotid had been tied for a vascular tumour of the left ear, sudden convulsions came on nine weeks afterwards, *during the period of dentition,* and the limbs of the right side became paralysed. The child grew thin, and a few days before its death, which took place sixteen weeks after the operation, the limbs of the right side became alternately stiff from spasms of the extensor muscles, and bent from contractions of the flexors; the vascular tumour had disappeared, but the child's emaciated condition was pitiable in the extreme. A post-mortem examination was not allowed.

In a girl eighteen years of age, whose common carotid was tied by Sykes,[2] hysterical convulsions came on the same evening, and on the following day she was attacked by a violent headache, accompanied by depression and restlessness.

Magendie published in the 'Journal de Physiologie' the case of a girl aged twenty-five years who suffered from attacks of a decidedly epileptiform character.[3] Being affected with an enormous tumour of the left antrum, her left carotid was tied, after she had been subjected to a fortnight's previous treatment of low diet and venesection. Directly after the operation the patient felt well, but soon afterwards suffered from toothache, headache, and dyspnœa, to remedy which twenty-four ounces of blood were abstracted. An hour afterwards she swooned away. The faintings returned on the sixth day, attended with complete loss of consciousness. Her right arm became totally paralysed, her left one partially so, and she was unable either to swallow or speak; some hours afterwards an epileptic attack came on, the head being bent backwards, the pupils extremely dilated, saliva flowing from the mouth, and consciousness being entirely suspended. At length she recovered, but her speech only returned gradually, and it was not before the expiration of three months that she was again able to move her right arm even in the slightest degree.

Wattmann[4] applied a ligature to the right carotid of a farmer aged fifty-five years, suffering from disease of the submaxillary glands. Directly after the operation spasmodic movements of

[1] 'Hamb. Zeitschr. für die ges. Medizin.,' 1836, vol. iii, p. 9.
[2] 'Fror. Notizen,' 1824.
[3] 'Jul. u. Gers. Magazin,' vol. xvi, p. 93.
[4] 'Salzb. Med.-Chir. Zeitg.,' 1852, p. 32.

the whole body took place, which, however, soon ceased. On the following day, he became delirious and paralysed in the left half of his body, and six ounces of blood were abstracted, at three different times. The patient died, but no mention is made, either of the time of his death or of the results of the post-mortem examination.

We will, in conclusion, mention a case by Kuhl,[1] who tied the left common carotid of a powerful man, fifty-three years of age, for an extensive aneurism of the left occipital artery and its branches. The patient was immediately attacked by swooning and convulsions, and had to be carried to bed in a state of insensibility. Forty-one days afterwards, the application of a ligature to the other carotid was rendered necessary, in consequence of violent hæmorrhages from the tumour. Paleness of the face and slight convulsions ensued. The patient's sleep was quiet during the night, only once or twice disturbed by spasmodic movements of the right arm. The next day he complained of heaviness in the head, painful spasmodic movements in the right arm, and dimness of sight. His recovery, though protracted by hæmorrhages, and suppuration, was eventually complete fifteen weeks after the second operation.

Hence it follows, that the tying of the common carotid in man may eventuate in paralysis, as well as in convulsions—the former of one side only, the latter general. Paralysis of one side affects the limbs of the opposite side and usually the opposite half of the face, though sometimes the same, if Sedillot's observation be correct. General paralysis manifests itself by syncope, coma, or, as in the case related by Magendie, the arm of the opposite side becomes completely, that on the same side only partially, paralysed.

Paralysis may either precede, accompany, or follow convulsions. Lateral convulsions are synchronous. General ones may altogether put on the character of epileptic attacks, as proved to demonstration by the experiments of Magendie and Kuhl; and may come on directly after the operation (according to Wattmann and Kuhl), or only some hours or even days afterwards (according to Abernethy and Magendie).

It is consequently a rare occurrence for epileptic convulsions to make their appearance immediately upon the application of a ligature to the carotid, whilst in the majority of instances

[1] N. Chevers, loc. cit., p. 1145. Unfortunately I could not obtain the original.

syncope and paralysis of the side opposite to the one operated on will follow. In post-mortem examinations the cause of this paralysis has been traced to anæmia and softening of the cerebral hemisphere to a greater or less extent, on the same side as that on which the carotid had been tied, and in all cases which have come before our notice of thrombosis of the internal carotid, or of the ramus sylvianus, with subsequent softening of the whole or greater part of the cerebral hemisphere, the thalamus opticus and corpus striatum included, paralysis of one side has been observed to come on without convulsions in a similar way to an apoplectic fit. Hence we are fully justified in deducing these corollaries, viz.: that epileptic convulsions only manifest themselves in man when, together with the cerebrum, some or all of the parts of the encephalic mass lying behind the thalami optici are suddenly deprived of blood to a sufficient amount; but that sudden "falling down," announcing the approach of an apoplectic attack, unconsciousness, and insensibility, originate in causes proceeding from the brain proper.

## CHAPTER VII.

### INTERRUPTION OF THE CIRCULATION IN THE GREAT ARTERIES OF THE NECK CAUSES ARTERIAL ANÆMIA OF THE BRAIN, AND THIS ANÆMIA PRODUCES CONVULSIONS.

THE controversy as to whether the quantity of blood in the brain is susceptible of diminution, or whether the cranium, "as a closed, undilating capsule, having a capacity always the same," contains a certain and constant quantity of blood, may be regarded as finally determined[1] by the celebrated experiment of Donders.[2] This physiologist closed air-tight, with a piece of glass, an opening made by trephining in the cranium of a rabbit, and clearly demonstrated by this process the possibility of a change in the diameter of the vessels of the membranes of the brain, as well as of those of the brain itself.

There is no other method that leads with equal certainty to the knowledge of the processes of the blood's circulation in the cranium. The results of post-mortem examinations afford a great source of errors, as we shall explain in the next paragraph. In order, therefore, to be certain whether the simultaneous application of a ligature on the carotids and vertebral arteries causes an arterial anæmia of the brain, nothing remained for us but to adopt Donders' procedure. But here an unexpected difficulty arose. The different cements recommended by Donders for the air-tight insertion of the small glass plate into the wound caused by trephining, such as gum arabic and collodion, completely failed in our hands, and it appears to us that Donders was singularly fortunate in the experiment as communicated by him, turning out so successfully. Collodion, or gutta percha dissolved in chloroform, which we employed in the first instance, does not adhere sufficiently

[1] Compare Virchow, 'Handb. der Pathol.,' vol. i, p. 111.

[2] Fully related in Schmidt's 'Jahrbücher,' 1851, vol. lxix.

to the glass and bone, contracts while drying, and gives way here and there, a mishap partly caused (according to Donders) by the liquid secreted by the membranes of the brain trickling through the pulverized gum into the gaps between the small plate of glass and the edges of the bones. After having tried various cements, we at last succeeded three times in cementing the glass plate air-tight, by the following method.

The surface of the frontal part of the cranium of an old and large rabbit is exposed to a sufficient extent, by cutting the skin into four flaps, which are turned backwards, and by completely scraping off the periosteum to a *great distance round*. A dry surface of the bone is thus obtained, which is of importance as regards a favorable issue to the experiment. A small piece of glass out of a watch-glass is then cut, eleven millimètres long, becoming proportionately narrower from back to front, so that its posterior end is nine millimètres wide, the front part eight. This is pressed on the surface of the bone, its contour marked on the bone by tracing with a pencil round the edges of the glass. Care must be taken that the edges of the glass are as straight as possible, and that those of its upper surface are ground down to the width of one millimètre, which is easily done on a rough sandstone. Then the piece of bone which has been marked is cut out with a small bone-saw, and the edges made as smooth as possible with a pair of bone-nippers, in order to make the piece of glass fit exactly.

Laying bare the dura mater generally causes a slight bleeding, whilst its removal is usually followed by more copious venous hæmorrhage, which is best arrested by a piece of tinder, or by the pressure of the glass itself. After the bleeding has stopped, the glass plate, being perfectly clean, is inserted and allowed to remain there. If the brain be somewhat sunk in, a drop of water may, according to Donders' procedure, be dropped upon it, in order to prevent any air remaining between the brain and the glass plate. Some finely powdered gum is then pressed into the gaps, as Donders likewise specifies, and rapidly touched with a red-hot iron, in order to dry it. The use of powdered gum has this advantage, that the serum which rapidly oozes out becomes collected, and adheres at the same time, whereby the glass is held until the proper cement can be applied. The surplus of the powdered gum is then blown off from the glass plate and bone. Instead of gum powder, a solution of shell-lac well saturated with spirits of wine may be used to fill up the gaps. Finely powdered shell-lac is now thickly sprinkled on the edges of the bone, and lightly touched with the red-hot iron. The shell-lac melts, and immediately hardens, forming a cover firmly adhering to the glass and bone, completely closing the several gaps. The small openings may in this way be completely closed. Whether the closing be air-tight or not is shown by compressing the innominate artery, while the left subclavian artery is closed. If the smallest opening be present, the brain will sink in, and an air-bubble appear between the brain and the glass. Upon the compression being removed, the brain presses against the glass plate, and air and serum come forth through the aperture. In this case the fault must be repaired. If the closure be air-tight, *no movement of any kind is to be observed in the brain,* no air enters when compression is made, neither, upon the cessation of the latter, is any serum pressed out.

Before we communicate the results of our experiments with compression when a glass plate has been inserted, it will be necessary, for the sake of a better comparison, to relate the results of compression on an opened cranium after eight experiments made by us for this purpose. It is a matter of indifference whether the dura mater remains entire or is removed; the brain sinks in as soon as compression is applied, and retreats from the cranium in the shape of a *cup,* the dura mater, if preserved, remaining closely adherent. The brain cannot, however, retreat so far, when the dura mater is preserved intact, as when the latter is removed as far as the bone cavity extends. In the latter case the brain sank in one experiment two and a half millimètres in the centre of the opening. As soon as the brain has become *completely pale,* the smaller veins cease to be visible to the naked eye, the more completely the smaller their diameter; while the larger veins, which pass across the hemisphere of the cerebrum and terminate in the large longitudinal vein over the falx of the brain, become one fourth to one third smaller in diameter, the longitudinal vein contracting to a less marked degree. If, in extensive anæmia of the brain, the animal's nostrils be closed, the brain and its vessels immediately commence swelling again.

Upon convulsions taking place the brain presses more and more into the fissure of the bone, and even fills it up again, but without turning red, although the veins on its surface visibly enlarge.

With the cessation of the convulsive attack the veins again become less swollen; and yet, even in death, the brain still remains protruding.

As soon as the blood begins again to flow, the brain becomes of a deep rose colour, a number of small arterial and venous vessels appear, the veins swell beyond their normal size, while the brain, exceeding its ordinary bulk, protrudes, into the hole made by trephining.

When the glass plate is inserted air-tight, the symptoms exhibited in the brain are no longer the same. It is not possible to induce further movements in the brain, even though the compression be continued until death, and the nostrils be closed; or the compression be removed, and the brain thereby be intensely congested. The brain remains, in all cases, immovably fixed to the glass plate. The phenomena exhibited by the vessels remain the same as those which manifest themselves when the brain has been laid bare. On compression being applied, the latter forthwith becomes pallid, the smaller vessels cease to be visible to the eye, the veins which open into the great longitudinal sinus contract with greater or less rapidity to a fourth or even to a third of their normal diameters. Whether the longitudinal sinus itself undergoes any contraction, remains a matter of uncertainty.

If, during this period, the nostrils be closed, a distinct swelling and an enlargement of the veins ensue. Even when the brain has become very pale, and the veins have undergone considerable contraction, yet does not the pale colour of the brain sustain any change.

When convulsions came on, the veins again swelled without the brain changing either its colour or position, and this continued even till the cessation of the convulsions by death, and, indeed, for some minutes subsequent to the last act of respiration.

When the circulation was restored, the brain immediately assumed a pink colour, a great number of the finest vessels became visible, and the veins appeared considerably swollen.

These experiments, therefore, bear signal testimony to the soundness of the doctrines which reflect so much credit upon Burrows and Donders, who established them. The doctrine, so highly important in practice in the application of bloodletting in cases of diseases of the brain, *that the quantity of blood in the brain and its membranes can be sensibly diminished,* cannot be so clearly demonstrated by any other experiment as by the one above mentioned. And it is only by that ingenious method, which will for ever render illustrious the name of Donders, that reliable information can be obtained as to the state of the cerebral circulation in asphyxia, strangulation, after section of the cervical cords of the sympathetic during the anæsthesia from ether, or during inebriation and narcotization by means of morphia, atropine, &c.

As it regards our special question it is shewn :—that compression of the great arteries causes capillary and venous anæmia of the brain and its membranes, until convulsions ensue, whereby the venous anæmia is at least partially removed, without that of the capillaries simultaneously ceasing. It is just this latter circumstance which leads to the destruction of life, since all organic activity is dependent on a constant change of matter, an undisturbed nutrition, and the presence of red blood in the capillary vessels. The brain is suddenly deprived of its supply, and the required quantity of nutritive matters to permeate its tissues and replace what is constantly being consumed, is no longer afforded. The brain, therefore, undergoes an internal chemical change and injury, which will be manifested by disturbance of its functions.

Burrows maintains that this alteration in the functions of the brain, attendant upon anæmia, is not susceptible of explanation upon the hypothesis of the withdrawal of nutrition, but that the disturbance is to be ascribed to the usual pressure to which the brain was subjected by the heart-pump, and which was necessary for a regular action of the brain, being no longer kept up. He consequently adheres to the opinion which Bichat endeavoured to establish in his celebrated work 'Sur la Vie et la Mort.'

Without altogether denying the importance of this pressure, we consider it as quite secondary in relation to the question under discussion, since these epileptic convulsions occur irrespectively in the rabbit both after the removal of considerable portions of the cranium and when it has been completely closed. We generally found, upon the skull being opened, if the experiments of compression lasted a long time and were frequently repeated, that the convulsions gradually appeared later than when the skull was closed. The assertion, therefore, seems fully justified, *that a stoppage in the supply of blood* (*i.e., the interruption of the change of matter*), *and not a suspension of mechanical pressure on the brain, occasions convulsions.* We beg, in conclusion, to mention an experiment which seems clearly to prove our assumption. In a strong black rabbit we first broke off the anterior portion of the cranium covering the cerebrum as far as the edges of the orbit laterally, and backwards as far as the transverse sinus; then, beginning at the divided membrana obturatoria, we also removed the cranium covering the cerebellum laterally as far as possible, and anteriorly to the transverse sinus. When, lastly, we removed the remaining bridge of cranium over the transverse sinus, and the animal was dying from violent hæmorrhage from the latter blood-vessel, then only, and in spite of the fact that the brain, cerebellum, and medulla oblongata, were so extensively exposed, did most frightful convulsions ensue, bearing completely the character of an epileptic attack.

## CHAPTER VIII.

### ON THE RESULTS OF POST-MORTEM EXAMINATIONS AFTER DEATH BY HÆMORRHAGE AND APPLICATION OF THE LIGATURE TO THE GREAT ARTERIES OF THE NECK.

After death taking place from hæmorrhage, we have always found the brains of the rabbits experimented upon of a pale colour; the surfaces obtained by section presented no blood-spots; the membranes of the brain, bones of the cranium, and soft integuments of the head, were pale; the sinuses and larger veins containing a small proportion of blood; and the great arteries at the base of the brain a still smaller quantity.

To demonstrate clearly the fallacy of the doctrines propounded by Kellie, Abercrombie, and Hammernik, no better plan can be adopted than that of opening two animals simultaneously, one of which shall have died from hæmorrhage and the other in the following manner: after dividing firstly both cervical branches of the sympathetic nerve, then applying a ligature to the veins of the neck, and (after waiting till respiration has considerably diminished, in consequence of the hyperæmia in the cranial cavity which is invariably present) finally strangling the animal with a strong piece of twine. We delayed the operation of strangling, in one instance, until the number of respirations was gradually reduced in the space of five hours from 140 to 28. In its last throes the animal's ears turned paler, whilst its arteries and veins contracted.

On examination of the head immediately after death the ears and skin of the head still appeared pale. So excessive a hyperæmia, both of the brain and its membranes and of the sinuses and bones of the cranium, had never hitherto come under our observation. The blood issued forth from the cut surfaces in quantities such as would hardly be seen upon dissecting the brains of living and full-blooded rabbits.

In death from the application of ligatures to the arteries of the head the results of the post-mortem examinations present but one uniform feature. We found, in every instance, the substance of the brain, as well as those of the medulla oblongata and the upper part of the spinal cord, deprived of blood, the cut surfaces without blood-spots, and the arteries of the cranium empty; some larger arteries at the base of the cranium excepted, which contained a slight quantity of blood. The quantity of blood in the veins, however, varied considerably.

We almost invariably opened the cranium after the last respiration, or shortly after the last pulsation of the heart. The sinuses, as well as the large veins with rigid walls in the roof of the cranium near the ears, generally contained even considerable quantities of blood. The larger veins and those of medium calibre in the pia mater were also frequently scarcely any smaller than in the animal trephined whilst alive; but the lesser veins appeared to contain very little or no blood. More rarely, perhaps once in ten cases, were all the veins of the neck, vertebral column, and cranial cavity, found distended with blood. Lastly, all the veins, even the sinuses and vertebral veins of the upper third or upper two-thirds of the cervical part of the vertebral column were sometimes found to contain very little blood.

The conclusion, therefore, at which we arrive, is, that, after applying ligatures to the arteries of the head, the proportion of blood in the cranial cavity is on the average much greater than after death from hæmorrhage. But it is in the larger veins more especially that we find a more abundant quantity of blood, while the finer ones and the arteries contain very little or none. Considerable hæmorrhages frequently take place after trephining the animal when dead, particularly if a vein holding blood be cut, and more especially if the heart is still beating. The blood may stream out in such an abundance, even if the head be kept erect, that the cranial cavity from which the brain has been removed frequently will be unable to hold it. This fact, as well as the finding of venous hyperæmia in the cranial cavity, may be easily explained from the following circumstances.

The closing of the great arteries of the neck in plethoric animals causes, in the first instance, hyperæmia in the left heart, and then in the lungs and right heart. The heart and great blood-vessels are consequently found greatly distended, the lungs containing much blood and sugillated, frequently œdematous, and, after repeated experiments with compression, sometimes hepatized in several places, whereby the flow of venous blood into the right heart is hindered. In those regions of the body whose veins enter the vena cava nearest to the heart, a collection and accumulation of venous blood takes place. To these regions especially belong the inferior part of the neck, and the dorsal part of the vertebral column, the veins of which region, in the rabbit, open directly into the two superior venæ cavæ. A greater fluid pressure is exerted upon the collected venous blood, and hence tends to flow back again from the greatly distended and gorged vessels of the back and inferior region of the neck to the less filled or empty and valveless veins of the head.

With this is associated a circumstance of no slight importance, which we may, perhaps, designate as a condition of active pressure, whilst that just mentioned represents a passive one. The total amount of the arterial blood withheld from the *reservoirs* of four great arteries of the neck is distributed among the remaining regions of the body, but not equally so. The greater proportion must necessarily be conveyed to those arteries situated nearest to the place of ligature, *i.e.*, to those given off from the thoracic aorta. The intercostal arteries convey, upon an increased pressure, a greater quantity of red blood to the dorsal and posterior cervical regions; for if the heart still continues to beat vigorously after the last breath and when the left ventricle becomes torpid, it becomes thereby contracted, and expels its contents.

The black blood in the veins of the region last referred to is consequently placed under a stronger "vis a tergo," whilst it experiences greater resistance on its way to the heart. It must, therefore, seek an outlet in the direction of the neck and head.

A third link is added to the chain of efficient causes in the convulsive attack and the last deep respirations previous to death. During the convulsion respiration completely ceases, the glottis is closed, and the cerebral veins swell, as our experiments after Donders' method prove. It may readily be conjectured that by the last deep respirations the quantity of venous blood in the brain must be diminished, in consequence of the powerful determination towards the heart and lungs. When, however, the heart and lungs, as is generally the case, are already overcharged with blood, and the latter have become œdematous, the effects of inspiration will be but slight, while every expiration will necessarily expel considerable quantities of blood from the thorax and dorsal veins and drive them to the head.

In fact, the experiment so frequently repeated by us shows that in dead animals whose crania have been opened, or whose membrana obturatoria have been divided, large quantities of blood can be propelled into the veins of the neck and skull by compressing the thoracic walls, or by simple pressure on the diaphragm, even if a cord shall have been tied two or three times round and so tightly as to make all the veins in the integuments of the neck impermeable. The blood has therefore of necessity to pass to the head through the dorsal and vertebral veins. This experiment always answers, provided the large vessels of the thorax contain a sufficient quantity of blood.

The question, however, arises, whether this experiment avails for cases of *closed cranium*. By taking off the upper part of the skull we remove an impediment which acts as a counter-pressure against the influx of blood from the vertebral veins. And this was certainly the cause of the great hæmorrhages which, soon after the cessation of respiration, so frequently took place during the operation, from the wounded veins of the skull and brain, in the animals which, in the course of our experiments, died of anæmia of the brain.

We may, however, be justified in affirming, that venous blood from the thorax can also enter the closed skull of a dead animal, as has been reduced to a certainty in the case of the living one both by Donders' experiments and our own. Why should it not be possible, that under favorable circumstances, even in death, the liquid contents of the skull, the proportion of blood and cerebro-spinal fluid, may change? The possibility of the entire contents of the skull being put out of place by an altered position of the tentorium cerebelli and membrana obturatoria does not cease with life, and the cerebro-spinal fluid can, in a dead animal, be pressed more easily into the spinal cavity, because with increasing putrefaction, the ligaments between the vertebræ and their integuments become softer and more yielding. The conclusion seems irresistible, that in living animals, in whom the most vigorous muscular apparatus for pressure is active, such as the organs of respiration, the heart-pump, and muscular coat of the arteries, such a change may take place much more rapidly and easily than in dead ones, especially if we date the approach of death from the last pulsation of the heart, and not from the last respiration. There are, however, also in the dead body some considerable dynamical forces, which drive the blood towards the head. We refer to the contraction and diminution of the heart, first commencing in the left ventricle, consequent upon the rigor mortis; the development of gas in the intestinal canal, whereby the diaphragm is pressed upwards, and the blood of the hepatic veins and of the inferior vena cava is urged towards the right heart and into the superior vena cava, and with a force so much the greater that the rigid abdominal integuments at first offer resistance to the pressure of the gases. Lastly, we refer to the decomposition of the blood, and the development of gas in the heart and great vessels themselves. More important, however, than these causes acting from within, appears to us, that external and casual circumstance to which the medical man's attention is always more directed, namely, the position of the corpse, whether it be with the head inclined downwards, or lying on the belly and chest, whereby a pressure is brought to bear upon the contents of these cavities.

Burrows[1] killed two grown-up rabbits with hydrocyanic acid, and, whilst the hearts were still beating, suspended one by its ears, and the other by its hind legs. After twenty-four hours cords were tightly fastened round the necks of the animals, which were placed on the table and opened. In the one suspended by the ears, all the external parts of the head, the ears, eyeballs, and so forth, were pale and flabby; the muscles and bones of the skull contained very little blood. Upon opening the skull, the membranes and substance of the brain appeared pale; the sinuses, and other vessels, free from blood. In the second animal, suspended by its hind legs, the external parts of the head, the muscles, and bones of the skull appeared of a dark colour and full of blood; the membranes and vessels of the brain gorged with dark liquid blood, the sinuses also filled with dark blood, and the substance of the brain uniformly dark and highly congested. To give these experiments their full weight, Burrows should have suspended the animals only when the heart had ceased to beat. Still they are instructive, and irrefutably demonstrate that the quantity of blood in the brain and its membranes will vary according to the position of the body during the last pulsations of the heart. We, ourselves, have

[1] Loc. cit., p. 14.

on several occasions noticed the ears of plethoric rabbits, in which we commenced the experiment twenty-four hours after death from ligature of the cervical arteries, become of a bluish-red colour and turgid with blood, after the head had been in a lower position for a length of time, although the ears were extremely pale when death took place, and for some time afterwards. The jugular veins and their branches, which after the application of the ligature had contracted and become almost empty, we have found, under these circumstances, gorged with dark blood. The veins of the neck, of the cranial bones, cervical vertebræ, and membranes of the brain have been found hyperæmic to such a degree, that one ignorant of the real cause of death might have easily drawn the false conclusion that the animals during life had suffered from congestion of the brain, and had, in consequence, died of apoplexy. The brain itself was not hyperæmic, but of a bluish tinge, and soft.

Engel[1] declares it to be impossible that cadaverous hypostasis can take place in the brain and its membranes when the skull remains closed, and he refers to experiments performed upon human bodies which he placed for two hours in a vertical position, the head downwards. Extensive hypostasis took place in the skin and muscles of the face and head, but he could not observe any alteration in the brain and its membranes, other than would have been shown if the bodies had remained in the ordinary posture.

We do not know whether the experiments performed by Engel were sufficiently numerous to entitle him to give such an unqualified opinion. At all events it certainly results therefrom that one does not so easily and under all circumstances succeed in producing a greater fulness in the veins of the skull by keeping the head in a downward posture, as has been frequently taken for granted.

As the quantity of blood in the veins of the cranial cavity may undergo alteration, certainly, in the agonies of death, and probably under other favorable conditions, it is evident that it must be *very difficult and often impossible to form an opinion from the quantity of blood observed in the skull after death as to the amount contained during life.* The greatest impediment, however, is met with in the state of the arteries, which, during the period of dying (in the ears of the animal, as seen by us even after section of the

[1] 'Darstellung der Leichenersch,' p. 17 et seq.

nervi sympathetici and application of ligatures to the. veins, and after strangulation), contract and drive their contents with some force through the capillaries into the veins. We could never deduce any results from the post-mortem examinations undertaken with a view to determine the state of fulness before death of the most important parts of the vascular system, viz., of the arteries and arterial capillaries; and even in the most favorable instance, when similar inquiries were directed towards the veins, our results could only be looked upon as approximate. It appears therefore to us to be especially necessary to study carefully the state of the brain's circulation in asphyxia, narcosis, intoxication, etherization, &c., in the living animal, according to Donders' method.

We have hitherto intentionally abstained from making any reference to the state of the cerebro-spinal fluid as it appeared in our experiments, for we have not been successful in discovering any method by which the slight quantities of humour contained in the cranial and vertebral cavities of these animals could be even approximately determined. We can only confirm the statement made by Malgaigne, in his 'Surgical Anatomy,' that in very thin rabbits, the exterior part of whose skull was opened during life, we found very great quantities of serum and but little blood, whilst the opposite condition was observed to hold in well-fed animals.

In order to determine whether the proportion of serum is increased by applying ligatures to the arteries of the head, we were accustomed, in most of the dead rabbits, before removing the roof of the cranium, to divide the muscles of the neck transversely, to lay bare the lig. obturatorium, and to open the fourth ventricle by puncturing through the middle of the latter, the head being kept in an upright position. The quantity of serum we obtained in this manner amounted generally to a few drops, but seldom did a greater quantity issue forth than would fill a teaspoon, while sometimes none at all appeared, or it only flowed out when the head of the animal was lowered and its body placed in a higher posture. The proportion of serum generally remained below what we obtained from a dozen living animals in whom we punctured the membrana obturatoria when in the same position and whilst the blood was still in free circulation. But here it must be carefully observed that during active processes of change, even within a few seconds, greater quantities of cerebro-spinal fluid may perhaps be secreted than the cerebral ventricles may be able to hold at any given time; and also, that whilst respiration still persists, a certain quantity of water is driven out of the vertebral cavity with every expiration. Estimating the quantity of water contained in the brain from the mere appearance of its surfaces, or of cut surfaces in the dead rabbit, does not lead to any more satisfactory results. Both the natural surface of the brain and that obtained by section, repeatedly presented in those animals which died from strangulation, and even in those which died from the application of ligatures to the jugular veins, no more marked appearance of moisture than in those which perished from cerebral anæmia; at least no striking difference could be perceived. Berlin[1] also obtained the same results, although he paid but little regard to them. Larger dogs will probably be better adapted than rabbits for investigation on this subject.

Lastly, the experiments according to the method of Donders did not afford any explanation of the increase and diminution of the quantity of serum in the brain and its membranes in arterial anæmia or hyperæmia.

There is certainly every justification theoretically for the assumption that the quantity of serum will increase and decrease inversely with the quantity of blood. We were not, however, unfortunately, in a position to establish this doctrine in the rabbit by an instance of rapidly increased circulation. Perhaps we should have succeeded better if we had compared the specific weight of the brains of such animals as had died from hæmorrhage with that of those strangled by the application of ligatures to the veins.

[1] Schmidt's 'Jahrbücher,' 1851, vol. lxix, p. 14; Nederl, 'Lancet,' Feb., 1850.

# CHAPTER IX.

## THE STARTING-POINT OF EPILEPTIC CONVULSIONS FROM RAPID AND PROFUSE HÆMORRHAGE IS NOT TO BE TRACED TO THE SPINAL CORD.

From the experiments communicated in the preceding pages, positive evidence has been obtained that epileptic convulsions are brought about by a rapidly induced anæmia of the nervous centres included in the skull. The next question to be solved will be that of the state of the spinal cord induced by withholding red blood. Mechanical, caustic, and galvanic irritation of the spinal cord may, it is true, produce general and violent convulsions, with persistence of consciousness. Does, then, the general abstraction of arterial blood act as an excitant on the motor ganglia of the brain as well as on those of the spinal cord, or do the former alone constitute the motor centre from which the impetus to general convulsions proceeds, whilst the spinal cord acts only as a conductor, simply transferring the irritation of the brain to the muscles? Our experiments teach that the latter is the case, that the brain and the spinal cord react in remarkably different ways against this influence. In ten rabbits, differing with respect to age (from four weeks to several years), sex,[1] colour, and species, we tied both subclavian arteries at their origins, so that the blood was conveyed to the brain through the carotids only. Then the arch of the aorta was tied round with a thread (an operation we succeeded in performing without injury to the pleura or any other important parts) drawn a little forward and compressed with a strong instrument especially constructed for the purpose. It consists of a small pair of forceps, named after Charriere, 8·5 centimeters long, its branches crossed at their posterior ends, and very elastic, the anterior ends, 3·5 centimeters long, lying closely together, with smooth surfaces, being

[1] The formation of the thorax in the female renders the application of a ligature to the arch of the aorta easier than in the male.

3·5 millimeters wide, and rounded off at the edges. This instrument closes the aorta so completely that not a drop of blood can pass through it to the posterior part of the body.

We reserve for another time the description of the symptoms caused by compression of the aorta, in respect to the sphincter of the anus, the muscles of the intestines and of the bladder. We will here only remark, that the sphincter of the anus is affected in the same way as are the constrictor muscles of the face in compression of the great arteries of the head. It first becomes spasmodically contracted; the terminal part of the rectum is thrown into a state of complete tenesmus, symptoms which undergo modification after some time into those of complete paralysis. The mucous membranes of the rectum and vagina turn pale, the circumference of the belly suddenly becomes smaller, and by degrees very much so (as in death from hæmorrhage), while the integuments relax and the belly feels very soft. Respiration becomes at once slower, and gradually in the direction from back to front weaker and weaker. The hinder part of the body soon becomes completely paralysed, while the fore legs are only partially so.

In most of the animals paralysis of the hinder part of the body came on without any convulsion. In three of them a short, slight trembling preceded; whilst these trembling movements were, in one case only, somewhat more rapid, resembling those occurring in paralysis tremulans, and lasting for some seconds. Within a few seconds, or at the most within from a minute to a minute and a half, the paralysis of the hind legs was complete.

Peculiar movements, similar to those witnessed in chorea, are regularly observed in the fore legs some time after tying the arch of the aorta. One can scarcely at the onset decide whether they are to be regarded as the expression of a voluntary endeavour to go forward, that is, as attempts to escape, or as real convulsions. It appears at first sight as if the animals were making efforts to escape, but that the fore legs moved for that purpose could not follow the direction of the will on account of their partial paralysis, and hence the resemblance borne by these movements to those of chorea. After waiting some time one becomes convinced that they are involuntary convulsions. The animal suddenly becomes alarmed, its head, mostly held backwards, is turned forwards, the closed eyelids open, the fore legs move more or less violently several times at rapid intervals, and step forwards. These movements are frequently repeated and are produced by a reflex act when the legs are touched. Between the stronger attacks affecting both fore legs, slight convulsive symptoms are observed in one or the other leg, which gradually become less strong and frequent, the animals are no longer able to keep on their fore legs, or hold the head upright; and finally, just as in the quivering movements of the hands of dying persons, a slight convulsive movement is all that is to be observed; a movement which ceases gradually during the last minutes of their existence.

Death first seizes the animals in the posterior and then in the anterior parts of the body. First the hind legs become paralysed, then the fore legs, then the muscles of the neck, and lastly those of the jaw and face. So, with respect to respiration, the action of the abdominal muscles is the first to cease; then the movements of the diaphragm and thorax become more and more imperceptible; finally the mouth and nose alone but at short intervals make certain violent gasping movements, phenomena as peculiar, as those presented by the respiration of the heads of decapitated new-born rabbits.

In a gray rabbit, one year old, the last respiration took place twenty minutes after applying the ligature. Others were subjected to several experiments by compression, and in these respiration ceased, from eight to eighty-one minutes after the last constant compression. Distinct cyanotic symptoms in mouth and nose were observed in most of the animals towards the end of their existence. The temperature not only of the hind part of the body, but also of the head, fell during the entire duration of the interruption in the circulation. In one case, at a temperature of 18° C. in the room, within one hour, that of the rectum became 12° C. lower, that of the ear 9° C. The heart stopped beating from eight to twenty minutes after the last breath. Consciousness appeared but little disturbed up to the last moment. The cavities of the lumbar, dorsal, and cervical vertebræ were, in four animals (the subjects of close examination), void of blood, with the exception of a small quantity contained in the venous plexuses of the vertebræ; and it was only in the middle and upper third of the cervical vertebræ, that the vessels in the membranes of the spinal cord appeared somewhat fuller, while the quantity increased more and more in the direction of the medulla oblongata. We never, however, found an abnormal quantity of blood in the cavity of the skull. The substance of the brain was always either partially or altogether devoid of blood, and it was only the veins of the cerebral membranes which contained that fluid in greater or less quantity. The heart and lungs presented the same characters as in cases where the great arteries of the head were tied.

Upon the circulation being restored, it lasted, after an interruption of more than one minute, remarkably long, until paralysis of the hind legs had gone off, and their free use had been restored. We never in any instance observed the capability of moving to return before from five to ten minutes, when the aorta had been closed for from three to five minutes; and it was never completely restored after an interval of from fifteen to twenty minutes.

The more frequently these experiments with compression were tried, the more difficulty was there experienced in bringing about a recovery. A slight twitching of some of the muscles in two examples announced the return of the power to move. If, therefore, the spinal cord of the rabbit be suddenly deprived of the supply of red blood nearly up to the medulla oblongata, the convulsions which ensue are never of the same character and violence as those which present themselves in death from sudden hæmorrhage, or in arterial anæmia of the brain; and thus complete proof is at the same time afforded that the source of general convulsions in death from hæmorrhage is to be sought, not in the spinal cord, but in the brain.

It might perhaps be objected, that convulsions do not ensue when the aorta is tied, for the simple reason that the muscles of the limbs are at the same time affected by anæmia, and attain too speedily a condition which prevents them from responding to the impulse given by the spinal cord. That such, however, is not the case is taught by the following experiment: Both the subclavian arteries of a young rabbit, eight weeks old, were tied near their origins and a thread passed round the arch of the aorta. No loss of blood nor the slightest painful convulsion took place during the whole operation. The animal was then set in an upright position and allowed to rest for ten minutes.

At 11 o'clock we closed the carotids. This proceeding was soon followed by a violent epileptic attack, and we removed the compressorium, whereupon the animal rapidly recovered. We now compressed the arch of the aorta, and suddenly a complete paralysis of the hind legs and a partial paralysis of the fore legs came on. The compressorium was removed thirty-six seconds afterwards, when full power of using the legs was restored in forty-five seconds.

At 11·5 we compressed the arch of the aorta a second time. The operation was almost immediately succeeded by complete paralysis of the hind legs and partial paralysis of the fore legs. Without delay we compressed the carotids, whereupon *a violent epileptic attack ensued within a few seconds.* Free circulation was allowed to return in the carotids and disturbance abated forthwith. The aorta, which had remained closed, was then similarly treated for forty-five seconds. Only after the lapse of a minute and a half did free power of moving the hind legs return.

11·10.—Compression is kept up on the arch of the aorta for one minute, and then only do we close the carotids. Only some slight convulsive movements in the fore legs take place, the head being drawn backwards. The pupils are extremely dilated, the breathing of the animal becomes very slow and deep, and death appears imminent. The circulation in the carotids is restored after their having been closed for thirty-six seconds, that in the aorta somewhat later. The head becomes hyperæmic, the fundus oculi of a ruby-red colour; the pupils remain for several seconds extremely dilated; no convulsions follow; the animal attempts in vain to get up on its fore legs.

11·17.—Hind legs and sphincter ani still paralysed.

11·18.—Sphincter ani again closed.

11·19.—The animal commences drawing up its hind legs again.

11·20.—The hind legs are again drawn up and the animal can now stand upon them. We now again compress the carotids, permitting free circulation through the aorta for an entire minute. *The animal draws near its end without being attacked by convulsions.* The obstruction is removed. Hyperæmia of the head with dilatation of the pupils lasts twenty seconds; no convulsive movement.

11·30.—*We again compress the carotids, and eight seconds afterwards general convulsions appear,* although free use of the hind legs is not yet re-established to its original extent. *The source of general convulsions in excessive hæmorrhage is therefore, without any doubt, to be sought within the cranium; and the spinal cord serves only as a conductor of the motor impulse proceeding from the brain.* It results at the same time that by the withdrawal of blood the spinal cord is easily damaged in its nutrition to such a degree as to be unable any longer to act the part of a conductor.

We tested the experiment just mentioned by two others. We first tied both subclavian arteries of an old male rabbit, then the arch of the aorta, and lastly the carotids. The animal expired under ordinary epileptic convulsions. The brain and spinal cord were found anæmic, their membranes and osseous coverings containing but little blood; while both lungs were highly œdematous, hyperæmic, and sugillated. The heart, whose cavities and coronary vessels were filled and distended with black blood, continued beating vigorously in all its parts even an hour after the last breath. Another rabbit of the same age died after compression of the aorta had lasted five minutes, the carotids remaining tied, without falling into general convulsions; the ordinary spasmodic movements in the muscles of the face being alone perceptible, and the head being drawn slightly backwards. The post-mortem examination gave the same result as in the former case, with the exception that the heart ceased beating sooner.

These experiments render it probable, in the highest degree, that Dr. Marshall Hall[1] was in error when, on witnessing convulsions in death from hæmorrhage after division of the spinal cord, he referred them to the hæmorrhage. We suspect that Dr. Marshall Hall allowed the hæmorrhage to come on directly after he had divided the spinal cord, and that he wrongly ascribed to the loss of blood those convulsions which result from the division and irritation of the spinal cord. We have repeated Dr. Marshall Hall's experiment on two different occasions, and have obtained results strongly corroborating our supposition.

*Experiment* 1.—In a female rabbit, a year old, of grayish colour, and of very vigorous and lively habits, we laid the innominate artery bare, and then divided the spinal cord above the third cervical vertebra. The animal did not lose more than about two drachms of blood. It was firmly tied by the fore legs, but only very loosely by the hind ones. Whilst the spinal cord was being cut through, and for some seconds afterwards, the hind legs moved in violent clonic spasms, and respiration became simultaneously slow and laboured. As soon as the spasms subsided we quickly loosened the animal and opened the innominate artery, which had already

[1] Compare Introduction.

been laid bare. Black blood issued from the vessels but slowly; the contracted pupils dilated, and the animal died without falling into convulsions.

*Experiment* 2.—In a gray, very strong, grown-up female rabbit, we laid bare the innominate artery, and then divided the spinal cord at the height of the fourth dorsal vertebra, by which operation about a drachm of blood was lost. While the spinal cord was being severed the animal shook violently, and the convulsions of the hind legs continued for some seconds afterwards. The animal was then loosened, and the hind part of the body was found completely paralysed. About three minutes after the severance the innominate artery was opened, and red blood issued forth with great violence; thirteen seconds afterwards violent convulsions of the fore part of the body took place, attended with dilatation of the pupils, which was preceded by great contraction of the iris, and by a drawing of the head backwards. One minute and a half after the vessel had been wounded, the animal died. The hind part of the body preserved the same position in spite of the convulsions of its fore part, and it was only after the last breath that the tail made some slight quivering movements, and the bladder voided some urine.

The post-mortem examination showed that in both animals the spinal cord had been completely severed. It may be remarked, that in the rabbit the spinal cord enters very far into the sacrum, so that in the second experiment a considerable proportion of the spinal marrow below the section remained untouched.

The proof just afforded that the source of epileptic convulsions after profuse hæmorrhage, or ligature of the great arteries of the neck, is not to be looked for in the spinal cord, appears to us to favour the assumption that these cannot be referred to the so-called reflex spasms, otherwise why do they not occur when so extensive a reflective source as the spinal cord is affected. Lastly, we may mention that when the spasms after hæmorrhage, or ligature of the arteries of the neck, have ceased, very often extended spasms can be produced in the form of reflex movements, by a mechanical irritation of the internal surface of the rectum, and likewise by direct irritation of the spinal cord.

## CHAPTER X.

### ON THE MODE OF PROCEDURE FOR DETERMINING THE CEREBRAL REGION FROM WHENCE GENERAL CONVULSIONS AFTER PROFUSE HÆMORRHAGE, ARISE.

Having succeeded in solving the problem we proposed to ourselves as to whether the starting-point of general convulsions in hæmorrhage was to be found in the brain or in the spinal cord, we have now to discover the means for solving a second and a more difficult one, viz., the determining from what particular parts of the brain these general convulsions arise.

The closing of some branches only of the internal carotid or of the basilar artery, may be effected by unirritating plugs driven into the current of the respective vessels; but then it will, in the first place, be uncertain whether, by the obstruction of these vessels, the districts supplied by them will always be sufficiently deprived of blood, considering how great is the number of anastomoses; secondly, the least irritating plug causes a certain degree of inflammation, which is not always confined in the blood-vessel to that part of its walls where the obstruction takes place; lastly, we cannot at will fix the spot which the embolus has to reach, and it is quite impossible simultaneously to deprive the brain, on both sides and in the same districts, of its red blood, which for our purposes was indispensable.

We, therefore, adopted another course. We cut out certain districts of the brain, and compared the effects of compressing the great arteries of the head before and after this operation. Experiments were previously made to determine the influence of the different preparatory steps of the operation upon the motor force which produces the general convulsions; for, before any confidence could be placed in the results obtained by these excisions, it was necessary to prove that these preliminary operations do not detract from or even altogether annul the motor force. Only under such circumstances, could it be inferred with certainty from the unaltered appearance or non-appearance of the convulsions after the removal of a part of the brain, that this does or does not contain the starting-point of the convulsions; and, from a considerable diminution after excision, could it be deduced, with great probability, that the removed district of the brain produces a part of the force that causes the convulsions.

It is true we did not possess any other means of comparing the force of the convulsions in the different attacks than those afforded by the eye. These, however, were amply sufficient, as in a somewhat strong animal the convulsions generally appear within a few seconds, and are, even in repeated experiments with compression, if not too protracted and recurring too quickly, of such violence, that a diminution of them from the influence of a weakening agent cannot be mistaken. In any case, however, where suspicions may attach to the results of compression, the experiment may be repeated on the same animal; and, when there is any uncertainty as to the results of *one* excision, the excision may be repeated on several animals, and the results compared.

In excision of parts of the brain, it is impossible to avoid the following complications:

1. The skull is removed to a greater extent, and thus the brain becomes subject to a different kind of pressure.
2. Blood is lost.
3. Some cerebro-spinal fluid escapes.
4. The temperature of the brain becomes lower.

With regard to the removal of the roof of the skull, it is frequently not without influence on the motor action. It is true that some animals seem scarcely or not at all weakened by it, but others fall for a shorter or longer time, even when the loss of blood has been inconsiderable, into a state of paralysis resembling faintness, or into a cataleptic stiffness, in which the limbs retain the position assigned to them. Sometimes these conditions pass off rapidly, the animals recovering in a few minutes, whilst at other times they last longer. This influence must, however, be regarded as unimportant in reference to our question, since the violence of the general convulsions after compression of the arteries of the neck, or after hæmorrhage, was not affected in more than twelve experiments, in which we paid especial attention to this point. We refer also to the results of our experiment previously communicated, in which the entire roof of the skull was removed, and the hæmorrhage was, nevertheless, accompanied by most frightful convulsions.

The same phenomena present themselves when the cerebro-spinal fluid flows away. If an incision be made in the membrana obturatoria, and as much serum as possible be allowed to flow off (an experiment we have performed three several times), the animal becomes weakened, it is true, but the convulsions produced by the anæmic state of the brain attain their former degree of intensity.

Excision of parts of the brain is always accompanied by loss of blood. The brain is an organ containing a very great quantity of blood, and what, in the dead subject, we generally call abundance of blood, would in the brain of the living be considered as scarcity of blood. There are, however, several ways of preventing exhausting losses of blood. In the first place the rabbits must not be fed altogether on green food, but for some days previous to the experiment they must have almost exclusively dry nourishment, such as vetches, oats, &c. In this way the easily coagulable blood of the rabbit is rendered much more so. After trephining, which, if carefully performed, rarely causes a great loss of blood (and a small loss is of no consequence whatever), the innominate artery has to be tied on a small piece of soft amadou in order that no more blood may pass through the blood-vessel. The thread can afterwards easily be cut at any time on the amadou with a pair of scissors, the ligature loosened, and the brain thereby thoroughly inundated, without any fear of wounding the artery. From the one vertebral artery the brain of the rabbit continues to receive a sufficient quantity of blood; upon compressing the left subclavian artery convulsions manifest themselves for some time with still greater violence, and now the whole exterior portion of the brain up to the vicinity of the corpora quadrigemina may be removed, if necessary, from the cranial cavity, without large and exhausting losses of blood being sustained. The blood accumulated in the cranial cavity is best removed with pieces of prepared amadou fastened to a pair of forceps. Moderate losses of blood, which still take place notwithstanding, are scarcely undesirable, since they afford a certain security against hyperæmia and œdema of the lungs, easily produced by applying a ligature to the innominate artery. In order to determine the effects of *copious and exhausting* losses of blood on the force of the convulsions occasioned by compression of the arteries of the neck (we already knew that smaller losses of from two to three drachms were of no importance), we performed the three following experiments:

*Experiment* 1.—A white, female, well-fed rabbit, ten weeks old, and weighing one pound nine ounces and a quarter. The left subclavian artery is tied, the innominate artery compressed. Violent convulsions take place. The right carotid is then tied and divided above the ligature. The blood first spouts forth and afterwards drops out. In the course of half an hour five drachms of blood are gradually withdrawn. The animal is put in an upright position. Is in a very weak state; the belly tolerably sunk in; the pupils very dilated; the fundus of the eye, however, of a red colour, and the animal still able to sit upright.

Ten minutes later, forty minutes after the commencement of venesection, the innominate artery is compressed. The animal leaps forward with great force, and falls into violent convulsions. Upon loosening the compressorium, consciousness returns, but slowly. Ten minutes later, the attempt to abstract some blood from the animal is renewed, whereby the left carotid is lacerated below the place where the ligature is applied, and the animal dies from hæmorrhage, terribly convulsed. As the animal was tied by its fore legs, we were able to collect all the blood which issued forth. Only a few drops were found in the left heart. The total amount of blood lost by the animal in all the hæmorrhages was seven drachms and a half. The last attack came on when the animal had altogether lost six.

In spite, therefore, of a gradual, copious, and debilitating loss of blood taking place within half an hour, ten minutes afterwards by compressing the arteries of the head, and twenty minutes afterwards by hæmorrhage, the most violent convulsions were produced, fully equal to those which had preceded.

*Experiment* 2.—A white, female, well-fed rabbit, about ten weeks old, weighing one pound seven ounces and three quarters; temperature of the rectum 39° C., temperature of the room 15° C.

The left subclavian artery is tied, and the innominate artery laid bare, by which operation only a few drops of blood are lost. Violent convulsions ensue within twenty-one seconds after compressing the innominate. Upon removing the compression the animal remains for nineteen seconds in a state resembling paralysis, when it springs up suddenly.

10·34 o'clock.—The right carotid is tied and opened above the ligature, and half an ounce of blood is voided within forty-two minutes.

At 11·20 the animal appears very much weakened and exhausted, its belly has become perceptibly smaller and softer, and it is only with difficulty that it keeps upon its legs. Placed upon its hind legs for five minutes, and held up by its neck, it does not fall into convulsions.

11·30.—Compression of the innominate artery. The convulsions appear ten seconds afterwards, and are somewhat weaker than before the hæmorrhage. The animal raises itself again twenty-seven seconds after the compression has been removed.

11·55.—Temperature of the rectum 33·4° C., temperature of the room 15° C.

12·20 and 12·30.—Compression of the innominate artery. The convulsions are considerably weaker than before, and manifest themselves for the first time after an interval of nine seconds; the second time after an interval of sixteen seconds. The animal rises each time soon after removal of the compression, but still remains for a time in a half paralysed state.

12·33.—Temperature of the rectum 31·6° C., temperature of the room 13° C.

1·8.—The animal gets restless and trembles occasionally, having up to this time remained very quiet, and as it were stunned.

1·16.—Compression. The animal is attacked by very violent convulsions, scarcely less severe than those which preceded the hæmorrhage. The animal is now, at intervals of from three to five minutes, repeatedly assailed with attacks of general and vehement shaking, whereby the head is drawn back, the fore legs move spasmodically, and the whole body trembles.

1·30.—Temperature of the rectum 29° C., temperature of the room 13° C.

1·55.—The spasmodic movements have ceased for the past twenty minutes, respiration is deep and slow (fifty-six inspirations a minute); the animal is quiet, and so exhausted that it can no longer hold up its head.

2·5.—Temperature of the rectum 27·8° C.; temperature of the room 13° C. The animal lies on its side.

2·8.—Compression brings on such violent convulsions, that the animal is thrown over, head forwards, and falls off the table. This attack is, moreover, very little weaker than that preceding the loss of blood. Upon restoration of the circulation the animal utters cries, and recovers with great difficulty.

2·16.—Respiration 36, deep and distressed. Rectum 27° C. The animal is now killed by compression of the innominate, whereby, moreover, it suffers from an attack of slight, but general convulsions.

In this case we observe that, after a copious, gradual, and very weakening loss of blood, sustained during an interval of forty-two minutes, the convulsions were slighter, immediately upon the commencement of the hæmorrhage, and in an hour after, than they were previous to it; but became very violent three hours afterwards, and even after an interval of three hours and three quarters, the animal, nevertheless, being in a state of great exhaustion.

*Experiment* 3.—A white male, very well-fed, and fat rabbit, about ten months old, weighing two pounds seven ounces. Temperature of the rectum 40° C.

11·15 o'clock.—Left subclavian artery tied; innominate artery laid bare. Compression performed with the usual result.

11·30.—Within six minutes, five and a quarter drachms of blood are taken from the right carotid in the manner repeatedly described by us. The mucous membranes of the animal are pale, but it is still very lively. Respiration was generally accelerated during venesection.

11·38.—Compression of the innominate causes strong convulsions, which are, however, weaker than before the loss of blood. When circulation is restored, the animal recovers slowly, remains still for some time, lying as in a swoon, and then it jumps suddenly up. It feels very cold.

12.—An experiment with compression induces convulsions as violent as before the loss of blood.

12·10.—Another drachm of blood is abstracted. Compression now causes very violent convulsions.

12·20·—A drachm and a half of red blood is further taken from the carotid.

12.28.—Compression produces very violent convulsions.

12·38.—One drachm of blood is abstracted. Exhaustion complete. Pupils dilated and pale. The animal is unable to sit, and can no longer hold up its head. The belly has become very small and soft.

12·43 and 12·53.—Compression produces each time very strong convulsions, which are preceded by complete opisthotonos.

Between the experiments the left fore leg sometimes moves spasmodically.

1·6.—The animal lies on its side, breathing 120 times in a minute. Rectum 31·6° C. Temperature of the room as before. The animal voids some urine.

1·18.—Compression. The animal still falls into convulsions, but their violence is much diminished. The compression is removed, but the convulsions still continue; the animal breathes rarely and distressedly, makes some spasmodic movements, voids urine, and dies. After the last breath the legs once more move convulsively. Quantity of blood abstracted eight drachms and three quarters.

Despite the repeated and exhausting losses of blood, very violent convulsions appeared after the numerous compressions, and the convulsions were weaker than before the carotid was opened, only after the first loss of blood, and again, when compression was applied for the last time.

To these experiments we add a fourth one, in which we endeavoured to determine the influence of refrigeration applied simultaneously with excision of parts of the brain, and which will appear to be considerable, resulting, as it did, both from the losses of blood as well as from the laying bare of the brain and the application of cold water (of which, however, we used as little as possible).

*Experiment* 4.—A white, female, well-fed rabbit, about twelve weeks old, weighing one pound fifteen ounces and a quarter. Temperature of the rectum 40° C., temperature of the room.

10·10 o'clock.—The left subclavian artery is tied, the innominate laid bare.

10·18.—Violent convulsions manifest themselves upon compression of the innominate.

10·30.—Removal of the roof of the skull covering the cerebrum, to the greatest possible extent.

10·42 to 10·47.—Two drachms of blood taken from the right carotid. The animal is put on its legs.

10·57.—Compression causes convulsions as violent as before the skull was opened.

11·15 to 11·20.—One and a quarter drachms of blood abstracted. The brain is cooled by applying snow from 11·12 to 11·30.

11·30.—Compression. The animal falls into violent convulsions, commencing with a violent leap. The refrigeration with snow is continued.

11·36.—The animal is excessively cold. The veins of the membranes of the brain are opened, and about a quarter of a drachm of blood taken away. Snow again applied.

12.—Compression causes violent convulsions. Snow again applied.

12·15.—Abstraction of one and a half drachms of red blood from the right carotid, and until convulsions appear. The animal becomes subsequently exceedingly weak (it lost five drachms of blood altogether,) and can no longer raise its body. Respiration quick. Snow is again applied.

12·30.—Compression brings on convulsions, but of less violence than the previous ones. Temperature of rectum 36° C., temperature of room 15° C. Renewed application of snow. The animal preserves its lateral position, and breathes slowly.

1 o'clock.—Compression induces an epileptic attack, which is weaker than the former ones, but still tolerably violent. Continuation of cooling with snow.

1·45.—The innominate artery is tied. The head is drawn backwards; the hind legs are extended; slight convulsive movements of the limbs ensue, and are followed by death. Temperature of the rectum 31·6° C.

The brain appeared at the post-mortem examination exceedingly pale, and the cranial cavity remarkably deficient in blood. Nothing abnormal was noticeable in the lungs.

It is certainly extremely remarkable that the susceptibility to convulsions, and to such violent ones, should have persisted so long a time, notwithstanding that the brain of the animal was constantly exposed to the influences of cold, and that great losses of blood were simultaneously sustained. The attacks still exhibited great violence an hour and a half after the removal of the skull; and even after two hours, when the exhausted animal could no longer keep upon its legs, they broke out again with great though diminished intensity. Only three hours and a quarter afterwards, when the animal was near death, was its motor power completely extinguished.

Compression of the arteries of the head, in the rabbit, is therefore capable of causing violent convulsions even after large and exhausting losses of blood, with or without simultaneous exposure and cooling of the brain. The spasms can be repeatedly induced in the space of from one to two hours, the time required for the experiments by excision. This, however, is not invariably the case. The convulsions are sometimes slight, though no satisfactory law can be laid down to account for this irregularity.

To obviate fallacious results, we therefore determined to make use of strong animals only, and to regard such experiments by excision as alone valuable and decisive, where the inevitable hæmorrhage was moderate—not exceeding, in young animals of from ten to twenty weeks old, two drachms, in older ones, from three to four drachms, quantities which a slight experience enables one readily to estimate—and where no symptoms of general anæmia (paleness of the mucous membranes, softness and diminution in the size of the belly) appeared. Further, we allowed shorter or more protracted intervals to elapse between the several acts of operation and compression, to afford the animals every chance of recovery. Compression was many times repeated in the same individual at greater intervals, that the several results might be checked the one by the other; and, finally, death was often brought on by hæmorrhage (wounding the innominate), instead of the application of the ligature. As a rule, our first experiments with compression were performed on the left subclavian artery, the innominate being uniformly closed; but the latter was afterwards freed, for the purpose of affording more nourishment to the brain. This method generally gave rise to effusions of blood, though rarely of an extensive nature, into the cranial cavity. After some time the left subclavian artery was tied, when compression was more conveniently repeated on the innominate.

## CHAPTER XI.

### ON THE RELATIVE IMPORTANCE OF THE SEVERAL PARTS OF THE BRAIN IN PRODUCING GENERAL CONVULSIONS UPON ABSTRACTION OF ARTERIAL BLOOD.

Out of more than twenty experiments which we performed for the purpose of tracing the source of general convulsions, we were entitled, in accordance with the principles laid down in the last chapter, to consider fifteen as successful and decisive. Their chief result is *that general convulsions arising either from profuse hæmorrhage or from closure of the great arteries of the neck, do not proceed from the non-excitable, but from the excitable parts of the brain.* Our experiments on the rabbit lead therefore to the same conclusion which the researches in the sixth chapter have made exceedingly probable in the case of human beings. *Convulsions in epileptic attacks sequential to the abstraction of red blood, do not proceed from the cerebrum properly so called, but from the motor centres situated behind the thalami optici, the excitation being induced by a sudden arrest of nutrition.*

Numerous experiments have taught us that large pieces can be removed from one or from both cerebral hemispheres, without the violence of the convulsions sustaining any diminution. Six particularly successful ones fully assured us—

(1) That the removal, of one or

(2) of both cerebral hemispheres, together with the corpus callosum;

(3) of the fornix and anterior commissure, as well as the cornua ammonis;

(4) of the corpora striata;

(5) of the pituitary gland, with the greater part of the tuber cinereum; and

(6) of the pineal gland,

does not exercise any influence upon either the production, or the violence of general convulsions. The source of the motor force is not to be found in these parts. As regards the thalami optici, we have ascertained, in four very successful experiments, that considerable pieces on both sides may be cut off from their superficial non-excitable parts, from the gray portion turned towards the third ventricle, as well as from the white substance of the external pulvinar and the corpora geniculata, together with the tractus opticus, without the strength of the convulsions perceptibly diminishing; but that such diminution will take place as soon as the excitable and deeper-seated portions are wounded, and pieces removed therefrom.

If the crura cerebri are removed in great slices or almost completely, together with the anterior corpora quadrigemina up to the pons, the liability of the animal to fall into convulsions, when blood is withdrawn, is by no means annulled, but only considerably impaired; and the spasms are sometimes confined to the hind legs, as we are justified in concluding from four experiments.

Finally, one experiment appears to be in favour of the belief that the removal of excitable pieces of the cerebellum likewise decreases the force of the convulsions. We omit giving full details of all our experiments, but restrict ourselves, to avoid prolixity, to an accurate description of the most remarkable and decisive ones.

*Experiment* 1.—*Excision of the cerebrum up to the thalami optici. The spasms bring on premature labour.*—A large, white female rabbit, weighing three and a quarter pounds.

3·40 o'clock.—The arteries of the neck are laid bare.

3·50.—The isolation of the innominate artery and of the left subclavian artery is completed, and threads are applied around these vessels. No loss of blood. The animal is made to sit up, and is lively.

3·55.—Compression of the arteries causes general and violent convulsions within a few seconds.

4.—The roof of the skull in its anterior circumference is removed with moderate loss of blood; the innominate artery is tied on a small piece of amadou; and

At 4·17 the dura mater is removed. The entire quantity of blood lost up to this time amounts to about a drachm and a half. The animal is but little affected, nor does it exhibit any symptoms of stupefaction or paralysis.

4·21 o'clock.—The left subclavian artery is compressed; six seconds afterwards general convulsions occur.

4·24.—The removal of the brain by means of a spoon and scissors is commenced; and

At 4·28 both hemispheres of the cerebrum, the corpus callosum, the fornix, and both corpora striata, had been entirely removed, as the post-mortem examination afterwards confirms. The tractus opticus and the optic nerves are well protected on both sides, as well as the tuber cinereum. The incision has been made exactly on the anterior limit of the thalami optici and downwards along the optic nerves. The pineal gland is torn off. During the removal of the brain the animal, although not tied, did not make any convulsive movement or attempt to escape, nor show any sign of suffering, but appeared greatly stupefied, and fell down. Put upon its legs, it was still able to stand, though no longer with its former strength; and, laid down upon the floor, it remained quietly, and "all of a heap," without making any effort to escape. The loss of blood during the removal of the brain was extremely small, perhaps half a drachm altogether. Some drops of blood gradually collected afterwards in the anterior cavity of the skull.

4·32.—Compression of the left subclavian artery. Five seconds afterwards strong convulsive shocks succeed; compression is suspended, and the animal sinks again into a fainting state.

4·37.—Compression of the left subclavian artery. After five seconds a violent attack of spasms commences, in which the animal is seized with premature labour and expels two fœtuses, one of which tries to breathe. Upon relaxing the compression it utters slow moans during the act of parturition.

4·40.—The ligature on the innominate is relaxed in order to supply the brain with more blood. The fundi of the eyes become darker; very little blood is lost within the skull, but the animal does not recover from its state of faintness.

4·48.—The innominate is wounded and the animal dies from hæmorrhage. Previous to death, and seventy seconds after the infliction of the wound, general convulsions of the most violent description come on, so that the animal is thrown from the table, and for fifty seconds struggles convulsed on the floor.

4·50.—The last respirations take place. Not a drop of blood appears under the pons or in the medulla oblongata. No pneumothorax nor œdema of the lungs. Three fœtuses are found in the cornua of the uterus.

Messrs. Payenstecher, M.D., Schiel, Ph.D., and Reichert, Student of Medicine, were witnesses of this experiment. *Just as in the human female, eclampsia gravidarum causes premature labour, and thus becomes eclampsia parturientium, so in the pregnant animal have we seen premature labour come on under the influence of an epileptic attach produced in the course of an of experiment.*

*Experiment* 2.—*Excision of the cerebrum up to the thalami optici.* —A white, male and very strong rabbit, about a year old, weighing two pounds nine ounces.

10·15 o'clock.—The great arteries of the neck are laid bare, and threads placed round them. No loss of blood. Compression causes violent convulsions within six seconds.

10·30.—The anterior part of the roof of the skull is broken off to a great extent, and the dura mater removed without any great loss of blood. The animal appears afterwards somewhat stupefied and paralysed.

10·40.—Compression brings on violent general convulsions within six seconds.

10·43.—A ligature is applied to the innominate on amadou.

10·45.—The right portion of the cerebrum is completely removed up to the anterior margin of the thalamus opticus. A moderate hæmorrhage ensues. The animal appears still more stupefied and weaker than before.

10·50.—Compression of the left subclavian artery. In a few minutes the animal is attacked with such violent convulsions that it is flung to a distance over the table.

10·54.—The left half of the cerebrum is likewise removed close up to the thalamus opticus. Moderate hæmorrhage. Up to the present time the animal has lost at the most two drachms of blood. The incision is made through the tractus opticus on both sides, through the tuber cinereum downwards, and separates the hypophysis cerebri. The animal neither moans nor even once stirs; on the contrary, it is completely paralysed, continues lying on its belly, and makes no attempt at escape. The limbs continue in any position in which they are placed.

11 o'clock.—Compression of the left subclavian artery. General violent convulsions ensue. The innominate is freed; the fundus of the eye turns of a dark-red colour. The animal loses within the next twenty minutes about one drachm of blood.

11·10.—The innominate and left subclavian artery are tied. The animal rapidly falls into frightful and general convulsions, which last for a minute and a half, and towards their termination are interrupted by tetanic spasms. At the conclusion of the attack the animal cries out loudly, voids urine, and begins afterwards to breathe quickly, until respiration becomes slower at 11·20.

11·21.—A thermometer is introduced into the rectum, whereupon general violent clonic convulsions ensue, and finally the hind legs are seized with tetanic rigidity.

11·23.—Respiration ceases. The crura cerebelli are irritated with a knife, and a violent and general convulsion succeeds.

In this case also no blood was effused below the pons or medulla oblongata; the lungs appeared in some places hyperæmic, but nowhere œdematous.

*Experiment 3.—Excision of the cerebrum and thalami optici to the limits of the excitable districts.*—A white female rabbit, ten to twelve weeks old, weighing one pound ten ounces and three quarters.

11·25 o'clock.—The arteries of the neck are laid bare without any loss of blood, and surrounded by a thread.

11·36.—The skull is opened and the dura mater cut away. The animal loses a moderate quantity of blood, and falls into a state of weakness, which lasts for some time.

11·45.—The innominate is tied on amadou; the left subclavian artery compressed; violent convulsions ensue.

12 o'clock.—The whole of the cerebrum anterior to the thalami optici is removed, and the latter are then cut off in slices with a pair of scissors from the outside, upwards and forwards to the interior and inferior portions, until the excitable parts are reached, which becomes apparent from a sudden convulsive motion of the animal. Thus are removed on both sides the gray substance covering the thalami optici, the white lateral elevations (pulvinar, &c.), together with the tractus opticus. At the base of the brain the incision is made through the middle of the tuber cine-

reum. The loss of blood amounts to from one and a half to two drachms. The animal becomes blind, the pupils dilate considerably (nn. oculo-motorii and quinti intact, as shown at the post-mortem examination); it assumes a strange position, which indicates that the animal has no longer the free use of its limbs. One fore leg is extended, the other is bent, and the hind legs become drawn very much forward under the belly. If touched, the animal makes some rapid but unsuccessful movements as though trying to escape. Placed upon its legs, it keeps upright only with difficulty, and soon falls upon its side. Respiration regular, ninety-six per minute.

12·8.—Compression produces very strong general convulsions, scarcely weaker than the previous ones. Upon the cessation of these the animal remains quietly lying on its side.

12·20.—Compression. The convulsions re-appear in full force, and continue for some seconds after the circulation is restored.

12·30.—The ligature on the innominate is loosened without any perceptible hæmorrhage occurring in the skull. The background of the eye has a dark-red tinge. After a short time the animal jumps up, but falls down again on its fore legs, while it still keeps on its hind legs. Respiration gets deeper and by degrees very difficult, (probably from the pressure of the extravasated blood, gradually exerted at the base of the skull on the medulla oblongata).

12·38.—The arteries are tied; the animal expires in weak and short, but general convulsions. Coagula are found below the pons and medulla oblongata. No pneumothorax. The lungs exhibit some portions about the size of a lentil which are condensed, dark brown, and several of them hyperæmic, but more of them, œdematous. The heart still beats at 1·30.

*Experiment* 4.—Exactly similar results were obtained from an experiment performed in the same manner on a male rabbit weighing one pound fifteen ounces.

*Experiment* 5.—*Excision of the cerebrum, of a part of the thalami optici, and slight wounding of the right crus cerebri.*—A large, vigorous, female rabbit, which kindled only a fortnight previously, but does not suckle, weighing three pounds two ounces and a half.

3·7 o'clock.—The arteries of the neck are laid bare.

3·30.—They are surrounded with threads, and the animal is made to sit up.

3·34.—Compression of the arteries causes, after nine seconds, moderately strong general convulsions.

3·59.—The anterior part of the skull is removed. The animal does not appear stupefied in consequence; the hæmorrhage is slight.

4·6.—The innominate artery is tied, and the dura mater removed.

4·16 o'clock.—Compression of the left subclavian artery gives rise to moderately strong convulsions within ten seconds. The animal is slow in recovering.

4·21.—The cerebrum is cut off anterior to the thalami optici. The tractus opticus is removed on both sides, together with the white rounded elevations on the external and posterior parts of the thalami optici, as well as a portion of the gray substance covering the internal part of the thalami. The incision is next carried downwards, through the posterior third of the tuber cinereum, and passes on the right side, (the animal meanwhile suffering violent convulsive movements) near the median line, somewhat further back than on the left side. The animal repeatedly turns its head to the right side, and at first keeps its left leg somewhat more extended, but suddenly makes a violent effort to escape, having previously appeared to be in a state of quiet stupefaction. It is then placed on the floor, where it becomes calmer; but, if scared, straightway springs up, describing greater or smaller curves in a direction to the right. The loss of blood is slight, amounting on the whole to about two drachms.

4·36.—The innominate artery is liberated, causing a very trifling bleeding within the skull.

4·41.—Application of a ligature to the left subclavian.

4·42.—Compression of the innominate, followed almost immediately by moderately strong and general convulsions. Upon now again opening the carotid the animal loses about half a drachm of blood from the cranial cavity.

4·48.—Compression. Fifteen seconds afterwards violent convulsions.

4·50.—Placed upon its legs, the animal runs about the room in a curved direction, endeavouring to escape.

4·55.—The innominate artery is punctured. General convulsions ensue in thirty seconds. They are of long continuance, and so violent, that it cannot be well ascertained whether any considerable part of the source of motor power has been removed with the portions of the brain that have been cut off. Two minutes and ten seconds after the opening of the innominate artery the animal breathes its last.

No extravasation of blood below the pons and medulla oblongata. No œdema of the lungs or pneumothorax. The right inferior lobe of the lungs is in some places of a bluish-red colour, but contains air.

*Experiment 6.—Excision of the cerebrum, of the anterior part of the thalami optici, of the hypophysis cerebri, and of a small portion of the right crus cerebri.*—A white, female and rather attenuated rabbit, twelve weeks old, weighing one and a half pound.

10·50 o'clock.—The operation of laying bare the arteries of the neck is completed, from which the animal has experienced a slight loss of arterial blood. Compression produces active convulsions.

11·3.—The innominate artery is tied, the skull opened, and the brain exposed, whereby more than the usual quantity of water flows away, but very little blood is lost. The animal appears weakened, and the fundus of the eye on both sides is very pale. The hemispheres of the cerebrum are removed up to the thalami optici without any indication of pain or convulsions.

11·8.—An incision is made through the middle of the right thalamus opticus, in front and in a downward direction, in consequence of which the animal, whose fore legs are tied, moves the left hind leg vigorously. An incision is likewise made in the same direction through the left thalamus opticus, but a little more in front, which is quietly borne by the animal. The pulvinar and the posterior part of the tractus opticus remain untouched. At the base the incision completely severs the tuber cinereum just anterior to the corpus albicans. On the right side the incision is carried further backwards than on the left, reaching up to the anterior part of the crus cerebri. The hæmorrhage is slight.

The animal is loosened. It cannot keep on its legs when set upon them. The left fore leg is extended tetanically; the three other ones are paralysed, and it is unable to keep its head erect. When touched, it tries to escape with its hind legs and right fore leg, but is unable to move from its place.

11·16.—The animal is still more recovered. Its hind legs are drawn towards the belly, and it sits up. When touched, it tries to run away. It is now able to move forward, but the fore leg which remains outstretched offers considerable impediment. Respiration is quiet and even, seventy-five times a minute.

11·20.—Compression of the left subclavian. Tolerably active convulsions ensue, yet weaker than before the removal of the brain. They are more active in the hind than in the fore legs. Upon the circulation being restored, the tetanically stretched fore leg becomes relaxed for a short time.

11·23.—To supply the brain with nourishment more effectually, the ligature on the innominate artery is removed. Extensive hæmorrhage takes place into the cavity of the skull, which, however, soon ceases. The animal breathes one hundred times a minute. The total quantity of blood lost since the commencement of the operation amounts to about three drachms.

11·27.—The animal lies quietly on the side. When touched it jumps up, sits upright, and remains in this position. The left fore leg still continues stiff.

11·30.—The left subclavian is tied.

11·31.—Compression of the innominate artery. General and active convulsions manifest themselves in all the animal's legs, stronger than those observed in the preceding experiment, weaker than before the removal of the brain. When the blood is again allowed to pass through the innominate artery, not only do the clonic convulsions subside, *but the rigidity of the left fore leg also disappears,* soon, however, to return. The animal loses another drachm of blood, and remains weakened, lying on its right side, breathing very quickly.

11·36.—Slight convulsive movements repeatedly appear in the left extended fore leg.

11·41.—Death from hæmorrhage on opening the innominate artery. The animal dies without convulsions, only a kind of quivering of the skin being noticeable. The quantity of red blood abstracted this last time amounts to three drachms.

Some coagulated blood is found below the pons and the medulla oblongata. Neither œdema of the lungs nor pneumothorax were observed.

*Experiments* 7, 8, 9, and 10.—*Excision of the thalami optici, crura cerebri, and a portion of the anterior corpora quadrigemina.*—Large pieces of excitable brain-substance were removed from four animals, after excision of the cerebrum up to the thalami optici, without exhausting losses of blood ensuing: in one, half a year old, the greatest part of the thalami optici and of the crura cerebri, together with the corpus mammillare; in another, one year old, the thalami optici completely, together with the crus cerebri, up to the neighbourhood of the pons; in a third and fourth, two to three years old (and these especially lost but little blood), the thalami optici, the anterior part of the testes, and the crura cerebri, close up to the pons. All of them became affected with opisthotonos, alternating with several attacks of clonic general spasms at irregular intervals, sometimes of ten minutes; compression of the left subclavian, which we repeatedly applied in each instance, to secure ourselves from error, produced clonic convulsions immediately in every case. Upon the blood re-entering the brain, not only the clonic spasms, but also the opisthotonos, ceased for a short time. *This cessation of the tetanic state upon removal of compression is not to be ascribed to the losses of blood frequently attendant upon compression, but to arterial congestion, which comes on when no blood whatever has been lost.*

The clonic spasms after compression were not weaker than those appearing spontaneously, but always weaker than those brought on before removal of the brain, and those directly following the separation of the crura cerebri. In one of the animals, in which the incision was made through the testes, up to the pons varolii, very violent general clonic spasms ensued, passing into opisthotonos, and returning within the first ten minutes, though with a gradual diminution of strength. When the tetanic state had lasted unchanged for thirteen minutes, the subclavian artery was compressed, when weak convulsions only, appeared in the hind legs. Twenty minutes after this experiment the animal was killed by applying a ligature to the subclavian, whereupon it fell into convulsions, not only general, but particularly violent.

*Experiment* 11.—*Removal of a great portion of the cerebellum.*—A white, male rabbit, about eleven weeks old, weighing one pound ten ounces.

10·15 o'clock.—The great arteries of the neck are laid bare without loss of blood. Upon compression the animal falls into strong convulsions.

11.—The cerebellum is laid bare to a large extent, whereby the animal loses much blood,—about two drachms. The innominate artery is not tied. Great slices of the hemispheres are now cut off without the animal's stirring, until the vicinity of the crura cerebelli is reached. The animal then is unable to keep on its legs, and becomes deprived of the free use of its limbs. The legs exhibit a certain degree of rigidity, and resist all our attempts to move them. The fore legs become more extended, the hind ones bent. When the animal is made to stand on its legs, it falls down, becomes attacked by clonic spasms, and relapses into its former state of stiff immoveability. Some minutes having been allowed to elapse, compression is applied to the vessels. The rigidity of the limbs vanishes, and general convulsions of considerable intensity come on. Upon the blood again flowing into the brain, they persist for some few moments. The body falls into a state of general relaxation, until after about a minute, the fore legs become again extended, and the hind ones contracted. We now remove the entire covering of the fourth ventricle, with the exception of a small piece which forms a sort of small commissure behind the corpora quadrigemina, and take off the hemispheres up to those lobes which lie hidden in the remotest niches of the occipital bones; by which operation the animal again loses much blood (about one drachm and a half), and exhibits some strong convulsions when the crura cerebelli are reached. After this the animal remains lying quietly, with its legs rigidly extended, but is still able to hold its head up. A compression of the arteries causes no more convulsions, but the rigidity subsides and the legs become quite flabby; respiration ceases; the pale pupils become narrow and afterwards dilated. Upon the blood again flowing in, some slight spasmodic movements come on in the hind legs, and afterwards the legs turn stiff again.

The animal is left to breathe quietly for twenty minutes. The hairs on the chin, the mouth, and muscles of the nostrils are in almost constant spasmodic agitation; respiration easy and superficial.

11·48.—Compression without any subsequent convulsions, but the stiffness gives way and respiration ceases. When the blood flows in again, a slight spasmodic movement of the hind legs is observed.

12·20.—Compression with the same result. If the animal is made to sit up, it endeavours to make certain movements, but without success; consciousness does not appear extinct.

12·30.—Unexpectedly, and without any previous compression or irritation, violent clonic convulsions manifest themselves, accompanied by gnashing of the teeth, and lasting for about a minute and a half, whereupon the limbs become again rigid and extended.

If the mouth or the legs of the animal are mechanically excited, convulsions break out at once. An experiment with compression is unsucessful, although continued until respiration ceases. The animal again falls into a state of rigidity.

1·10.—Violent gnashing of the teeth; spasmodic contractions of the muscles of the face and fore legs. Irritation of the mouth induces a violent attack of general convulsions.

1·15.—Compression of the vessels produces an attack of convulsions with all the peculiarities observable in those from hæmorrhage. The backward inclination of the head at the commencement, and the opisthotonic extension of the hind legs, are peculiarly marked, which was not the case to the same extent in those spasmodic attacks which appeared spontaneously, or were produced by reflexion.

1·20.—Mechanical irritation of the mouth and legs does not produce any spasmodic movements.

1·25.—The application of a ligature to the vessels is followed by death, characterised by general convulsions of moderate intensity, and similar to those just described.

The floor of the fourth ventricle is untouched, and contains some coagulated blood. No œdema of the lungs.

We give this experiment in detail, as offering many mysterious facts, although its value is but limited in consequence of the great loss of blood (difficult, to be avoided) attending exposure of the cerebellum. We communicate it because it is the only one we possess on excision of the cerebellum, and, to be candid, because we have been hitherto unable to overcome our repugnance to repeat so cruel an experiment.

## CHAPTER XII.

### ON THE NERVOUS CENTRES TO WHICH THE SYMPTOMS EXHIBITED BY EPILEPTIC ATTACKS ARE TO BE REFERRED.

Unconsciousness, insensibility, and general tonico-clonico spasms are considered to be the essential symptoms of a complete epileptic attack. If the affection from which these attacks proceed is chronic and unaccompanied by fever, it is styled epilepsy; if otherwise, eclampsia.

Between the several attacks (and this is especially the case in epilepsy at the commencement of the attack), no interruptions, or at all events only insignificant ones and of short duration, in consciousness, sensibility, and motion take place.

In addition to the perfectly evolved attacks of epilepsy, one is obliged to admit such as are incompletely developed. Whilst in the former, consciousness and sensibility seem to have completely vanished, and spasms seize all the muscles in the manner so well known, in the latter there is only giddiness and staggering (epileptic vertigo), or a falling down, accompanied by a slight and momentary trembling as well as by a more violent convulsion of the whole body, or by spasms confined to contain groups of muscles only (partial epilepsy).

Thus much it is necessary to preface before passing on to consider the origin and nature of epilepsy, which will be the subject of this part of our treatise.

The question so often propounded from the remotest periods in the history of medicine, with reference to the so-called—and improperly so-called "seat" of epilepsy, comprises, in fact, two distinct questions, each of which necessitates a special examination. *Firstly, we have to determine which are the nervous centres to which the symptoms of the epileptic attack are to be referred.* This problem once solved, it then remains to inquire, *whether the alterations in those nervous centres from which the symptoms of the attack proceed, emanate from another special centre of the nervous system, and,* *if so, where this latter is located.* The second part of the inquiry can only be proceeded with when we shall have acquired some information *as to the nature of epilepsy itself,* i. e., *the alterations in the nervous centres which occasion it.*

The epileptic attack must always be immediately attendant upon alterations which rapidly and simultaneously affect the organ of consciousness, the sensorium commune, and the central organs of motion. We are not justified in endeavouring to find the proximate seat of the attacks in a certain part of the brain or spinal cord, so long as we are unable to prove that one of these parts contains the anatomical centre of consciousness, sensation, and motion. But who is there at the present day that believes in the existence of a certain circumscribed spot, a "nodus animæ," in the brain, to which all sensations radiate, from which all voluntary movements proceed, and where the unity of consciousness is to be found, or thinks that the spring that keeps up the clockwork of respiration lies concealed in any single "nodus vitæ?" The unity of the soul cannot anatomically be referred to this or that monas of ganglionic cells, but is communicated in an unknown way as the ultimate result of the mutual operation of the extremely numerous and complicated structures of the brain. The times of Cartesius are passed, when the soul was believed to reside in the pineal gland, and with those times should cease the ridiculous attempt to explain the epileptic attack—*a combination of symptoms proceeding unitedly from the three great circles of nervous life*—as issuing from this or that spot in the brain or spinal cord.[1]

The comparative anatomy of the brain of vertebrate animals, physiological experiment, and clinical observation, demonstrate with certainty that the higher active movements of the soul proceed from the cerebrum, from the non-excitable nervous structures aggregated in front of the crura cerebri. We may add, that there is a great deal which speaks in favour of the gray cortical substance of the cerebrum in particular as communicating intelligence; whilst it appears to be the purpose of the medullary substance to transfer to the cortical the impressions received by the sensory nerves, and to the motor nerves the impulses proceeding from the cortical structure.

In the nervous substances lying behind the thalami optici the

[1] Wepfer, as is well known, placed the seat of epilepsy in the pineal gland on the same grounds that Cartesius located the soul in that substance.

existence of great excitable districts, central sources of reflective and automatic motion, is proved beyond a doubt; there are, however, some non-excitable districts (the hemispheres of the cerebellum); and experiment as well as clinical observation demonstrates, that behind the thalami optici there lie sources of a very obscure consciousness and indistinct sensation; that active motions performed instinctively take their rise in this locality; that there exist auxiliary organs for carrying out the purposes of the will, for the correct adjustment of the movements, and for the communication of conscious sensations.

We know, moreover, that not only may very large pieces of the cerebrum be lost on one or both sides, but that, according to the celebrated observations of Bell, Cruveilhier, and Lallemand,[1] even an entire hemisphere of the brain may be wanting, and, indeed, even a corpus striatum, thalamus opticus, and the corpora quadrigemina, cerebellum, pyramids, and olivary body of one side may be found diminished in size, without the intellect and senses being necessarily impaired; whilst, however, the opposite side is always found paralysed.

Paget[2] gives a description of the brain of a full-grown girl in which the corpus callosum was for the most part deficient, from congenital malformation; yet was she lively, sensible, and in full possession both of her senses, and of the power of co-ordinating her movements.

Combette[3] relates a case of a child who had no cerebellum or pons, but was sensible; its intellect was not destroyed, but only limited; its legs were weak. In order that complete unconsciousness and insensibility may ensue, certain alterations must take place simultaneously and suddenly in both hemispheres of the cerebrum, as well as in those districts of the posterior parts of the brain which are connected with consciousness and sensation. Every attack, therefore, of fully developed epilepsy presupposes an alteration in the principal parts of the brain, because consciousness and sensation, which are communicated only by the co-operation of the greatest part of the brain, are in such a case completely destroyed. Our researches, however, still prove, with respect to the general convulsions which, in epileptic attacks, come on in consequence of a sudden

[1] Longet, 'Anatomie et Physiol. du Système nerveux,' vol. ii.

[2] 'Med.-Chir. Transactions,' 1846, vol. xxix, p. 55.

[3] Longet, vol. i.

arrest of the flow of blood to the brain, that these spasms proceed from the posterior excitable parts of the brain, and it therefore becomes highly probable *that in every attack of complete epilepsy the same material alteration affects at the same time the whole cerebrum, and, in addition, the greatest part of, if not all, the cerebral districts situated behind the thalami optici.* It appears to us an established fact that, even from the commencement, the medulla oblongata is drawn into the sphere of action, because, in like manner, at the beginning the respiratory movements suffer, and are entirely arrested in a completely developed attack, when spasm of the glottis is present. This is, we think, the only satisfactory explanation that can be given respecting the coincidence of unconsciousness, insensibility, and general convulsions.

The convulsions, therefore, in epilepsy and eclampsia fully deserve the denomination of *brain-convulsions*, and it becomes a matter of doubt, from the results of our experiments, whether or not the alteration which is the proximate cause of these attacks extends beyond the boundaries of the skull. We found that the same cause (sudden stoppage of the supply), if acting upon the brain, produces unconsciousness, insensibility, and terrible spasms; if upon the spinal cord, paralysis, which, when lasting some time, renders the approach of brain-convulsions an impossibility. The spinal cord need not, therefore, perform any other part in the paroxysms than that of a conducting cord, transferring the irritation of the motor districts of the brain to the motor nerves of the periphery. It is true that hereby the motor tubules of the spinal cord and the peripheric nerves must be excited and drawn within the sphere of the morbid action, but this alteration will be of another kind, and less energetic than that of the motor centres of the brain. This possibility becomes a probability if, as will soon be demonstrated, one frequent cause of epileptic seizures is to be found in the sudden arrest of the brain's nutrition.

## CHAPTER XIII.

### UPON THOSE CHANGES IN THE SUBSTANCE OF THE BRAIN WHICH ARE THE PROXIMATE CAUSES OF EPILEPTIC ATTACKS AND AFFECTIONS.

However great the obscurity may be in which the doctrine as to the internal alterations of the brain-substance that produce epileptic attacks and affections is still enveloped, the results of actual observation on the subject justify us in pronouncing some very decided opinions on this important matter.

In the first place the observations we have just made, with respect to the nervous centres from which the symptoms of the attacks proceed, demonstrate that alterations of the brain proximately causing them can by no means be confined to a small part of this organ, but must affect the whole or at all events the greater portion of it. Hence it follows, *that a circumscribed anatomical alteration of the brain must not be regarded as the proximate cause of epileptic attacks.*

Secondly, it may be affirmed *that the proximate cause of the attacks cannot be one of long duration, but an alteration merely of a temporary kind.* It must be quickly developed to its full extent, and pass during the attack through its different phases, and when the latter are over, cease completely or nearly so. How otherwise is it reconcilable, that, after an attack, the patient so frequently and often for so long a time recovers the full use of the action of the brain? And how could the circumstance be explained, that in chronic organic affections of the brain, spinal cord, or nerves, the attacks frequently, appear for the first time, only when a new influence is added, for example, psychical excitement or irritation of the extremities of sensitive nerves? As for the epileptic *conditions,* they, as something constant, must also be based on a constant alteration of the brain, and closer investigation is required to determine whether the latter affects the whole brain or only some parts of it. We must, therefore, discriminate between the alteration of the brain which causes the *epileptic attack,* and that which produces the *epileptic affection.*

Thirdly, *it can be no visible alteration of the brain, anatomically demonstrable, that can act as the proximate cause of an epileptic attack.* This proposition, resulting from the two former ones, is also valid in the case of epileptic affections. Every physician of the present day, who is at all judicious, will relinquish the hope cherished with childlike confidence by certain schools and times, that pathological anatomy is destined to give an explanation of the nature and seat of epilepsy,[1] and he will only expect that result from the progress of the experimental physiology of the nerves. Material alterations in the brain and its membranous and osseous coverings are, it is true, most frequently found in those who have died from epilepsy and eclampsia, and are often enough recognised as the cause during life. Often, however, in spite of most careful examinations, no anatomically demonstrable alterations are found in the structure of the brain;[2] and those which do exist must be generally regarded, especially in epilepsy, as produced by interruptions to the circulation and nutrition during the attacks, particularly if the latter have frequently been repeated and for a long time. Most of the patients suffering from this disease for years, afford the usual appearances found in chronic diseases of the brain, viz., thickening and condensation of the skull, thickening, ossification, coalescence, œdema, exudations, extravasations, tubercles, tumours in the membranes of the brain; numerous Pacchionian glands (according to Wenzel), hyperæmia, hardened and shrivelled-up parts of the brain. Not one of all the anatomical alterations in whose train epilepsy frequently appears, such as cicatrices, tubercles, and atrophy of the brain, or premature coalescence of the sutures of the skull, with lessening of its cavity, leads invariably to this disease. But frequently we have seen it proceed from extra-encephalic anatomical lesions, particularly from cicatrices of the

[1] See the lucid explanation of the error of looking for the cause of epilepsy in some coarse lesion of the brain, and the critical and concise grouping of anatomical facts by Hasse, in Virchow's 'Handbuch der speciellen Pathologie,' vol. iv, i, pp. 262, 267, et seq.

[2] In thirty autopsies of epileptic patients Delasiauve (loc. cit., p. 177) obtained seventeen times only negative results.

spinal cord,[1] cicatrices of the skin, neuromas, &c.; and cases are related which have been radically cured by the removal of carious teeth, foreign bodies in the ear, pieces of necrosed bones, tape-worms, &c. The same has been observed, as is well known, in eclampsia. It is almost superfluous to mention how frequently not the slightest alteration in the brain-substance is to be found in children who have died from eclampsia, in pregnant women, in those affected with uræmia, or who have been poisoned; how often in children a series of attacks is brought on, simply by temporary irritations of the mucous membranes, the so-called irritation from saburra, as well as that from worms; and how, upon removal of the irritation, all the symptoms of a morbid action of the brain likewise disappear: such observations every practitioner will have made. Lastly, we observe that very frequently psychical influences (fright, seeing an epileptic, &c.) at once bring on epilepsy, that reflex irritation forthwith leads to eclampsia, and further we have the efficacy of the "traitement moral" in the mitigation, diminution, and even the complete removal of real epilepsy. All these different facts furnish sufficient grounds for asserting that it is only microscopic alterations of the brain that can be the cause of epileptic affections. Tubercle of the brain, cicatrix of the brain, of the spinal cord or of a cutaneous nerve, are therefore in an exactly similar way to be regarded only *as remote causes* of epilepsy, and should visible alterations occur in the brain or other parts of the body during eclampsia and epilepsy, they must be regarded as nothing else than *predisposing* influences.

If the visible alteration of any part of the nervous substance is to be regarded as the predisposing cause of an epileptic affection, the question suggests itself—what will be the nature of the disposition with respect to the attack? The disposition is nothing else but that state of the brain which forms the basis from which the attacks

[1] Very instructive and remarkable are the experiments of Brown-Séquard ('Gazette Méd. de Paris,' 1856, No. 41), who observed different traumatic injuries of the spinal cord produce epilepsy after some time. The attacks then appeared either spontaneously or upon irritation of certain parts of the skin. When the injury was done on one side of the spinal cord, simple irritation of the face and neck on the same side occasioned the attacks. When the injury was done on both sides, they could be called forth from both sides of the neck and face. Lastly, it is the chief branches of the facial and cervical nerves, especially of the fifth, and not their trunks, which thus become capable of producing the attacks.

arise, and can scarcely be conceived of otherwise than as a very slight alteration of the whole brain, or of a narrowly circumscribed district; whilst the alteration which is the cause of the attacks, must always affect the whole substance of the brain, or at all events the greatest part of it, and that moreover in an energetic manner. The *predisposition* is not alone sufficient to bring on the attack. An internal or external cause has still to supervene to make the alteration more extensive and deeper; that finally the ontological characteristic of epilepsy may become conspicuous to us in the form of paroxysms. Thus the image is not manifested on the daguerreotype plate directly after the action of the light, but only upon the plates being exposed to a further influence, when, all at once, the result of the two changes appears before the eyes as one uniform whole. From the intimate manner in which the various parts of the nervous system are united in their nutrition, whereby even the remotest districts of the nerves are linked together in one common bond (we here call to mind the crossed and progressive atrophies of the nerves, and the important microscopical researches of Türck, Waller, Schiff, and others; compare also Ludwig, 'Physiologie des Menschen,' vol. i, p. 172), the supposition is certainly warranted that these visible anatomical alterations dispose to epilepsy only in the manner of gradual and invisible changes in the nutrition of certain districts.

The epileptic affection is not, however, always so slow in developing itself; it often comes on rapidly, as though produced by a stroke. An influence may operate on the brain, and the attack immediately follow, and with it the epileptic affection be manifested simultaneously. The epilepsy has become fixed, and the whole of the brain or a portion of it has suddenly been affected by that delicate alteration that will henceforth manifest itself in the periodical appearance of the well-known symptoms.

What is sometimes the case in epilepsy, is the rule in eclampsia. In the latter the epileptic status is always rapidly induced, and leads quickly or immediately to the attacks, ending, contrarily to epilepsy, either in recovery or death.

We regard it as the greatest merit of our work, the having investigated more exactly a state which infallibly causes epileptic attacks in the vigorous rabbit and probably in all warm-blooded animals. We allude to that alteration in the brain produced by a rapidly arrested nutrition brought about by a sudden interruption in the supply of blood. A dozen or more attacks can be produced in the same animal at short intervals; and if it were possible to apply compression to the four great arteries of the head without endangering life, convulsive attacks might be easily produced from time to time, *ad libitum*, and for years, just as in real chronic epilepsy. We do not even consider the supposition hazardous, that, by frequent and long-continued attacks, a disposition, a really epileptic affection, could be finally brought on, as, in general, frequent returns of spasmodic attacks seem to produce, or at all events to favour, a so-called "convulsibility." (Compare also Experiment 2, in Chapter X.)

We have thus demonstrated by facts that there is a condition of the brain which fulfils all the requirements which we should be compelled to make, if, proceeding on theoretical assumptions, we should endeavour to discover one that would sufficiently explain the appearance of epileptic attacks.

1. It comes on very rapidly;
2. It can be rapidly removed;
3. It is capable of bringing on the entire group of epileptic symptoms;
4. When of short duration the attacks appear in an incomplete form; when lasting a longer time they are completely developed;
5. The attack directly follows the alteration in the brain;
6. And can immediately produce death;
7. By a frequent repetition of the attacks, the action of the brain would at last be as much impaired, as in epilepsy itself.

Although we are of opinion that certain forms of epilepsy and eclampsia should be referred to a sudden interruption in the nutrition of the brain—a supposition which, in the course of this chapter, we shall find sufficiently tenable—still we are far from regarding this in general as the proximate and real cause, either of the attacks thereby occasioned, or of the origin of epilepsy or eclampsia. The sudden arrest of nutrition acts, as it appears to us, only indirectly by producing certain molecular alterations of the brain-substance, which are in necessary connexion with it; but these alterations may likewise be brought about by chemical and nutritive agencies of another description. Thus, by stoppage in the flow of blood to the muscles (according to Wundt), molecular alterations are produced, which manifest themselves by an altered state of their elasticity, and finally bring on rigidity; but there are other influences in addition, as, for example, injections of substances acting chemically into the arteries of the muscles (according to Kussmaul), which have the same effect, although the muscle is thereby brought into different internal conditions. In like manner attacks of various kinds (mechanical, chemical, or produced by inflammatory irritation) on the molecular arrangement of the brain, although the latter is altered in dissimilar ways, may have the same final result in one direction, perhaps to alter the electrical order of the finest particles in the same manner, and thus give rise to epilepsy. Hydrocyanic acid brings on fits very similar to those of epilepsy. Still, until definite proof can be offered, it would be very hazardous for this reason to maintain that hydrocyanic acid acts by bringing on anæmia of the brain (according to Pereira), or by rendering the blood unfit for nourishing the brain, as Dr. Harley[1] has recently asserted with respect to different poisons producing convulsions.[2] We do not question, but that at some future time, a class of poisons will be found possessing the common property of rendering the blood incapable of nourishing the nerves and muscles; and numerous hypotheses might easily be framed as to the several different ways in which poisons comprised in this class might act. We deem it advisable, however, not to enter upon this subject until we become more thoroughly acquainted with the facts of the case, and here only desire to draw attention to the remarkable resemblance which exists *in the symptoms from large and rapidly fatal doses of most poisons*, adding this simple question, viz., whether in these cases the cause of the sudden appearance of unconsciousness, insensibility, as well as of general clonico-tetanic convulsions in which the pupils are first contracted and then dilated, is not to be mainly sought in the suddenly interrupted nutrition of the brain? Do we not also observe, that death, when suddenly caused by internal and very different causes, comes on with partial or general convulsions attended by unconsciousness and insensibility; and do not the majority of children succumbing to acute diseases die in so-called "fits," *i.e.*, more or less distinctly developed eclamptic attacks?

[1] 'The Lancet,' 1856.

[2] Coze ('Gaz. Méd. de Paris,' 34, 1849) states the cause of convulsions from poisoning by hydrocyanic acid to lie in the sudden stoppage of the flow of blood to the spinal cord. This theory is completely refuted by our researches.

Scarlatina, measles, and smallpox often commence with general convulsions and loss of consciousness; meningitis, hydrocephalus, uræmia, and cholæmia are frequently accompanied by them. They also occur in dentition, when the teeth are cutting through the gums, as well as in parturition when the head of the child is protruding. If, in all these cases, we were to regard the suddenly interrupted nutrition of the brain as the cause, it would be difficult to furnish sufficient grounds for this hypothesis, and we might make ourselves as ridiculous as those toxicologists, who, in their faulty manner of judging, are only able to refer the actions of most of the drugs and poisons acting on the brain to anæmia and hyperæmia of that organ, making use of the narcotics for producing the former condition, the excitants the latter.

The division of epileptic convulsions into two different classes, eclamptic and epileptic, is manifestly based on the correct assumption that, in spite of complete uniformity observed in the external form of the attacks, there will exist an internal difference. In what this difference consists will certainly be ascertained at some future time, and then only will it be possible to separate the epileptic convulsions into various groups according to the character of the cerebral conditions producing them, whilst at the present day eclampsia and epilepsy do not represent anything else than ontological forms of disease, whose boundaries can alone be fixed by subjective dogmatism, or at the best by practical necessity.

It has been frequently asserted that the attack in epilepsy always proceeds from *sudden hyperæmia of the brain.* Experience of epilepsy after great losses of blood, together with our own experiments, sufficiently refutes the general soundness of this theory. The only question now remaining is, therefore, whether in some cases congestion of the brain or hyperæmia is able to produce an attack.

The majority of the best pathologists have always been decidedly unfavorable to every theory of congestion; we need only mention the celebrated names of Georget, Watson, Copland, Romberg, Hasse, &c. Romberg,[1] for example, in his clear and decided manner of expressing himself, says, "The time is not long passed since congestions to the brain were almost exclusively regarded as causing diseases of the nervous system in general as well as epilepsy. At the

[1] 'Lehrbuch der Nervenkr.,' vol. ii, p. 348.

present day such an assertion, to be credited, must be supported by critical arguments, and it must be matter for surprise that in hypertrophy of the left ventricle of the heart[1]—a morbid condition which more than all others causes an increased determination to the brain and hæmorrhages—epilepsy hardly ever ensues, whilst dizziness, apoplexy, and paralysis frequently do. The plethora resulting from suppressed hæmorrhage is of undoubted influence, especially that caused by arrest of the catamenia or of epistaxis; that following the stoppage of hæmorrhoidal loss is less influential, as also that produced by a luxurious life. *Attacks of this sort of epilepsy have an apoplectic character; are accompanied by weak convulsions; and leave the patient in a lethargic state of some hours' or even days' duration, and suffering from paralysis of single parts, especially of the tongue.* Frequently, however, the opposite condition, anæmia, is their cause, especially in females, whether it arises from an original crasis of the blood or from insufficient food and loss of humours. Maisonneuve relates a case of eighteen sailors, who, after having saved themselves from the enemy by swimming to a rock, remained there for seven days in a state of starvation and exposure to severe cold. All of them, after having been received into the hospital, were four weeks afterwards affected by epileptic attacks, which were preceded and followed by violent pains in the right hypochondrium. In ten months six of them died, and in eighteen months four more, so that only four survived."

Delasiauve, who has paid great attention to this subject, and is very well acquainted with it, observed anæmia as the cause of epilepsy much more frequently than plethora; and in this most careful observers agree with him.

Those who advocate the theory of congestion may be divided into two classes: the first considering the attack as produced by an increased congestion of arterial blood; the other maintaining that the attack is induced by an impeded ebbing of the venous blood. Mr. Solly may be regarded as the chief representative of the former, and Dr. Marshall Hall of the latter opinion.

Solly[2] considers the cause of the paroxysm to lie in a determination of blood to the head; in an arterial congestion, the result of an

[1] On a case of epilepsy following stenosis of the mouth of the aorta, see Bamberger, 'Zur Pathol. des Herzens;' Virchow, 'Archiv,' ix, 3 and 4, 1856.

[2] S. Solly, 'The Human Brain, its Structure, Physiology, and Diseases,' London, 2d edition, 1847, pp. 590 et seq.

increased action of the heart, with simultaneous paralysis of the muscular coats of the arteries of the head; and the principal grounds on which he bases his opinion are the following:

1. "Increased determination of blood to any organ augments its secretions to an abnormal extent. Sudden determination to the head must rapidly increase the generation of nervous power, which in a healthy state conveys volition to the muscles, and is identical with electricity. This excessive secretion is carried off by the motor nerves, like a discharge from an electric battery, and from its quantity and excess produces excessive action of the muscles."

But why, we ask, does not this superabundance, if it produces excessive motion, produce also excitement of the mind and increased sensibility? Why do general convulsions never attend the violent congestion to the head caused by removal of compression from the arteries of the neck; but, on the contrary, paralysis, even when both cervical tracts of the sympathetic nerve have been divided, and the superior cervical ganglia extirpated, and thus, at all events, numerous branches of the carotids become paralysed, as we have seen in many experiments on rabbits?

2. "The pulse of the carotids is exceedingly strong during the attacks."

This well-known fact can, however, be quite as well explained by supposing an arterial anæmia of the brain from an impediment barring the progress of arterial blood to the brain; for example, a contraction of the smaller branches of the carotids, which contain more muscular fibres.

3. "At the post-mortem examination of persons who have died during the attack, the brain has frequently been found in a hyperæmic state (Foville)."

Hyperæmia was, however, almost always found on the part of the venous system, and might, even if the epileptic attacks proceeded from arterial anæmia, have only arisen in consequence of the attack—an opinion which Foville himself shares—or during the act of dying, or even after death, as is made clearly apparent from our previous researches.

In truth, not one of Mr. Solly's reasons is sufficient to support his theory as to the origin of the epileptic attack. On the contrary, it seems to us highly improbable that arterial congestion can produce such an attack, although it may bring on dizziness, fainting, and paralytic symptoms, similar to those occurring in apoplexy.

Marshall Hall's theory, which he has endeavoured more or less fully to establish in numerous works and essays,[1] is substantially as follows:

The first link in the chain of symptoms ushering in the epileptic attack, is represented by the direct or reflective irritation of the centrum spinale, causing the muscles of the neck and glottis to contract, by which latter the second link is obtained. The third is compression of the veins of the neck (sphagiasmus), by the contracted muscles of the neck (trachelismus), and asphyxia, by spasm of the glottis (laryngismus). In the fourth series, unconsciousness, insensibility, and general convulsions break out as the result of venous hyperæmia of the brain and of asphyxia. The incomplete attacks (*le petit mal* of the French) proceed principally from trachelismus; the complete ones (*le haut mal*) from trachelismus combined with laryngismus. This ingenious theory contains a combination of correct and incorrect assertions.

The assertion is especially incorrect, that contraction of the muscles of the neck and glottis always precedes unconsciousness and insensibility; in the majority of cases, consciousness and sensibility vanish first, general paralysis of the organs of volition follows—the patients fall down, and then only do general convulsions commence, accompanied by spasms of the muscles of the neck, and stoppage of the respiration. The cerebrum is accordingly already placed out of the sphere of action before the motor nervous centres begin to be excited. The undeveloped forms, where consciousness and sensibility only are disturbed, without any spasm of the muscles of the neck and with no straitening of the glottis, and their insensible transition to developed and general convulsions, prove likewise that the theory of trachelismus and laryngismus is by no means of general validity.

Marshall Hall is, however, correct in asserting that a sudden closing of the glottis produces epileptic convulsions; and it is his merit pre-eminently to have drawn attention to the resemblance be-

[1] We mention only the following: 'Essays on the Theory of Convulsive Diseases, being a Supplement to the Diseases and Derangements of the Nervous System;' 'On the Neck as a Medical Region,' in the 'Lancet,' 1849; 'Synopsis of Cerebral and Spinal Seizures of Inorganic Origin and of Paroxysmal Form;' and 'Synopsis of Apoplexy and Epilepsy, with Observations on Trachelismus, Laryngismus, and Tracheotomy,' 1852.

tween the effects of strangulation and those of epilepsy.[1] If animals are strangled by a ligature on the trachea, as we have frequently done it, they soon expire in a state of insensibility and with general convulsions; and these spasmodic attacks are exactly similar to those from hæmorrhage, only that in the former case the head swells and turns blue, while in the latter case it shrinks and turns pale. The approach of convulsions in strangulation can be accelerated if the arteries are simultaneously compressed. In men dying from hanging or suffocation the same symptoms are observed as in animals. Liability to epilepsy may even remain in persons who, after having been suspended for a considerable time, have been restored to life. In 1842 or '3 Kussmaul saw in the clinical wards of the late Professor Puchelt, at Heidelberg, a strong servant girl, who had been cut down and with difficulty restored to life, affected with violent epileptic attacks for many weeks. The conjunctiva of one eye appeared sugillated with blood for a longer time in consequence of the strangulation.

We find the simplest explanation of the appearance of these attacks upon closing the glottis or trachea, in sudden arrest of the nutrition of the brain. Hæmorrhage, closing of the arteries of the head, and strangulation, cause the blood-vessels of the head to be in different states of fulness, and the brain to undergo various gradations of pressure, but they agree exactly in the one point above mentioned. In the one case there is a scarcity of red blood because it is abstracted from the body or kept away from the brain; in the other because it has suffered a transformation into black blood. The correctness of our opinion seems partially proved by the fact that even in profuse hæmorrhage the convulsions do not proceed from an altered pressure; and partly, by the observation, that in strangulation, convulsions more rapidly ensue when the conveyance of red blood to the brain is at the same time prevented; and finally, by the results of our experiments on the artificial production of stasis of the brain, on which we shall treat further on in these pages. No one will, therefore, contest Marshall Hall's assertion, that spasm of the glottis (laryngismus) may lead to epileptic convulsions. Direct or indirect (psychical, or caused by reflexion) excitement of the motor nerves that close the glottis can produce them secondarily, and no doubt certain

[1] Comparison of the effects of strangulation and epilepsy, in M. Hall, 'Synops. of Cerebr. and Spin. Seizures,' pp. 63, 38, 39, and 40.

epileptic attacks depend upon this cause.[1] In particular may certain states of eclampsia in children, and of epilepsy in hysterical persons, be referred to this cause. To construct upon it, however, a theory of epilepsy, which shall admit of universal application, does not seem to us by any means feasible, because in real epilepsy, as already mentioned, laryngismus generally follows, and does not precede, the cessation of the actions of the mind, and "because we sometimes see cases where clonic spasms appear in their full extent before symptoms of laryngismus are noticeable." (Hasse.)

The assumption seems incorrect that sudden stoppage of the circulation in the cervical veins is a common cause of epileptic attacks, whereby the theory of sphagiasmus becomes as a matter of course valueless. Marshall Hall lays great stress on an experiment of Sir A. Cooper (loc. cit.), who tied both the jugular veins of a rabbit, which after five days appeared in a state of stupefaction, fell on the seventh day into convulsions, lost its sensibility, and died. On the post-mortem examination an extravasation of blood into the left ventricle of the cerebrum was found. Although we have tied the external jugular veins of rabbits (and sometimes the internal ones at the same time) upwards of two dozen times, and have often allowed the animals to live for weeks, even for months, we have never seen a similar result. In fact we have never observed general convulsions at all. In the majority of instances, no symptoms of brain affection of any importance appeared; at most the animals seemed to be stupefied during the first twenty-four to thirty hours, and sometimes gnashed their teeth. The most constant symptom upon stoppage of the venous circulation, and one which did not escape the vigilance of Sir A. Cooper, is a retarded respiration. Thus the above-mentioned experiment forms an exception to the rule, and only proves that the retention of venous blood within the cavity of the skull may, under certain circumstances, produce extravasation of blood, apoplexy with convulsions, but no real epileptic attack. In the reticular distribution, especially, of the superficial veins of the anterior and posterior part of the neck, the number of anastomoses is so great that the obstruction of the jugular veins alone cannot so easily give rise to serious cerebral symptoms. For this reason we several times compressed or tied the cervical

[1] Compare, for example, the very remarkable case of epilepsy in a girl, nineteen years of age, in consequence of irritation of the epiglottis by a long uvula, in the 'Wiener Wochenschr.,' 39, 1856.

and clavicular veins simultaneously for a longer time. In two cases, where the operation succeeded without any hæmorrhage, repeated compression, continued for a quarter of an hour, did not produce any important brain-affections, whilst the other animal, whose veins were tied, died after forty-eight hours under general convulsions, and the symptoms during life, as well as in the corpse, indicated a considerable hyperæmia in the head and cranial cavity. After death the veins of the neck, of the membranes of the brain, and the sinuses were found gorged with blood, but the brain was pale. In this experiment, as well as in that of Sir A. Cooper, convulsions appeared only *some time after* the veins had been closed, whilst M. Hall's theory would require them to be immediately sequential.[1]

It is true that, according to the present state of our knowledge, it cannot be denied that in a venous stasis of the brain it is possible for epileptic affections sometimes to come on rapidly. It is, for example possible, that in a sudden and complete retention of venous blood within the cranial cavity, the veins may become so gorged that no more blood can be introduced through the arteries, and consequently the nutrition of the brain will be at once impeded. In reality, however, venous congestion seems to be rarely formed with the requisite rapidity and in a sufficient degree.

In retention of venous blood within the cranial cavity, the heart is, notwithstanding, generally able for a long time to force blood into it, and, in consequence of the increased pressure on the brain, and of the smaller and greater hæmorrhages from the bursting vessels of the brain and its membranes, apoplectic attacks come on either with or without convulsions, which in the latter case may, it is true, easily assume the appearance of epilepsy. Marshall Hall himself is obliged to derive the epileptic comatose symptoms in epilepsy more from sphagiasmus and trachelismus, whilst he considers asphyxia and general convulsions as caused by laryngismus. Bibliographical research has not furnished us with any cases affording sufficient proof that simple stasis or plethora

[1] Compare Kussmaul, 'Ueber den Einfluss der Blutströmung auf die Bewegung der Iris,' p. 32. We draw attention, however, to the fact that in this experiment the surfaces of the wound, and the inflammation were very considerable. Convulsions and death ought perhaps to be attributed to other causes than to hyperæmia within the cranial cavity. At that time we had a bad place wherein to keep the rabbits, they were therefore easily affected by wound-fever.

of the brain has produced real, or, at any rate, pure epileptic attacks.[1]

Being anxious to ascertain the influence of plethora of the brain, and likewise of the pressure on that organ which it occasions, in the production of epileptic affections, we divided the cervical branches of the sympathetic nerve of several rabbits, tying the external and internal jugular veins. Directly after we applied the ligature, the eyeballs protruded considerably from their sockets; the number of respirations gradually diminished, but in no instance suddenly—sometimes, however, to an extraordinary degree (once, within half an hour, from 135 a minute before the operation to 18 after the same); the respiration became snoring and rattling; *the glottis became paralysed;* while stupefaction, weakness in the legs, and difficulty of breathing became more and more marked, without the animals, however, losing consciousness, or the power of sitting upright; and finally, gnashing of the teeth, and slight transient convulsive movements of the limbs succeeded. These dangerous symptoms, notwithstanding, disappeared in all cases as gradually as they had come on, and the disturbance in the circulation became at

[1] Compare in particular Stannius, 'Ueber die krankhaften Verschliessungen grösserer Venenstämme des menschlichen Körpers,' 1839; and M. Hall, 'Synops. on Cerebral and Spinal Seizures,' &c. Of the various cases the following appear to us especially important. Gintrac (according to Stannius) observed, in a child four years old, attacks consisting of a momentary stoppage of voluntary movement with diminished sensibility, in which the mental faculties are said to have remained active whilst speech was *completely gone.* The child began to suffer in this way when only a year old. The superior longitudinal sinus was transformed into a stiff cord, and the veins emptying into it were gorged with coagulated blood. Prichard (loc. cit.) found in the corpse of an epileptic subject organized plugs in the whole of the lateral sinus. (Were the plugs the cause or effect of epilepsy?) Tonnelé ('Froriep's Notizen,' 1829, vol. xxiv, p. 142), in a girl nine years old, after obstruction by plugs of the superior longitudinal, the lateral, and the occipital sinuses of the right side, observed dizziness, with tendency to swooning for two days; then deep sleep, attended by slight convulsions of the left side, and finally resulting in death. A child two years old, during the last moments of its existence, became suddenly affected with convulsions, and great rigidity of the body and limbs. Plugs filled the superior longitudinal sinus, both lateral sinuses and the internal jugular veins. In both instances blood was extravasated below the arachnoid of the cerebral hemispheres; in one it even went so far as to produce softening of a portion of the right hemisphere of the cerebrum.

least partially balanced, without the animals having fallen into real epileptic convulsions.[1]

These experiments are in remarkable accordance with the above-mentioned observation of Romberg, that epilepsy in plethoric subjects has an apoplectic character and is attended by feeble convulsions. We feel, therefore, induced to express our doubts as to whether these so-called epileptic affections in plethora are to be at all ascribed to true epilepsy, or whether they are not rather to be set down among the series of apoplectic affections, and those which have in common with each other, unconsciousness, insensibility, and even the appearance of clonic spasmodic movements of the limbs, although in a slight degree; but which differ in their symptoms with respect to the state of the respiratory muscles, and are, in particular, accompanied by *paralysis of the glottis,* whilst epilepsy is distinguished by *spasm of the glottis.*

The results of our researches are accordingly decidedly at variance with any theory which offers sudden congestion of an active, passive, or mixed character, as the cause of an epileptic attack. We have, on the contrary, proved that the sudden appearance of arterial anæmia of the brain gives rise to epileptic attacks; and we are, therefore, fully justified in propounding the question, "What is the value of the theory which explains them by a spasm of the muscular elements of the vessels of the brain, especially of the smaller arteries containing many muscular fibres?"

If at any time we can observe that fright is capable "of expelling the blood from the cheeks," it cannot be denied that it is possible for the same cause, one of the most frequent of epileptic attacks and affections as is well known, to contract the smaller branches of the carotids and vertebral arteries. We know that anæmia, the most fruitful source of epilepsy, renders the nervous system very irritable and very accessible to the influences of fright; that anæmic and chlorotic persons possess a small and compressible pulse, and readily turn pale and swoon away. Numerous and accurate observers, such as Georget, Watson, Copland, Trousseau (De l'épileps., 'Gaz. des Hôpit.,' 1855, No. 49), and others, expressly mention that at the commencement of the attack the face is always pale, and only turns red and blue subsequently. Nevertheless, the carotids and the heart pulsate strongly; indicating the existence of an impediment to the circulation in the

[1] A more detailed account of the results of these experiments, which are not entirely completed, shall be given at some future time.

smaller branches. Cases are even known where the aneurismatic aorta has burst during the epileptic attack. Finally, Pereira[1] relates that Holst observed an epileptic subject at Christiania whose pulse always disappeared in the left arm during the attack. At the post-mortem examination a deviation in the course of the arteries was found; the left arm receiving its blood from the vertebral arteries, which themselves obtained their supply through the basilar artery from the carotids. The disappearance of the pulse renders it probable that the circulation through the carotids within the cranial cavity was arrested during the attack. If the last-mentioned facts speak in favour of the theory that the smaller arteries are contracted at the beginning of, and during the attack, they do not prove, nevertheless, that this spasm of the vessels is the cause; and it may just as correctly be regarded only as one of the phenomena accompanying the general morbid affection. What has been said about Marshall Hall's theory of spasm of the glottis consequently holds good in this case. But, just as spasm of the glottis will often undoubtedly cause epileptic attacks, it appears to us that the latter can also be produced by spasms confined at the onset to the muscles of the blood-vessels only. We endeavoured experimentally to satisfy ourselves of the correctness of the theory—a task beset with many difficulties. The ascending cervical branches of the sympathetic nerve do not seem to be the only channels by which the carotids and their branches receive nerves. The thickness in the sympathetic branches differs considerably in different rabbits; and the experiments of Schiff, Donders, and Callenfels render it probable that vaso-motory fibres reach them from other sources. When the subclavian arteries are tied, and the cervical branches subjected to faradisation, certainty is thereby afforded that all the nerves of the branches of the carotid are excited. Acting directly on the superior cervical ganglia would be productive of more satisfactory results, if the sensibility of this part would allow such an operation. Faradisation of the cervical branches of the sympathetic nerve must therefore be performed, leaving to mere chance the finding an animal in which they form the exclusive, or almost exclusive, vaso-motory nerves of the branches of the carotid. In three experiments which we performed, we first convinced ourselves, after having tied the subclavian arteries, that compression of

[1] Pereira, 'The Elements of Materia Medica,' 3d edit., vol. ii, p. ii, p. 1797.

the carotids did produce general convulsions. Both sympathetic nerves were then laid bare to a great extent, divided at the inferior cervical part, and separated upwards from the cellular tissue, were placed on small leaves of gutta percha. It was unfortunate that in all the three animals (white rabbits) the nerves were uncommonly thin, but the usual symptoms appeared in the blood-vessels of the ear when the nerves were divided, as well as when faradised, though general convulsions did not ensue after the latter operation. We then tied one of the carotids, so that the brain only received its supply of blood by means of the other one, and faradised the nerve on the side where the circulation continued. In two of the animals no effect was as yet obtained, but the pupils were not so dilated nor the background of the eyes so pale as we had noticed in other cases. In the third rabbit, however, the background of the eye turned completely pale, the pupil became dilated to such an extent that the iris could scarcely be seen, the eyeball protruded very much, the neck was drawn backwards, and violent convulsions seized the hind legs, which were not tied. (The fore legs were made fast, the animal was lying on its back.) The electrodes were removed, when the spasms ceased, the pupil contracted, and the background of the eye turned red, but the animal continued in a swooning condition. After some minutes we again succeeded, by the action of electricity upon the sympathetic nerve, in producing the same effects as at first. A third attempt to excite by faradisation did not succeed. We tied the other carotid, which was still free, and the animal died, (probably from exhaustion of the brain) without again becoming convulsed.

On account of their importance, these experiments deserve to be repeated in a greater number of cases, reducing, thus, perhaps, to a certainty, what at present is only probable;—*that epileptic convulsions can be brought about by contraction of the blood-vessels induced by the vaso-motor nerves.*

## CHAPTER XIV.

### UPON THE NERVOUS CENTRES FROM WHICH THE ALTERATIONS OF THE BRAIN RESULTING IN EPILEPTIC ATTACKS PROCEED.

Many causes producing epileptic attacks—for example, great losses of blood and strangulation,—affect the whole brain simultaneously, and this organ undergoes at once the same alteration. These are undoubtedly epileptic affections whose seat is not to be looked for in this or that part of the brain, but which occupy the whole organ. We conjecture, for example, that this is the case in those frequent forms of epilepsy which appear after great losses of blood and humours; in those connected with congenital and acquired atrophy of the brain; in those connected with imbecility following madness producing atrophy, and in eclampsia of anæmic and cholæmic subjects, as well as of many who are poisoned.

But in those epileptic attacks which are produced by spasm of the glottis, the central point of departure is to be transferred to the place where the roots of the nervi vagi and of the nervi accessorii Willisii originate, probably therefore to the medulla oblongata. It may be assumed that this source, by direct or indirect agencies, may undergo either a temporary functional alteration, so-called excitement, producing epileptic attacks, or be affected by a lasting alteration of a more powerful character, and thereby cause an epileptic disposition.

If it be true that spasms of the cerebral arteries are capable of producing epileptic attacks, the central point from which these arise would consequently lie in the part where the vaso-motory nerves take their origin, and therefore, if the results of Schiff's researches be correct, in the medulla oblongata. An excitement of this nervous centre would then be the first link in the chain of these processes, anæmia of the brain the second, and the epileptic attack the third.

This is what, relying upon the facts brought forward, we have ventured to pronounce upon this obscure subject. The field of possibilities is, however, not yet exhausted. We, nevertheless, feel but little inclined to wander about in the dark and fanciful paths of mere hypothesis.

Lastly, it should be borne in mind that pathological anatomy can give but little information as to the origin of epilepsy. It only supports the supposition to which all the symptoms of epilepsy already point, that this origin is to be sought in the brain. But, as we have seen in our researches on the nature of epilepsy, this is more vigorously supported by the etiological forces, and the great importance of the *traitement moral*. Physiological experiment alone furnishes reliable information.

## CHAPTER XV.

### SYNOPSIS AND GENERAL SUMMARY.

*Synopsis of the ways in which Epileptic Attacks resulting from a sudden arrest of the Nutrition of the Brain may arise.*

I. Rapid losses of blood.

II. Sudden stoppage of the flow of arterial blood to the brain.

1. Mechanical closure of the great arteries of the head, their larger and smaller branches (ligature, compression, plugs, injected air, &c.)
2. Spasms of the muscles of the blood-vessels.
   - *a.* By direct excitement of the central seat of the vaso-motor nerves (inflammation, local anæmia, poisons, &c.)
   - *b.* By excitement proceeding from the mind (fright).
   - *c.* By excitement from the sensitive nerves.
   - *d.* By excitement from other motor districts which have been irritated.
3. Venous stasis of the brain.

III. Rapid transformation of the red blood, by which it is rendered incapable of nourishing the brain.

A. Transformation of the red blood into black, by asphyxia.

1. Asphyxia by mechanical methods.
2. Spasm of the glottis (laryngismus).
   - *a.* By direct excitement of the central seat of the motor nerves passing to the muscles that close the glottis.
   - *b.* By indirect excitement of the same (especially by irritation of the sensitive nerves of the mucous membrane of the trachea).
3. Asphyxia by gases.

B. Alteration of some other kind of the arterial blood (by ferments, poisons, &c.)

## *General Summary.*

For the sake of greater perspicuity we concisely group together the chief results obtained from our researches under the following heads:

1. The convulsions appearing in profuse hæmorrhage of warm-blooded animals (including man) resemble those observed in epilepsy.
2. When the brain is suddenly deprived of its red blood, convulsions ensue of the same description as those occurring subsequent to ligature of the great arteries of the neck.
3. Epileptic convulsions are likewise brought on when the arterial blood rapidly assumes a venous character, as, for example, when a ligature is applied to the trachea.
4. It is highly probable that in these cases the attack of spasms depends upon the suddenly interrupted nutrition of the brain. It is not caused by the altered pressure which the brain undergoes.
5. Epileptic convulsions in hæmorrhage do not proceed from the spinal cord.
6. Neither do they proceed from the cerebrum.
7. Their central seat is to be sought for in the excitable districts of the brain lying behind the thalami optici.
8. Anæmia of those parts of the brain situated before the crura cerebri produce unconsciousness, insensibility, and paralysis in human beings; if spasms occur with these symptoms, some excitable parts behind the thalami optici must have likewise undergone some change.
9. Anæmia of the spinal cord produces paralysis of the limbs, of the muscles of the trunk, and of respiration. When the anæmia suddenly attains its greatest intensity, then only and even then but rarely, do slight trembling movements of the limbs precede paralysis. The sphincter ani acts analogously to the constrictor muscles of the face, in anæmia of the brain, that is, it contracts spasmodically before it relaxes.

10. Convulsions from hæmorrhage are neither psychical nor reflective.

11. Convulsions from hæmorrhage do not ensue—

*a.* In cold-blooded animals, at least not in the frog.

*b.* When the hæmorrhage is slow, so that the vital power is only gradually consumed.

*c.* When the animals are very much debilitated.

*d.* When the nutrition of the spinal cord has suffered.

*e.* When large pieces of the excitable districts of the brain have been removed.

*f.* In animals subjected to etherization.

*g.* Doubtless also when excitable districts of the brain have undergone certain pathological alterations.

12. As suffocation brings on convulsions, and etherization averts them, it is evident that etherization and asphyxia are two different conditions.

13. The brain of warm-blooded animals can only be deprived of red blood for a short time; otherwise it loses its capability of resuming its functions when again supplied with the nutritive fluid, and the appearance of death becomes a reality. The brain of some rabbits preserved this capability for two minutes.

14. It is sometimes observed, after the arteries of the neck have been tied, that the muscles of the trunk perish and take on the rigor mortis before the action of the left heart is extinct. Hence the left heart is not always the *primum moriens* among the muscular organs.

15. Contraction and subsequent extreme dilatation of the pupils in the agonies of death, is no certain sign of real death and of the incapability of being revived, as maintained by Bouchut.

16. To cure epileptic attacks caused by anæmia, there is no better method than that of renewing the supply of red blood.

17. The debilitating method of treating epilepsy, especially by *abstracting* blood, should almost always be rejected.

18. The quantity of blood in the cranial cavity can by way of experiment on the living subject be considerably increased or diminished.

19. Hyperæmia in the cranial cavity is caused by releasing the stoppage of circulation in the cervical arteries (arterial congestion), by tying the cervical veins (venous congestion), especially by simultaneously dividing the cervical branches of the sympathetic nerve

(venous arterial congestion), and lastly by tying the trachea during inspiration (venous congestion by asphyxia).

20. Anæmia in the cranial cavity is produced by hæmorrhage and by tying the cervical arteries (passive anæmia), as well as by electric excitation of the vaso-motor nerves of the head (active anæmia).

21. The quantity of blood contained in the cranial cavity after the application of a ligature to the arteries is greater than after hæmorrhage; the anæmia as regards small arteries, the capillaries, and the smallest veins being always present to a greater extent.

22. From the quantity of blood contained in the skull after death, it is seldom possible to draw certain conclusions with respect to the quantity contained during life. The death-struggle brings on numerous conditions altering the circulation of the blood in the skull, and even in the corpse the quantity of blood may still undergo alterations.

23. The phenomena of the incomplete epileptic attack can be explained by alterations occurring in the cerebrum only; whilst the phenomena of the complete attack presuppose an alteration of the whole brain. Convulsions in epilepsy are justly styled cerebral ones, and the spinal cord probably plays only the part of a conductor, transferring the impetuses it receives, from the brain to the muscles.

24. Circumscribed anatomical alterations of the brain or alterations of protracted duration cannot be regarded as the proximate cause of epileptic attacks, but may cause epileptic *affections* (dispose to epilepsy).

25. Pathological anatomy cannot give any explanation as to the nature of epilepsy.

26. Suddenly withheld nutrition is only one of the causes by which the brain is brought into that peculiar internal condition which is manifested in the form of an epileptic attack.

27. Arterial congestion of the brain does not seem to be capable of producing any other symptoms than those of paralysis (dizziness and apoplexy).

28. Venous congestion of the brain, as well as arterio-venous congestion, brings about conditions which belong more to those of apoplexy than to those of epilepsy, and are characterised by paralysis of the glottis, together with a slower respiration and slight spasmodic symptoms.

29. Marshall Hall's sphagiasmus and trachelismus are not to be regarded as a source of epileptic attacks, but laryngismus will produce them. All theories are false which assert the epileptic attack to be derived from a sudden determination of blood, whether active, passive, or mixed.

30. It is probable that certain forms of epilepsy result from a spasm of the muscular coats of the cerebral arteries.

31. The epileptic affection, which disposes to the attacks, occupies either the whole of the brain, or some districts only, and by it the brain is brought into that altered state on which the epileptic attack is based.

32. The medulla oblongata, as being the part whence the nerves causing the constriction of the glottis and the vaso-motor nerves take their rise, seems frequently to be the spot from which eclamptic and epileptic attacks proceed.

## APPENDIX.

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After the preceding treatise was finished, we became acquainted with a highly remarkable case of epilepsy strongly supporting the opinion expressed by us that the medulla oblongata sometimes forms the centre from which the epileptic attacks proceed.

In 1823, died in the Infirmary at Frankenthal, in the Palatinate of the Rhine, an imbecile boy, twelve years old, who had been affected with epilepsy from his birth, and had a remarkable propensity to steal. The attacks frequently recurred, even on the same day. They exhibited this peculiarity, that they especially appeared when the patient made certain strong rotary movements with his head; were of remarkably short duration, never lasting more than a few minutes; and consciousness returning very rapidly, much sooner than in other epileptic cases.

After a violent attack the patient became very ill, and on the following day all the symptoms of acute phrenitis manifested themselves, to which the patient succumbed on the seventh or eighth day afterwards.

At the post-mortem examination the skull was found unaltered, indications of meningitis were present, and serous exudation had taken place into the cavity of the skull and spine, as well as into the ventricles. There was moreover an anomalous and unique formation of the first cervical vertebra. The atlas was not completely ossified, but consisted of two separate lateral halves, united in the middle of the anterior arch by soft cartilage and by strong ligaments, but at the posterior arch only by very thin moveable thread-like ligaments, so that in the latter place the ends of the bones could be moved one over the other, whereby the foramen for the spinal cord could be very much narrowed. Hence there is much reason for conjecturing that in this case the epileptic attacks were caused by the pressure on the medulla oblongata when the head was turned. The vertebra is still preserved in the Infirmary, which possesses a rich and interesting collection, where we lately had occasion to examine it. We are indebted for the above-mentioned observations on the patient's case to the kindness of Dr. Bettinger, the present excellent Director of the institution. They are partly taken from the annual report of 1823, given by the late Dr. Dapping, at that time Director of the Infirmary, who, in 1829, laid the vertebra before the meeting of German Naturalists at Heidelberg (compare the report by Tiedemann and Gmelin, p. 73); partly from a letter of Dr. Hepp, of Zurich, dated 31st March, 1857, who likewise had seen the patient.

We have to mention, in conclusion, that on the left side of the superior surface of the vertebra, behind the massa lateralis, a sort of half canal was seen, through which the vertebral artery probably passed, whilst on the right side no trace of such a groove was to be found.

ON THE

# PROCESS OF REPAIR

AFTER

# RESECTION AND EXTIRPATION OF BONES.

BY

DR. ALBRECHT WAGNER,

OF BERLIN.

TRANSLATED, WITH AN APPENDIX OF CASES,

BY

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MDCCCLIX.

# INTRODUCTION.

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The claims which may be asserted in behalf of the practice of resection of bones, over the other operations which used formerly to be adopted in its stead, may be thus stated: I. That it involves less danger to life. II. That it removes only the diseased bones. III. And that thus it becomes the first step in a process of repair by which a part of the body is restored to more or less complete usefulness, which would otherwise have been sacrificed to the removal of the disease and the preservation of life. The difficulties in its performance (such, I mean, as the anatomical relations of the part render insuperable), and the length of time after the operation which is required for the cure, ought not to be set against these considerations in forming a judgment as to the value of resections, or at least only in a subordinate degree and under peculiar circumstances. But is it really a fact, that resections do possess these advantages? or, what are their real results, and what place therefore is to be allotted to them? This is the question—which has, indeed, been answered up to a certain point, but the complete determination of which is still a desideratum.

After resection of bones had been introduced into the list of surgical operations by White and Park, towards the end of the eighteenth century, it reckoned few supporters for a period of many years, and also few opponents—in fact, it remained almost unnoticed. It was reserved for our century to decide whether resection should be admitted among recognised operations. The number of its advocates increased rapidly in the early part of this century, together with that of its opponents. The chief points on which observation was concentrated in deciding this contest were—

the relative mortality after resection compared with other operations; the possibility and certainty of removing entirely the diseased bones; and especially what assurance there is of preserving the limb, and what is the degree of its usefulness after recovery. When the balance had gradually inclined in favour of resection, and in consequence of the increasing number of its supporters, the operation had been extended over the whole skeleton, both in the substance of the bones and at their extremities, observation was necessarily directed, besides those general points, to the differences which arose according to the bone on which the operation was practised, according as the piece of bone was removed from the substance or the extremity and according to the extent which the resection had embraced. Here also the results spoke loudly in favour of resection. Soon it was no longer a question whether resections should be recognised among the operations of surgery; they had won this recognition indubitably, and were greeted as one of the greatest advances of operative surgery; and it then became rather the question (and this remains our task at present) to mark out the limits of the applicability of the operation, and to preserve it from the dangers of falling into disrepute, in consequence of results being demanded from it which it has never entitled us to expect, and which it can never afford. This task must necessarily go hand in hand with an endeavour to make the operation perfect in all respects, and to explore as widely and investigate as deeply as possible the region which it may command.

It is remarkable that, while numerous resources have been expended on establishing the indications in cases of resection, *e.g.*, the treasures of surgical science and experience for the diagnosis, the study of anatomy for perfecting the operative proceedings, and clinical observation for the after treatment, very little attention has been paid to the healing process after the operation. And yet it is indubitably from a faithful observation and accurate knowledge of this process, that we may obtain sure grounds for improving the operation in various directions, and for deciding the question as to its value.

There are two ways in which this may be advantageously studied. The first is that of clinical observation of the process of cure; and this has been often used, but without earning the fruits which might be obtained from it. The observations which we find on record as to the course of the symptoms after the operation are for the most part so inaccurate, that they allow of no conclusion being formed as to the process of healing, and in some respects it seems impossible that a more secure conclusion can ever result from them. We must, however, express still greater surprise at the inaccuracy of the data which relate to the result of the operation and the functional power of the part operated on. Except the remark, in resections of the extremities of bones, that a perfect ankylosis was produced, and in resections from their substance that the solidity of the bone was re-established, or a false joint formed, there is hardly anything in these records which can be made useful in the investigation of the healing process; and even when we find an observation of this kind, we get hardly anything said about the other tissues, besides the bone, which have been involved in the resection—nothing about the extent of the ligamentous union between the resected extremities of bone—nothing about the condition of the latter themselves. Perhaps this also will not be found possible until the other course, that of *anatomical* investigation of the healing process, has been more industriously followed. Thence, perhaps, a starting point may be obtained for an accurate and exhaustive investigation on the living body; and in this manner we shall succeed in finding the connecting links of the chain, the opposite ends of which we hold in our hands at the time of the operation and at that of the examination of the patient after recovery.

The course of anatomical investigation into the healing process after resection of bones leads in two directions. The surest way of arriving at the object is to examine on the dead body, at the most various times possible after the operation, the parts on which resection has been performed. It seems almost to afford a presumption in favour of resection, that so little material (and, unfortunately, still less profitable material) has been obtained. It might be assumed with some confidence, that a fatal result after resection is uncommon, and that the necessity of subsequent amputation has still less frequently occurred. An opportunity has very seldom been found of examining the body of a man who has been cured by resection, and survived for a considerable time.

But even in the cases where the opportunity has occurred of making an examination a short time after the operation, this has not often been done. When, however, examinations have been made, what is displayed to the investigators is usually the product of a diseased action, and not the normal condition of the healing process, so that nothing is gained towards the knowledge of the latter.

The other method consists in *experiments on animals.* These offer opportunities for studying the healing process in all stages, and usually give results which do not diverge from the normal state of that process. We must be cautious, however, not to draw direct conclusions from what we observe in animals as to the phenomena in men. Thus, to speak only of operations on rabbits, the ratio of mortality would be fixed exceedingly unfavorably for resection, inasmuch as nearly half the rabbits which I operated upon died. It would be assumed that in most cases, after resection of the head of the humerus, inflammation of the pleura, pericardium, or lungs, would be set up, as I have found to be the case in rabbits. Others have observed the same thing, and, in fact, Steinlin allowed himself to be thus brought to the general conclusion, that resections of the extremities of bones were not likely to supersede exarticulations and amputations—a view, however, from which he has since receded. Besides, we must not forget how imperfect the treatment subsequent to the operation must be in animals, at the best, and, at the same time, how important it is to take the greatest possible care of them, and how much success depends on it. This circumstance causes a much more important difference in resections upon animals than in experiments on the healing of fractures, though there also the difference is not inconsiderable. The errors which have arisen from this source, and which have long prevailed, have been recently exposed by Voetsch.[1]

The errors, however, into which the use of these two means of anatomically investigating the healing process after resection may lead are mutually destructive. By the differences which appear between observations on the dead body and experiments on animals, we shall learn to separate the essential from the non-essential, the normal from the exceptional; while in other cases they will lead us to the causes upon which they depend. In the end we shall gain a clear insight into the process, and besides this shall obtain numerous hints which will teach us how to guide it for the patient's benefit.

I have endeavoured, in the following pages, to contribute to the

[1] 'Die Heilung der Knochenbrüche per primam intentionem,' Heidelberg, 1847.

illustration of the healing process by as complete a digest as possible of the recorded anatomical examinations of men and animals, and by new experiments on the latter. The longer my investigation has lasted, the more clear it has become to me how far I still am from being able to form a perfect theory of the process; I hope, however, that I have contributed something towards this, and that, by the collection of new materials, I have been of some use towards the construction of a theory which shall be true to fact.

The greatest differences are observed in the healing process according as the resection is performed *at* the *extremity* or in the *substance* of a bone, *i. e.*, according as the shaft or the epiphysis is resected. This division will, therefore, be observed in what follows; and a chapter will be added about the healing process *after extirpation of bones.*

# ON THE HEALING PROCESS

AFTER

# RESECTION AND EXTIRPATION OF BONES.

## CHAPTER I.

### ANATOMICAL EXAMINATIONS OF THE HUMAN BODY.

#### I. *Resections of the Extremities of Bones.*

A. *Resection of the head of the humerus.*—I find five examples of dissection of the human body after resection of the head of the humerus. Three of these belong to Textor,[1] and two to Syme.[2] The operation was performed three times on account of caries, once on account of comminuted fracture, and once on account of fracture complicated with other injuries. The patients had survived the operation six months, six, ten, eleven, and nineteen years, respectively. The usefulness of the arm had been very great in all of them. It is reported in the case of one of them, a woman who was under Syme's care, and who could sew, knit, wash, and with the left arm (the one operated upon) could raise a full pitcher of water, and also in that of a man under Textor's care, and who continued his work as a thatcher, that abduction of the arm was very

[1] Hummel, 'Ueber die Resection im Oberarmgelenk,' Wuerzburg, 1832; Textor, 'Neuer Chiron.,' Thl. i, stck. 1, 3; Textor, 'Ueber die Wiedererzeugung der Knocken nach Resection bei Menschen.,' Wuerzburg, 1843, p. 11.

[2] Syme, 'Treatise on the Excision of Diseased Joints,' Edinb., 1831, pp. 51, 58; 'Contributions to the Pathology of Surgery,' Edinb., 1848, p. 97.

imperfect, and could only be effected to any considerable extent by the patient making a movement as if to fling the arm away from him. I have seen the same thing in several cases, especially that of an officer on whom Professor Langenbeck[1] removed the head of the left humerus, on account of its having been crushed by a gun-shot wound, and in whom the motion of the arm was so good that he is still doing duty in the Prussian army. In the thatcher operated on by Textor the deltoid muscle was found remarkably thin eleven years after the operation, and firmly consolidated to the newly formed articular capsule and to the infra-spinatus muscle. This atrophy of the deltoid muscle, which is usual after resection of the shoulder, is probably occasioned (as Reid also says) by the division of the nerves and vessels of the muscle at the time of the operation, even if the whole muscle has not been cut across. Syme found in both his patients—who had died, one six months, the other ten years, after the operation—the head of the humerus rounded off and united by a firm ligamentous tissue to the shoulder-blade; Textor, however, gives expressly two cases, six and eleven years after the operation, of formation of bone, which in the first appeared as a long styloid prominence, resembling the styloid process of the ulna, directed upwards; and in the second covered the upper end of the humerus, in the form of an uneven tubercular mass, about half an inch long. Of the eminences upon it, one served for the insertion of the long head of the biceps, the tendon of which must therefore have been divided; a second, of small size, served to articulate with a small depressed portion of the glenoid cavity of the scapula, which was covered with cartilage. In the case of the thatcher, and in that of a patient who died nineteen years after the operation, Textor found a thick fibro-cartilaginous(?)[2] meniscus, in one case freely moveable, between the newly formed mass of bone and the glenoid cavity. This disc was in the latter case united by numerous bands with the acromion, the coracoid process, the sub-clavius and pectoral muscles, and the humerus. In the first case, in which alone of the five a new articular capsule appears to have been formed, the meniscus was united to it. The articular capsule was found, united with a peculiar fibroid tissue, along about the upper fourth of the humerus. It embraced the bone firmly, and

[1] Petruschky, 'Diss. de Resect. articulor. extremit. sup.,' Berol., 1851, p. 31.

[2] The notes of interrogation are the author's.—Trans.

was united intimately to all the parts in the neighbourhood of the joint, especially to the inner surface of the deltoid and to the skin at the situation of the cicatrix. The inner surface of this tissue was rough, and difficult to separate from the bone. Immediately around the joint the tissue was much harder than in other parts, and resembled fibro-cartilage. The disc consisted of the same tissue, but was more advanced in cartilaginous (?) formation. It appears from this that the so-called meniscus can only be regarded as a thick fibrous envelope to the resected end of the bone, and cannot be classed as an inter-articular cartilage. How the tissue connected with it is to be looked upon will be shown farther on. Textor considers the circumstance, that the two patients in whom this meniscus existed were obliged to use their arms much more than the third, who, being a tailor, worked more with his forearm, of much importance in the production of this so-called meniscus. Perhaps, also, the fact that the two former patients survived eleven and nineteen years, and the third only six, should be taken into account.

Ankylosis after resection of the shoulder-joint has not been observed up to the present time.

B. *Resection of the elbow.*—The cases where arms, in which the operation of resection has been performed, have been examined a considerable time after the operation, are not more numerous than those above described, but they give a more uniform result. I find six of them, of which two belong to Syme.[1] In one of these cases, when he examined the patient, who had survived the operation (which was undertaken on account of caries) only thirty-six days, and then died of pleuro-pneumonia, with formation of a large abscess in the lumbar region, he found the wound healed in most of its extent, but the cut ends of the bones were carious; so that it appears probable that he had not removed the whole of the diseased bone. In the other case, amputation of the arm operated on was rendered necessary, ten months after the resection by caries, which attacked the wrist. Up to the time of the return of the caries, the patient had been able to use her arm almost as well as the sound one, and had occupied herself principally with knitting. The ulnar nerve had been divided in the operation, and this had occasioned a feeling

[1] 'Treatise on the Excision of Diseased Joints,' Edinb., 1831, pp. 91, 105.

of coldness and numbness along the ulnar side of the hand, but it had disappeared entirely after a few weeks. The third case, which is recorded by Heyfelder,[1] was also examined after consecutive amputation of the arm. The resection was performed on account of caries, with false ankylosis of the arm at an acute angle. The wound was cicatrized in four weeks, and all movements of the forearm and hand were performed with great facility. Pain, however, continued in the joint, and abscesses formed twice in its neighbourhood anteriorly, and a year and a half after the resection the forearm was hanging from the body, without any power of voluntary motion. The fingers could not be moved without pain, followed, after a short time, by convulsive trembling. There was a space of one third of an inch between the bones of the forearm. The resected ends were enlarged, and there was pain in them and in the shaft of the humerus. The muscles were flaccid, and the radial pulse was close to the finger. In this condition amputation was performed three years after the resection.

The three other cases belong to Roux,[2] Thore,[3] and Textor,[4] and contain examinations of persons who had survived the operation four and a half months, three and a half years, and six years.

Textor is the only one who, after "a preliminary" examination of the arm operated upon, expressly asserts that there was new formation of bone, and this to the precise extent necessary to produce a perfect new articulation of the ends of the bones upon each other. He found "a lengthening of the ulna to the extent of a quarter of an inch, on which the radius moved, as in the natural state, and the trochlea of the humerus appeared as perfect as if none of it had been taken away."

All the others speak only of a rounding off of the bones and a union between them by firm fibrous tissue, which also partially covered the bony extremities. From the drawing which Syme gives, it is impossible to say whether it is fibrous tissue or a newly formed mass of bone which covers the lower end of the humerus. It almost

[1] Amputation of an arm three years after resection of the elbow. Baier, Corresp. Blatt., 1843, No. 45; Schmidt, 'Jahrbuecher,' 1847; 5 Suppl. Bd.

[2] 'Diction. des sciences médicales, Art. Resection,' tom. xlvii, p. 548.

[3] Thore, A.M., 'De la Resection du coude et d'un nouveau procédé pour la pratiquer,' Paris, 1843; Schmidt, 'Jahrb.,' 1844, p. 123.

[4] 'Ueber die Wiedererzeugung,' &c., p. 13.

seems to be the latter, since separate parts of newly formed bone on the ends of the radius and ulna are represented similarly.

Roux found the lower end of the humerus rounded off, smooth, and as it were encrusted (encroutée) by cartilage. The upper end of the ulna was in the same condition. In the upper end of the radius was a carious spot, corresponding to a fistulous channel in the soft parts. In no case had a new articular capsule been formed.

The muscles of the arm were atrophied in Heyfelder's case, and a considerable deposit of fat was found in them, as well as in the subcutaneous cellular tissue. All the other muscles, except the triceps, had their natural points of insertion. Whether these had been spared in the resection is left undecided by the statement, that the portion of bone removed "was not large." The triceps was inserted, in the case described by Syme, into the posterior surface of the newly formed ligamentous tissue, and through this was connected with the upper end of the ulna.

In Textor's case, in which the flexion and extension of the arm had been quite perfect, the triceps was firmly united to the cicatrix in the skin, without any prolongation to the ulna.

Heyfelder found the median and radial nerves in their natural position. The ulnar nerve made a peculiar bend at the point where it runs behind the inner condyle of the humerus. The nerves were more broken up, and disproportionally thicker and softer than in the natural condition, almost like strings of cellular tissue. Between the separate nerve-fibres were found numerous fat-vesicles. Heyfelder believes that this formation of fat must be considered as the most potent determining cause of the incapacity for motion to which the arm had recently been reduced.

The ends of the ulnar nerve, in Syme's case, where it had been divided, were encysted in an oblong swelling, an inch and a half long, and overlapped one another inside this. The substance of this swelling was grayish in colour, and extraordinarily hard and tough; it was united to the sheath of the nerve, and stretched inward between the separate nerve-fibres, which were thus spread asunder. Most of them terminated in the swelling in a free extremity, which appearance, however, might have been produced in the dissection. The remaining nerve-fibres became broader, stronger, and whiter in the swelling than they were elsewhere. Their upper and lower ends approached one another in this altered condition, and finally were united by a flaky substance hardly a line in width, which, under the microscope, was found to consist of numerous fine fibres crossing each other. These fibres turned of a deep yellow colour on the addition of strong nitric acid, and became firmer and less transparent.

The process of regeneration of the nerve is thus seen to have begun. This fortunate event after division of a nerve in resection appears to be rare.

Reid[1] believes that the reason of this rarity is to be found in the fact that the cut ends of the nerve are situated in the thickness of the flaps formed in the operation, and thus even by the most careful management can very rarely be brought into exact apposition, but almost always overlap each other. Such, however, was the case in this instance. Thus the impossibility of regeneration, which Reid believes to be caused by this overlapping, is disproved.

Besides the cases which result in the formation of a flexible and more or less long and firm material between the resected ends of the bones, we find healing frequently reported with more or less complete ankylosis. The incomplete ankylosis may depend on an extremely short and very firm fibrous mass, occupying the space between the resected ends of the bones, or on an intimate union of the muscles which surround the situation of the joint, by which they are hindered from acting freely. But perfect ankylosis can only be caused by bony soldering of the ends of the bones together, and its occurrence speaks decisively of copious production of callus, and an approximation of the resected ends of the bones by muscular action.

Esmarch[2] observed perfect and imperfect ankylosis thirteen times among forty cases of resection of the elbow, thirty-three of which were healed. The after treatment has the most important influence on this result of resection. Most of the cases of ankylosis just mentioned occurred among the patients who had suffered resection of the elbow in the Schleswig lazarettoes, after the battle of Idstedt, and had afterwards been treated in the Danish lazarettoes. The Danish surgeons had never practised the operation, and being apparently ignorant of the value of timely passive motion, had entirely neglected it.

c. *Resection of the lower end of the ulna.*—Blandin[3] resected the lower end of the ulna in the extent of five centimetres (nearly two

[1] 'Die Resectionen der Knochen.,' Nuernberg,' 1847.
[2] 'Ueber Resection nach Schusswunden,' Kiel, 1851.
[3] 'Journal de Méd.,' par Champion, Avril, 1843.

inches), in a man thirty-two years of age, a baker. On the death of the patient, seven and a half months afterwards, a fibrous tissue was found in the place of the excised bone, in which several points of ossification had been deposited. The wrist-joint had preserved its mobility completely. From the absence of ankylosis between the separate carpal bones, Blandin deduces the conclusion, that the joint had not been opened in the operation. (?)

D. *Resection of the hip-joint.*—Anatomical investigations, which might give any data as to the changes after resection in the hip-joint, are almost entirely wanting. Perhaps I may be allowed to produce here a case observed at the surgical clinique at Jena, and which is related by Reid.[1] The head and neck of the femur, which had separated spontaneously after an abscess in the joint, in a boy of fifteen, were extracted through an incision. After the death of the patient, which was the result of Bright's disease, a year afterwards, a new joint was found, two rounded processes having been formed on the remains of the neck of the femur, the upper of which was connected with a bony prominence above the acetabulum, and the lower (situated immediately in front of the small trochanter) with the original articular cavity, by firm fibrous tissue, in such a way as to admit of motion. The motions of the limb were limited.

Two accounts of dissection after excision of the upper end of the femur are given by Textor[2] and White.[3]

In Textor's case the patient was a man of fifty-four years of age, who suffered from caries of the neck of the femur and the trochanter major. The head and neck of the femur and the trochanter major were removed. The patient died of hectic fever fifty-three days afterwards. The wound was united, except a small part. From the small trochanter outwards new bone was deposited over the upper third of the femur, the cut surface of which had become rounded off. At the upper and inner side of the femur a depression resembling a neck was formed. The acetabulum, which was partially covered by granulations, was healthy; at separate points of it there was also found a deposit of new bone, which, however, separated again on

[1] Loc. cit., p. 388.

[2] 'Oppenheim. Ueber die Resection des Hueftgelenks,' Wuerzburg, 1840, p. 45.

[3] 'Catalogue of the Pathological Specimens contained in the Museum of the Royal College of Surgeons of England,' London, 1847, vol. ii, p. 230.

maceration of the pelvis. The upper end of the femur rested against the ischium at the posterior edge of the acetabulum, so that a depression had been formed in this bone one and a half inch long, half an inch broad, and two lines in depth.

White resected the upper end of the femur, just below the trochanter minor, on a boy thirteen years old. In one year recovery was so perfect that the boy could execute flexion, extension, and in fact every other motion of the joint, except rotation outwards. He died within five or twelve years[1] after the operation. The account is not exact on this point. The ilium and the remains of the femur were found thin and light. The thigh-bone rested with its upper extremity against the hinder part of the acetabulum, and was united to it and to the neighbouring portion of the os ilii by a firm ligamentous tissue, which appeared to belong partly to the remains of the articular capsule which had been left between the bones. A muscle was inserted into this tissue and into the upper portion of the femur. Nothing more is added in the description of the preparation.

E. *Resection of the knee-joint.*—Among the comparatively few cases of resection of the knee there are only two which elucidate the healing process by dissection. Those who have recovered after resection of the knee have obtained, some a perfect, some an imperfect ankylosis, and others free movement at the situation of the joint. The first result seems to be the only favorable one, since in the two others the union between the resected surfaces of bone does not attain, even after a long period, the degree of firmness and solidity which is necessary for voluntary motion of the leg at the knee. The patients in whom these results had occurred, and in whom the immobility of the knee could not be replaced by a machine, either demanded amputation at a later period, or they went on crutches, dragging the leg after them as a mere incumbrance.

In the case examined anatomically by Wachter[2] the resected

[1] The true date appears to be five years. This, at least, is the time mentioned by Mr. South in his account of the case ('Chelius' Surgery,' vol. ii, p. 980); and the appearance of the bones in the preparation shows that the patient could not have attained the age of twenty-five, as he would have done had he survived the operation twelve years.—TRANS.

[2] 'Dissert. de Articulis Extirpandis,' &c., Groning., 1810.

bones had been soldered together by a mass of callus, but the latter had again undergone partial softening in the puerperal state. The patient was thirty-four years old, had borne nine children, and had suffered from caries of the knee-joint. Mulder removed on this account the lower end of the femur, about two inches above the condyles, and the end of the tibia close above its junction with the fibula, and took away the patella. Immediately after the operation the space between the resected extremities of the bone was diminished by the contraction of the muscles and skin. The limb was kept in a state of extension by an apparatus, and the resected ends approximated as much as possible. The wound was almost entirely closed by suppuration; this was accompanied by tolerably severe continued fever, and there was present also a train of symptoms, which were probably dependent on the (unrecognised) pregnancy of the patient. A month after the operation the ends of the bones were already so firmly united that the patient could raise her limb easily without pain, and enjoyed perfect motion of the foot and toes. About four weeks afterwards she was unexpectedly brought to bed of twins. Two days after this the suppuration in the wound, which was then in small quantity and healthy, was replaced by an extraordinarily profuse secretion of a watery fluid mixed with white flocculi, and this afterwards gradually diminished and gave place again to suppuration in the wound, which was now almost all broken open afresh. Acute cough, with profuse expectoration and continuous diarrhœa, so exhausted her strength during her lying-in that she died about three and a half months after the operation. The extensors of the leg on the limb operated on were rather shorter than natural; the extensor tendons were firmly united to a newly formed process of bone, which projected above the lower end of the femur, and had nearly the form of the knee-pan. The flexors of the leg had their usual attachments to the tibia. Beneath the newly formed bony process was found, between the ends of the bones, a small cavity filled with pus. The callus, which surrounded the ends of the bones with a firm covering and soldered them together, appeared to have been again broken up and dissolved at the lower part of the newly formed process corresponding to the patella. The upper end of the tibia, corresponding to this spot, appeared to be carious. At each side of this process there was found running obliquely backwards a cleft of similar appearance, between the ends of the bones and the mass of callus, and by means of this cleft the bones, which had before been soldered together, were in part separated again. The head of the fibula, to judge by the drawing given by Wachter, was unaltered. The mass of callus extended up to it. In the ankle-joint was found some pus, and there was incipient caries of the contiguous articular surfaces of the tibia and astragalus. Reid[1] describes a second case operated on by Jaeger. The operation was performed on account of caries on a man twenty-eight years of age; one inch and four lines of the lower end of the femur, the articular end of the tibia, for the extent of nearly an inch, down to the head of the fibula, and the patella, were removed. The section of the tibia sloped rather sharply upwards in its posterior half. The surfaces of the bones were kept constantly in contact, and the limb extended. In the tenth week the first attempt was made to raise the limb, and in the fifteenth to walk. Five weeks later the patient was in condition to be discharged, with a thoroughly useful limb. The femur and tibia were firmly united by callus. The lower end of the femur had slipped somewhat forwards and outwards, and its projection could be plainly felt in this situation beneath the cicatrix, which was firmly united to the bones; while the prominence of the posterior edge of the tibia could be made out in the popliteal space. This displacement had occasioned an inconsiderable curvature outwards in the neighbourhood of the knee. The muscles of the leg and thigh were not much diminished in size, but were flaccid. The shortening of the limb measured two inches. The patient on recovery was able, after the interval of a year, to walk securely and for any length of time with a raised heel an inch thick on his boot, could ascend mountains, stairs, or ladders, and could even dance. A few years before his death he fell off a ladder and broke his fibula in the lower third. Thus it seems that the union at the knee was firm enough to resist the force which caused this fracture. Fourteen years after the operation the patient died of pulmonary consumption. Reid found the cicatrix firmly united to the bone, the extensor and flexor muscles of the leg atrophied, and partly converted into fat. The ends of the femur and tibia were firmly united by bony union, with displacement transversely and partial rotation on each other. The joint between the tibia and fibula was unaltered. The traces of the fracture of the fibula were still plainly apparent.

The preparation of a bony ankylosis, which was formed in a

[1] Loc. cit., p. 44.

case of resection of the knee by Crampton, may be found in the Hunterian Museum at London. I have been unable, however, to find the description of it.[1]

F. *Resection of the lower end of fibula.*—Grist[2] performed this operation on account of caries limited to the external malleolus. The patient was a bricklayer of phthisical constitution, weakened by frequent confinement in prison. The motion of the ankle-joint was unimpeded and the joint unaffected by the carious process. The tendons of the long and short peronæi muscles were cut through in the operation. The deep cavity left by the resection was filled with charpie, and the edges of the wound brought together over this with sticking plaster. Violent inflammatory symptoms appeared in the neighbourhood of the wound, but yielded to topical antiphlogistic measures. The wound healed by granulation, and was cicatrized in from forty to fifty days. The patient was discharged on the ninety-sixth day and immediately went to his work. The foot was capable of adduction as in the natural condition; but the power of abduction, as well as the rotatory movements of the foot, was destroyed. Extension and flexion were almost as free as in the natural condition; they were effected, however, not in the joint between the tibia and astragalus, which appeared to be ankylosed, but in those between the astragalus and the scaphoid and calcaneum. The patient died of consumption nearly three years after the operation.

The tibia and astragalus were found ankylosed; the capsular ligament between the astragalus and scaphoid had become very loose and extensive, and allowed of very free movements in the corresponding joint. The fibula was closely approximated to the tibia, and was firmly and intimately united with it. No regeneration of the bone had taken place, but the periosteum was continued directly into a ligamentous substance, which formed a sort of blind pouch around the cut end of the fibula, and passed over to the bones of the tarsus. By means of this newly formed ligamentous tissue, the danger of dislocation, which occurred whenever the sole was not planted quite level on the ground, was obviated; it also opposed extreme adduction of the foot, and was sufficient, by its structure,

[1] See Appendix.

[2] Resectio fibulæ in articulatione tibio-tarsea. 'Baiersch. Corresp.,' Blatt 1843, August, No. 33.

strength, and extent, as well as by the nature of its attachment, to protect the joint and to replace the lost malleolus. Nothing is said as to the state of the tendons of the peronæi muscles, which had been divided in the operation.

G. *Resection of the inner half of the os calcis.*—The power of regeneration of the short bones is usually placed far beneath that of the tubular bones. With respect to regeneration after resection of the extremities of the bones, the difference cannot *à priori* be assumed to be so very considerable. The articular ends of tubular bones are hardly distinguishable in anatomical structure from the short bones; even the periosteum, which covers the short bones, is wanting in a portion of the others, and the difference can *à priori* be founded only on this consideration—whether in resection of the long or tubular bones the shaft is more or less involved in the operative proceeding. That this *à priori* conclusion is correct is shown also by experience. The only account of an anatomical investigation after the resection of a short bone which I have been able to find, gives a result not essentially different from that which we have seen after resection, for example, of the lower end of the ulna or the fibula. Fergusson,[1] in the case I allude to, amputated a foot at the tibio-tarsal joint, in which he had seven years before extirpated almost all the inner half of the calcaneum on account of caries. He found the bone partly regenerated, and the place of the lost substance partly occupied by a fibro-cartilaginous material. The utility of the foot had been perfect.

## II. *Resection in the substance of a bone.*

Anatomical examinations on the human subject, in cases where the patients have survived for a long time after resection from the substance of bones, are very scanty. They are confined exclusively to resections of the ribs and to trephining. If we call to our assistance the examinations of patients during life, what was said in the Introduction applies to them. They show us, in cases of the removal of pieces embracing the entire thickness of the shaft of a bone, its replacement either by a new, solid, bony union, or by a non-osseous flexible uniting medium, with more or less shortening of the limb.

[1] 'Medical Times,' June 14, 1851.

The cases in which resections have been performed in the substance of bones for the extraction of sequestra in central necrosis, or for the removal of bones affected with peripheral or total necrosis, cannot be made use of unconditionally here, in endeavouring to illustrate the healing process after resection. These operations for necrosis have also not been usually reckoned as resections. The healing process in these cases does not take its origin from the operation only, but the beginning of the process of regeneration, by which the dead bone is to be replaced, is to be dated rather from the commencement of the necrosis; and its conclusion is accelerated on the removal of the necrosed bone, whether that removal has been accomplished by the powers of nature or by operative means. The regenerative process which was previously in full march, may, however, possibly receive a fresh impetus from the operation and the inflammation consequent upon it. It is therefore no matter of surprise, that most of the resections performed for necrosis have obtained the most favorable result, viz., that of the regeneration of the resected bones; and that after these operations bony restoration occurs in those bones in which the loss of substance after resections for other diseases is very rarely indeed replaced by bone. This is the case especially with the lower jaw. After resection of this bone for comminuted fracture, for new formations, and so forth, the piece removed is in most cases replaced either not at all, or by a narrow and strong, but flexible cord; while Lesser[1] has put together about thirty cases; and more recently Thormann,[2] Virchow,[3] and Geist,[4] have communicated others of a similar nature, in which, after partial or entire removal of the lower jaw, when necrosed, bony reproduction has taken place; and Shulze[5] has even observed the formation of teeth in the regenerated jaw. Perhaps this difference may be explained also by the circumstance that in resection of the lower jaw for other causes than necrosis, the periosteum is not

[1] Fall einer Zerstörung und Absonderung des Grössten Theils des Mandibula nebst Regeneration des Knochens, 'Graefe u. Walther Journ.,' Bd. xxii, p. 354.

[2] 'Graefe u. Walther Journ.,' Bd. xxx, Hft. 2.

[3] Regeneration des Unterkiefers nach der Phosphor. Nekrose, 'Verhandlungen der phys. med. Gesellsch. z. Wurzburg,' No. 1, 1852.

[4] 'Die Regeneration des Unterkiefers nach totalen Nekrose durch Phosphordämpfe,' Erlangen, 1852.

[5] 'Walther. u. Ammon Journ.,' N. F., Bd. ii, St. 4.

preserved; while in resection on account of necrosis, this membrane is usually so thickened and separated from the bone, and so closely united to the other soft parts, that it is almost more easy to leave it behind than to take it away. This consideration must be permitted to have its due weight, inasmuch as the periosteum is allowed to be the principal, though not the sole agent, in the reproduction of bone. Ried on this account advises that, in resection of the lower jaw, the posterior lamella of the periosteum at least should be preserved. I cannot, however, coincide in his opinion, that this preservation of the periosteum is easiest in resection on account of mechanical injury, and that, in caries and inflammation of bone, the periosteum is usually found firmly united to the bone. All the particulars which establish a difference between the healing process after resection in necrosis and the healing process after resection on account of other affections, result from the researches of Troja,[1] and the series of experimenters who followed him. Lately, Geist[2] has called attention to the "regenerating membrane" which he asserts to be formed in the process of necrosis, and to possess the exclusive property of the new formation of bone. I have not been able to find this in resections upon animals, and must, therefore, class it among the differences above alluded to between them and men.

The differences between the healing process after the operation for necrosis which has been treated by resection or extirpation of the bone, and the healing process after resections performed for other diseases, appeared to me to be most conveniently touched upon in this place, where resection of the substance of a bone is spoken of; since necrosis most usually attacks the shaft, and seldom the extremities of the bones. What has been said about necrosis is generally true of all the cases in which the separation of the diseased bone from the soft parts which surround it is produced by the natural forces, and the operative proceeding effects only the final removal of the bone. The process of regeneration is a far more productive one than in other cases; and, especially as relates to the bone, the restoration of the part removed occurs more rapidly and more certainly than in the cases where the separation of

[1] 'Neue Beobachtungen und Versuche über die Knocken, übers: von Schoenberg,' Erlangen, 1828.

[2] Loc. cit.

the part removed is effected by the operation only. The anatomical details which have been described after resection in the substance of a bone support this assertion.

Karajew[1] and Textor[2] examined the bodies of two men on whom they had resected a carious piece of a rib, respectively eight and four and a half months previously. The length of the piece was twelve and a half lines in the first case, and two inches four lines in the second. In both cases the periosteum was left in the operation; in both the piece had not been reproduced in its whole cubical extent, but the two cut surfaces were united together by irregular deposits of bony material. Karajew remarks expressly, that the deposit, especially at the posterior surface, where the periosteum had been preserved, was found to be about a line in thickness; while on the anterior surface, and between the two ends of the rib, no bony matter was to be seen. In Textor's case, to judge from the drawing, the state of the parts seems to have been somewhat similar. The same may be said as to the various smaller and larger foramina through which the nutritious vessels passed into the interior of the new masses of bone. Only Karajew mentions them expressly; but Textor figures them, and at the same time the envelope of very much thickened periosteum by which the new mass of bone was covered.

An examination by Ried[3] had an opposite result to this. He resected the sixth rib at its junction with its cartilage. Violent compression of the thorax had caused a fracture of the rib at this spot, followed by the formation of abscess; and at the opening of the abscess the bony end of the rib was found carious, and the cartilaginous fragment exposed. At the operation about half an inch of each was removed. Three years afterwards, on post-mortem examination, a narrow fistula was still found running in the direction of the costal cartilage, which had by degrees entirely exfoliated. The bone was covered by a cicatrix, and there was no trace of reproduction either of it or of the cartilage.

Equally scanty with the cases referred to above, are the notices of dissection of persons who have survived trephining for a long period. In examinations performed a short time after the operation, the

[1] 'Fricke u. Oppenheim Zeitschrift für die gesammte Medicin,' Band xvi, Heft 2.

[2] 'Ueber die Wiedererzeugung der Knochen,' &c., p. 15.

[3] 'Die Resectionen der Knochen,' Nürnberg, 1847, p. 250.

pericranium surrounding or covering the loss of substance of the bone has been found swollen and reddened, and a similar alteration has been discovered in the dura mater lying at the bottom of the opening, with occasionally the deposition of a red brawny material on the latter. Later on, the whole opening has been found filled with granulations, proceeding from the skin, dura mater, and sections of the bone; and then a bevelling off of the sharp margins of bone through partial necrosis and exfoliation has usually been observed. The closure of the opening is finally effected for the greater part by a fibroid mass, intimately united to the dura mater and the pericranium, and in smaller proportion by bony formations proceeding from the edges of the outer and inner tables of the skull. Rokitansky has observed such formations proceeding also from the surface and edges of the wound in the soft parts, and divides them, as in the union of fractures by the first intention, into primary and secondary callus-formations. He leaves unexplained the causes of the scanty production of callus in the cranial bones, a circumstance which is found also in the perforations caused by necrosis. The case is different with resections in which a piece is removed not including the whole thickness of the cranial bones. The loss of substance in these cases, as occurs in similar circumstances after an injury, is usually replaced completely by a newly formed mass of bone. Dubreuil[1] does not believe that a defective power of reproduction peculiar to the bones of the skull is a sufficient cause, but refers the phenomenon to the injury or destruction of the pericranium and dura mater which generally takes place at the same time. He examined the body of a sailor, who had died of apoplexy eight years after trephining. A fibrous material only closed the opening of the trephine, while on the contrary a bony cicatrix was found on the forehead in the situation of a loss of substance of the outer table. New bony substance covered by pericranium was found in this part. This substance was separated from the vitreous table by a small interval, which became perceptible after maceration, and was filled with irregular bony granulations (?)[2]

An account of a similar dissection has been communicated by Guensburg.[3] It is distinguished for accuracy, and therefore worthy of mention. The skull was that of a female who had survived the

[1] 'Presse Médicale,' 1837; 'Froriep Notizen,' 1837, p. 236.

[2] The note of interrogation is the author's.—TRANS.

[3] 'Deutsche Klinik,' 1850, No. 8.

operation of trephining for seventy-nine years. The loss of substance, which was situated at the junction of the coronal and left squamous sutures, was covered by a membrane which had a tendinous lustre, and was convex towards the cavity of the skull. This membrane, however, was deficient in several places, and in these was filled up by a deposit on the dura mater to the height of a line. The upper layer of this deposit consisted of irregularly polygonal flakes, or of a mass resembling horny epithelium, while deeper down a firm fibrous structure was found, which consisted of thick bundles of fibres crossing each other in various directions, and was inserted into the thinned edges of the bone. From the sharply-defined and wall-like edge of the deposit fine bundles of fibres resembling needles ran out in a radiating manner into the tissue of the dura mater, and corresponded to the grooves between delicate processes of bone, which were deposited on the vitreous tables starting from an inch beyond the opening, and proceeding up to it and in part across its edge. The material first mentioned as having a tendinous lustre consisted of layers of horny epithelium closely packed one over the other.

Against these facts is to be placed the restoration of the bones of the head after complete loss of both tables, which has been observed in a whole series of cases collected by Klencke,[1] to which he has also added a fresh instance. In all these cases, which relate to loss of substance, partly by necrosis, partly by trephining, the dura mater was preserved. On this account, and from his experiments on animals, Klencke considers this membrane the true matrix for the regeneration of the bones of the skull.

### III. *Extirpation of bones.*

What has been said about resection from the substance of bones is true also in general of resection of entire bones. It seems in this case also to be a question of saving the periosteum as much as possible, since where this has been found possible the bone has been regenerated more or less perfectly without any considerable shortening of the limb; while, where the periosteum has not been preserved, a fibrous cord firmly united with the cicatrix has usually been found in the place of the extirpated bone. Ried seems to con-

[1] 'Physiologie der Entzündung und Regeneration in organischen Gewben,' Leipzig, 1842, p. 197.

sider even this appearance as, at least frequently, deceptive, and puts down this cord for nothing more than a cicatrix of the soft parts around the extirpated bone matted together. My experiments on animals oblige me to assent to this view. When he speaks, further on, of irregular cartilaginous or osseous points, which are occasionally deposited to replace extirpated bones, I do not understand whether he places the seat of the deposit in this cicatrix, or in a veritable fibroid cord which he may have observed in other cases. I am almost led to believe the latter, since he mentions, as a known fact, the deposit of such points in the ligamentous uniting medium which, under certain circumstances, is found between the cut ends of bone after resections from their substance.

Very few accounts of dissection after extirpation of long bones are on record. Meyer,[1] of Zurich, extirpated the clavicle, on account of caries, on a man thirty-one years of age. The wound was cicatrized in seven weeks; the patient soon obtained perfectly good use of the arm. In the situation of the extirpated bone a mass of new bone, of the form of a normal clavicle, was plainly to be felt. The patient died about five years after the operation. At the dissection there was found, between the facet for the clavicle on the sternum and the acromion, a fibrous, almost cartilaginous (?)[2] band, on which the lower edge of the newly formed bone was supported, and with which it seemed to be continuous in some places. The length of this band measured four and a half inches, that of the newly formed bone three inches ten lines. The latter was very thin, flattened towards the sternum, but more rounded towards the acromion; the end towards the manubrium sterni, which was somewhat broader and thicker, articulated with it by a well-marked articular surface. About an inch from the acromion the new bone ended in a thick head, which was united to the acromion by a broad thick band. In the latter a few well-marked granules of bone were deposited. The upper edge of the new clavicle formed towards its sternal end a marked angle pointing upwards, and towards the acromial end an angle pointing downwards; its lower edge did not correspond, in consequence of a few deposits of bone passing further down into the fibrous band.

[1] 'Graefe u. Walther Journ.,' Bd. xix, p. 71.

[2] The query is the author's.—Trans.

D'Angerville[1] relates a similar case, in which Moreau removed the whole clavicle in a young man on account of necrosis. The wound healed quickly, and the arm regained its former usefulness. On dissection a few months later a new clavicle of the normal length and solidity was found in the situation of the extirpated bone, articulated in the normal manner to the acromion and sternum.

A case operated on by Kunst[2] is to be added to these, which indeed has not as yet been the subject of dissection, but where accurate examination during life enables us to arrive at a conclusion as to the changes which occur after extirpation of the clavicle. Here no bony reproduction of the clavicle took place, yet the arm was perfectly serviceable for the hardest work, and the shoulder firm enough to carry burdens. The left clavicle had been removed eleven years before the examination, on account of caries. On examination the articular surface on the manubrium, about as large as a walnut, could still be felt empty; from this point up to a tubercle on the first rib (apparently the elevation for the insertion of the scalenus anticus muscle) the skin was firmly united to the rib. A cord-like material stretched outwards from this latter point to the acromion, in firm connexion with the cicatrix of the skin. This cord could be moved a little upwards and downwards, and separated the supra- and infra-clavicular depressions from each other. The clavicular portion of the sterno-mastoid was inserted by a cord-like process into the before-mentioned elevation on the first rib, and was tensely stretched from this point to the fourth cervical vertebra, but without affecting the position or mobility of the head. The left shoulder had sunk an inch and three quarters below the right; the point of the scapula was directed rather obliquely backwards, and was higher than on the sound side, and at a greater distance from the ribs. If the patient placed the left arm upon the right side of the neck, the head of the humerus approached the cervical vertebræ within two inches and a quarter, while the head of the right humerus in a similar movement remained at a distance of four inches from them.

Racord[3] has observed a case of regeneration of the whole of the humerus, together with its upper articular end, in a case which, although it does not belong to the class which we are here con-

1 'Mém. de l'Académie Roy. de Méd.,' tom. xiv, p. 56.

2 'Deutsche Klinik,' 1850, No. 24.

3 'Gaz. Méd. de Paris,' 1842, p. 639.

sidering, yet deserves to be noticed, because it affords a proof how abundant the reproduction of a bone is, if its separation have been effected principally by the natural forces, and if the periosteum has been left behind. After an amputation of the forearm below the elbow, the stump was attacked by gangrene, which stopped at the upper arm. The separation of the slough was fully accomplished by suppuration in a month; after this the humerus lay perfectly exposed in the lower part. Six months afterwards the humerus, which had become spontaneously dislocated, was extracted by a long incision. The periosteum was firmly united to the neighbouring muscles, could be clearly recognised, and was left behind. Two months later the stump, thus deprived of its bone, had again acquired considerable solidity; at the end of another month it became necessary to amputate it at the shoulder-joint. In the centre of the amputated stump a new bone, twenty-two centimetres (eight inches and a half) long, and three to four centimetres in breadth (about one inch and a quarter), was found. At the upper end of this there was an articular surface corresponding perfectly to the glenoid cavity, and closely united to that cavity by a ligament attached all round it. Another process on the inner edge of the new bone was connected firmly to the third rib by a ligamentous structure.

Anatomical examinations after the extirpation of short bones are almost entirely wanting. The dissection which Textor, jun.,[1] performed on a forearm eighty-four days after extirpation of all the bones of the carpus displayed a large cavity with numerous pouches in the situation of the wrist-joint, the walls of which were covered with a rich crop of granulations, for the most part very fine, red, and healthy; and these formed in many places projections and folds, or imperfect partitions. The walls of this cavity were formed partly by the periosteum of the metacarpal bones, partly by the remains of the ligaments which united the bones of the metacarpus to those of the carpus, as well as by the tissue of the cicatrix of the healed wounds of the operations, and by the resected ends of the second and third metacarpal bones. Both bones of the forearm were deprived of their cartilaginous covering, and carious. The palm was smooth and flattened. The loss of the carpal bones was not very perceptible externally. All the tendons which pass across the wrist-joint were uninjured. That of the flexor profundus muscle was united over

[1] 'Prager Vierteljahrschrift,' 1849, Bd. iv.

the metacarpus with the periosteum of the metacarpal bones, and with the cicatrix of the wound of the operation. The ulnar nerve ended in a small swelling in the same cicatricial tissue, as did the median nerve and its branches.

Examinations during life of persons who have recovered after extirpations of short bones, show that the defect has been remedied as far as possible by approximation of the bones which lie nearest together. The interval which is left seems to be filled up with a ligamentous material, in which, according to Ried, masses of cartilage or bone are sometimes deposited.

Regeneration of flat bones, as for example of the scapula, has as yet been observed only after necrosis. Cases of it are quoted by Chopart,[1] Klencke,[2] Rudolphi,[3] and Kortum,[4] by the two latter in the horse. Resection was not practised in these cases, therefore the cases are not applicable here.

After extirpation of the upper jaw, there is formed between the cut ends of the zygoma and those of the nasal and alveolar processes a fibrous membrane, by which principally the falling-in of the cheek is prevented. A membrane of precisely similar character is formed in the situation of the lower wall of the orbit. The large cavity which is left behind is lined by a red covering resembling mucous membrane, and is narrowed considerably by the soft palate being drawn forwards and upwards. Besides this, Ried considers that the approximation of the bones around the cavity is a probable cause of its diminution. No trace is ever observed of regeneration of the bone.

[1] 'De necrosi ossium theses præs. Chopart,' Paris, 1776, p. 7.

[2] Loc. cit.

[3] 'Bemerkungen ueber Naturgeschichte, Medicin und Arzneikunde,' Berlin, 1805, ii, p. 56; 'Edinb. Med. and Surg. Journal,' April, 1823, p. 217, figs. 1, 2, 3.

[4] 'Experimenta et observationes circa regenerationem ossium. Diss.,' Berol., 1824.

## CHAPTER II.

### EXPERIMENTS AND ANATOMICAL INVESTIGATIONS ON ANIMALS.

THE second method of investigating anatomically the healing process after resection of bone, which proceeds by experiments on animals, has led to much richer results, and is also more easily attainable, than dissections of the human body. We should have arrived long ago by this method at a view of the healing process in its various stages, had it not been that all experimenters have confined themselves to endeavouring to discover only the *final* result of the process. The animal was operated on, and the immediate and subsequent results of the operation left unnoticed; and only after a considerable time was an examination undertaken into the changes which had gone forward in the parts concerned in the operation, at a time when the process had run its full course, the parts had been restored more or less completely to their functions, and no further changes were to be anticipated in them. In these cases also the description of the appearances on dissection is wanting in that trustworthiness and certainty which can only be obtained by the microscope in the determination of the nature of the tissue which has been substituted for the parts removed, or has united those divided, in the operation. The first observer who undertook the labour of following step by step the healing process after resections of bone was Steinlin.[1] I have had the opportunity, while endeavouring to follow the same method, of subjecting the results of his observation to a careful and well-founded criticism. I will therefore postpone entering upon them, until I come to that part of my subject where I set out in order the particulars which my own observations have taught me. I will merely say here, that I can confirm Steinlin's results in their principal points. What former inquirers

[1] 'Ueber den Heilungsprozess nach Resection der Knochen,' Dis. Zürich, 1849.

have taught us with respect to the final results of resections on animals, I believe I have succeeded in embracing fully in the following chapter.

### I. *Resections of the extremities of bones.*

Vermandois[1] was the first who excised the upper part of the femur just below the trochanter minor on a dog. His object was to recommend the excision of the head of the femur in preference to amputation at the hip-joint. In a few days the end of the resected bone rose up to the level of the acetabulum, and two months afterwards the wound had healed by suppuration. The animal carried the shortened limb pendulous at first; towards the end of the second month it supported itself a little on the back of that foot. At the dissection, which was performed about the above time, the femur was found to be thicker than on the sound side, the medullary cavity very large and full of marrow, the compact substance thinner than in the healthy femur. The upper end was studded with irregular prominences of compact bony substance, which were directed more especially outwards, towards the cicatrix in the soft parts, and were united to the acetabulum by a ligamentous material. The acetabulum was diminished in circumference, and was filled with a soft, very red substance, which Vermandois took for the synovial gland enlarged and injected.

To this experiment are to be added the observations of Chaussier,[2] Korler,[3] Wachter,[4] and in more recent times B. Heine.[5] They all of them operated on dogs. The results are tolerably consistent with the preceding. The wound was in most cases united by the interrupted suture, and healed by first intention. Chaussier met with this so often, that in order to investigate the influence of suppuration on the healing process he was obliged to use irritants of various kinds. This was followed by numerous collections of pus, which were allowed to open spontaneously. The final result was not essentially different from that of those cases in which

[1] 'Journal de Médecine,' 1786, tom. lxvi.

[2] 'Magasin encycloped.' An. V., tom. vi, No. 24; 'Hufeland, Harless u. Schreger Journal der ausländischen Med. Litt.,' Bd. i, 1802.

[3] 'Experimenta circa regenerationem ossium,' Goett., 1786.

[4] 'Dissert. de articulis extirpandis,' &c., Groningen, 1810.

[5] 'Feigel Chirurg. Atlas,' Würzbg., 1850.

the wound was united immediately. In all cases the animals carried the shortened limb pendulous at the commencement; from the fourth to the sixth week they began to support themselves upon it, and about the tenth week almost all of them began to use the limb quite well in running. In dogs which were killed from two months to four years after the operation, the resected end of the femur was found rounded off or swelled out into a club-like form. The mass of new bone was usually uneven and tubercular, more seldom smooth; its form was quite unlike that of the resected head and trochanter. In a few cases the exposed articular surface is said to have been covered with a cartilaginous (?)[1] substance. Usually the acetabulum was deprived of its cartilage and filled up with firm fibrous tissue or a deposit of recent bone. New formation of bone was found also on the bones in the neighbourhood of the acetabulum. The upper end of the femur was situated usually close to the pelvis, either opposite to the situation of the acetabulum or above or behind it. Its union with the pelvis was effected by ligamentous tissue, which was sometimes attached around the end of the femur in the form of a closed capsule normal in appearance, and only much thickened, extending frequently to some distance from the situation of the acetabulum towards the ischium and pubes; at others (and especially if the suppuration had been great) ran across between the free end of the femur and the pelvis, in the form of a cord made up of numerous bundles. In a case reported by Koeler a quantity of fat was scattered between the separate bundles of this cord. Within this articular capsule a serous fluid was occasionally found. If the contact between the pelvis and the upper end of the femur had been very close, a shallow depression was formed at the adjacent part of the pelvis to receive the clubbed end of the femur. In a case of Wachter's the femur was supported against the outer part of the foramen ovale, which was filled up with a very solid *ligamentous* material of almost bony (?)[1] consistence. Heine alone gives any observation on the condition of the muscles and their insertion; the latter had become almost the same as before the operation. In most cases the limb operated on was somewhat shortened.

The resections of the head of the humerus, performed on the dog by Chaussier and Wachter, had the same results.

The resections of the lower end of the femur, of the sternum, the

[1] The query is the Author's.—TRANS.

humerus, and the lower end of the tibia, as well as the excisions of the knee- and elbow-joints, yielded a very unsatisfactory result in the experiments undertaken by Chaussier. Both the soft parts which had been divided and the bones did indeed cicatrize favorably, but instead of forming a new joint the ends of the bones rode on each other, and were united to each other by ligamentous material, so that the part of the limb below the joint was pendulous, and quite useless for motion.

The results of other observers differ from these. After resection of the lower end of the radius, Heine has observed the medullary cavity at the level of the section become closed by bony substance, and a mass of new bone given off from it to support the tendons and to form a joint with the scaphoid bone. After resection of the lower end of the ulna, the periosteum being preserved as far as possible, he found after the interval of a year perfect bony restoration of the resected part. Similarly, Wachter observed, after resection of the lower end of the radius and ulna, that when the wound had healed, at first a firm union was formed with the carpal bones. But the dog would not bear the splint, on which the fore-arm had been secured, and ruptured this firm union again. After the paw had been hanging loosely from the forearm for some time, the articulation became gradually firmer, and at length the original usefulness of the extremity was completely restored. In the dissection, which was performed three months after the operation, a new joint was found surrounded by thick capsule; the end of the radius had been reinforced by new bony deposit, so as to be nearly as strong as natural; the tendons of the muscles were adherent to the radius and ulna.

Heine has observed after extirpation of entire joints in dogs the reproduction of a kind of new joint; but the utility of the extremity operated upon, even if greater than Chaussier found it was, nevertheless always limited. Two complete resections of the shoulder-joint, in which the parts were dissected nearly a year afterwards, showed, one the resected ends rounded off and united by a strong fibrous substance, the other the end of the humerus rounded off and received into a corresponding depression on the scapula, the two being surrounded by a membrane resembling a capsule, with a meniscus between the ends of the bones, which were covered by a reddish enveloping substance resembling cartilage.

The resection of the upper end of the femur together with the acetabulum has been found to lead to similar results. In one case the pyriformis and gluteal muscles were found inserted into the upper end of the femur, which was covered by a mass of new bone. A few bony deposits had formed around the acetabulum, and the sections of the pelvic bones, which were rounded off by means of these deposits, were found united by firm fibrous tissue; the femur was supported against these bones, and was moveable. A strong capsule, containing a serous fluid, surrounded the upper end of the femur and neighbourhood of the acetabulum; it was in part formed and partly strengthened by the agglutinated muscles, more especially the tendinous extremities of the psoas and iliacus internus.

After the extirpation of the elbow the animal has been observed to be unable to step with the extremity, eighty-four days after the operation. On the resected extremities new masses of bone were found laid down in a wreath of irregular nodules, one of which on the humerus corresponding to the external condyle gave insertion to the extensor muscles, another on the ulna to the flexors, and a protuberance on the radius to the muscles of the paw. The course of the biceps muscle was essentially changed. It was adherent to the pronator teres muscle, which was shortened, and to the flexors of the paw, and inserted on the posterior aspect of the radius. The union of the ends of the bones was effected partly by the remains of the capsule, partly by the muscles surrounding the situation of the joint, united together.

The resection of the ascending ramus of the lower jaw with its articular process was performed once by Heine. It was followed merely by a deposit of new bone covering the surface of the section.

## II. *Resections from the substance of bones.*

The experiments on the healing powers after resection from the substance of a bone, which have been performed on animals, as well as those (to be presently detailed) on recovery after extirpation of entire bones, have been directed principally to elucidate the process of regeneration only in the bones themselves. The most important point in this has been to clear up the question as to the organ, or the system of organs, which furnish the material necessary for reproduction of bone. We shall see how far the investigations have accomplished this aim, how far the question may be considered as settled by experiments on the healing process after resection.

A. *Resections in long bones.*—Klencke[1] and Heine excised portions out of the shaft of one of the tubular bones without carrying the section completely through its whole thickness, the former on birds, the latter on dogs, and found in all cases complete restoration of the loss of substance by new bony material. Klencke believes that the soft parts surrounding the bone, as well as the periosteum, are capable, either of them by itself, of furnishing the exudation necessary for this restoration. The grounds for this assertion are not, however, satisfactory. Thus, he concludes that the exudation is sometimes furnished by the soft parts from this fact: that he has seen, twelve days after the operation, a gelatinous extravasation connected with the soft parts, which was extended across the loss of substance in the manner of a bridge, and showed a fibrous transformation at its edges. That the periosteum alone may furnish the exudation, he concludes from the fact that in another case the periosteum was very vascular and covered the material of the callus, while the soft parts were hardly at all adherent to the bone.

Klencke has always found the medullary cavity corresponding to the excised portion of bone completely closed by new bony material, and the hole occasioned by the operation materially altered in its form by the absorption of its bony edges. Heine observed only a hardly perceptible narrowing of the medullary cavity corresponding to the situation of the resection. After an operation on the thigh-bone, he found necrosis of the cut edges of the bone, to which a sinus led through the callus-material which, although the interval was only twelve days, had been already deposited around the whole of the femur.

After resection of the whole thickness of portions of long bones Heine has observed, as early as about two months after the operation, complete restoration by bony material in all the cases in which he had been careful to save the periosteum, and in the opposite case rounding off of the resected extremities by new bony material, and in operations on limbs having two bones, union of them to the neighbouring bone on which callus-material was also deposited. This was either without any connecting tissue between

[1] Loc. cit., p. 163.

the ends, or else a fibrous material with nodules of bone deposited in it, uniting the cut ends, which were rounded off, and, in operations on limbs with only one bone, forming a false joint. The relation of quantity between the fibrous and the bony material deposited around the ends of the bone varied, so that occasionally a considerable piece of new bony matter passed out from the surface of one of the sections, and there was only a small interval filled with fibrous substance; sometimes there was a considerable piece of new bone in the centre, united by fibrous material with the surface of each section; sometimes the fibrous tissue was by far the most plentiful. In almost all cases a considerable shortening and curvature of the limb injured by the resection had occurred, and this was especially the case in limbs with one bone, equally whether the union of the ends of the bone had been effected by new bony matter or by fibrous tissue. In limbs with two bones, a more or less considerable curvature of the uninjured bone had been produced. In most of the cases in which Heine[1] endeavoured to bring the parts together again over pieces of bone which he had cut out and replaced, as, for example, in the ribs, he found a far greater reproductive power in all the parts interested in the operation, and the portions of new bone produced under such circumstances showed in a far shorter time a higher grade of organization than in those cases where the hole in the bone was not filled up again with the excised piece. In these cases the vessels surrounding the situation of the resection were considerably enlarged. Heine believes correctly that the replaced portion of bone acts as a foreign body, and compares the phenomenon in the main to the treatment of false joints by setons. The replaced piece of bone is gradually thrust aside by new products deposited in its place, and thrown out; in other cases it is encysted in the soft parts, or it may be absorbed. In a few cases this absorption could not be clearly made out, and in these it was doubtful whether the replaced piece of bone had not really become united.

The observations and experiments of Flourens[2] and Syme,[3] to which latter an experiment of Heine is to be added, are decisive, to a certain extent, as to the periosteum being the principal agent in

1 'Graefe u. Walther Journ.,' Bd. xxiv, p. 527.

2 'Théorie experimentale de la formation des Os,' Paris, 1847.

3 "On the Powers of the Periosteum to form New Bone," in 'Contributions to the Pathology and Practice of Surgery,' Edinb., 1848.

the regeneration of the bones. Flourens observed, after resections from the substance of the ribs, where the periosteum had been spared, the first trace of formation of new bone occurring on the inner surface of that membrane, and on that precise part of it which lay in the middle between the two cut ends of the bone, whence it gradually extended towards those extremities. This experiment, if it be not allowed to be decisive by itself, gains in value from the fact that it agrees with the cases described by Heine, and elucidates them; those, I mean, in which a considerable piece of new bone covered with periosteum lay between the cut ends of the old bones, and was united with the cut surfaces by fibrous substance. Still more important is the following well-known experiment of Flourens, to which I will here merely allude. He bored a hole down to the medullary cavity of a bone, and placed a silver tube within it. The periosteum and medullary membrane became tumefied, and projected into the tube, and then a piece of new bone was formed within the latter.

Syme excised on two occasions a portion of each radius of a dog an inch and three quarters in length. In one leg he took away the periosteum with the bone, in the other he took the greatest care to preserve it. Six weeks later, in the leg in which the periosteum had been removed with the bone, the ends of the bone were conical and pointed, and united by a fibrous cord; on the other leg, where the periosteum had been preserved, the whole loss of substance had been repaired by a copious and even superabundant deposition of bone.

Syme has discovered a further proof of the conclusion which follows from this description in two experiments, which do not, indeed, belong to the class of resections, but which must be mentioned here because they combine with an experiment of Heine, to afford an answer to the question as to the activity of the periosteum in the regeneration of bones. On a dog the periosteum was carefully separated from the radius, and a metal plate thrust in between the membrane and the bone; while, in the other experiment, the separated periosteum was removed, and the exposed bone merely covered with a plate of metal. Six weeks afterwards there was found in the first case, above the metal, a plate of new bone, which had no connexion with the old bone; in the second case only a thick, tough capsule, without a trace of bony substance. Heine observed the same things in the femur of a dog as Syme did in the first case. The piece of bone was denuded of periosteum, and a longitudinal incision was made into it down to the medullary cavity; a piece of linen was then laid between the periosteum and the bone. Twelve days afterwards the whole shaft of the femur had become necrosed, and was surrounded by a capsule of new bony material, which above and below the piece of linen was in connexion with the bone, but in the part occupied by the foreign body was separated by the latter from the surface of the bone, and was covered in every part with highly injected periosteum. On the portion of bone enveloped in the linen no trace of new formation of bone could be detected. If we bring these facts into connexion with the researches of other experimenters on the activity of the periosteum in the formation of bone after fractures and in necrosis, we cannot hesitate to decide in favour of the view that the periosteum plays the *principal* part in the process of the regeneration of bone. We shall see further on whether this principal part is to be held as an exclusive one, or, if not, what limits are to be assigned to it. That it cannot be exclusive, is proved by a single experiment reported by Michaelis Medici.[1] After the resection of a piece, an inch in length, out of the first false rib of a sheep, in which the periosteum and a portion of the intercostal muscles had been removed with the bone, the loss of substance was found fully replaced about four years afterwards. The new piece of bone was thinner, but broader, than in the healthy condition, and was pierced by small openings in three places. Its outer surface was rough, the inner quite smooth. The structure of the new bone was indistinguishable on a section from that of the old. The new portion of bone had been enclosed again in a fibrous membrane. It is a singular fact, that the new piece was two and a half inches in length, while the piece which had been originally removed was only one inch long. The circumstance that the sheep was only fourteen months old at the time of the operation, and afterwards grew very considerably, must be accepted as an explanation of this fact. The consequence must have been either an equal growth of the reproduced portion and the orginal rib, during the growth of the animal, or, perhaps, an excessive growth of the reproduced portion. I have observed in the human subject a case which may be placed by the side of the above. Professor Langenbeck excised, on a boy, a piece out of the substance of the lower part of the shaft of the humerus. The opera-

[1] 'Novi Comment. Bononienses,' tom. ii.

tion resulted in complete regeneration of the bone, with perfect use of the arm, which was shortened three quarters of an inch. About a year and a half after the operation the boy was attacked by a violent gastric fever. He grew during and after this time very quickly, and when a short time afterwards I repeated my measurements, which had been taken on many previous occasions, I could no longer discover any trace of shortening of the arm.

B. *Resection from the substance of flat bones.*—The healing process after resections from the substance of the cranial bones is what has most interested the various observers on this head. Their views, however, especially on the subject of repair of loss of substance by bony material, and the conditions on which this is dependent, are at variance with each other. Dubreuil[1] considers that the regeneration of the bone is dependent principally on the integrity of the pericranium and dura mater after the operation. When this integrity was maintained, he found the round opening made in trephining, when not very large, filled up by a bony pad, which was occasionally united by fibrous tissue to the edges of the old bone. Without the preservation of the pericranium or the dura mater the hole in the bone was closed only by a firm cicatricial tissue. He attributes also to the vessels of the bone a share in its reproduction, but without showing us on what he founds that opinion. Heine's views agree in the main with these, only he attributes a greater influence in the regeneration of the bone to the diploic substance of the cranial bones, after the pericranium and dura mater, than Dubreuil does. According to him, when the pericranium and dura mater had been preserved, but the diploë was very scanty, the closure of the hole in the bones by new bony material was only imperfect; when one only of these two membranes was wanting, while the diploic tissue was abundant, the regeneration of the bone was completely effected; but when both the pericranium and dura mater were wanting, even when the layer of diploë was a thick one, the greater part of the loss of substance was closed by fibrous tissue, in which numerous granules of bone were deposited, and new bony material was found deposited only around the edges of the bone, in the form of needles, or as a thin rim around the opening.

The dura mater appears, according to experiments on animals, to

[1] 'Presse Médicale,' 1837, No. 57.

be of more importance than the pericranium in the reproduction of bone. This might even have been assumed *à priori* from its greater vascularity; still the observations on the human subject, which have been mentioned above, do not favour this idea and do not agree with the results of experiments on animals. Thus, in animals where only a piece of the external table and diploë has been removed, the pericranium being preserved, the restoration of bone in places where the diploë was scanty has been observed to be more sparing than when the same loss of substance has been extended, under the same circumstances, through the whole thickness of the cranial bones. If, in the same trephine-hole, the internal table has been removed in one part and left in another, in the part where the latter has been the case the deposit of new bony material is less considerable than in the part of the wound where the vitreous table has been also removed. Simple cuts, too, penetrating through the whole thickness of the skull, have been observed to heal by bony union, while after cuts involving only the external table and diploë, it has been often found (and especially if the layer of diploë were only thin) that there was nothing except fibrous material between the edges. If the pericranium has been preserved, it unites firmly to the substance which closes the hole in the bone; if it has been removed in the operation, it is completely regenerated. The newly-formed portion is found in the form of a strong membrane continuous with the uninjured pericranium at the edges of the section; it may be separated from the material which fills up the opening in the bone. Deficiencies of the dura mater, on the other hand, are not repaired. The edges of the wound in the dura mater usually unite to the other membranes of the brain, or to the bones. The brain protrudes through the hole in the dura mater into that in the bone, and becomes intimately united to the membrane which closes the latter. When the dura mater is preserved at the operation it usually unites firmly around the opening to the bony edge, and sometimes there is found, in the situation of the loss of substance in the bone, intimate union of the membranes to each other and to the brain. The brain is then much reddened at this part.

Necrosis and exfoliation of the bony edge has not been frequently observed. When it has, it has usually attacked only one, and generally the outer, table of the bone. If the hole has been closed entirely by new bone, the cut edges of the old bone were not to be distinguished from the new; while when the reproduction of bone has been partial only, the edges of the old bone have usually been found rounded off. If one of the cranial sutures has been cut across in the operation, it is not reproduced in the bone which replaces the loss of substance.

It occurs only in the rarest cases that the excised piece of bone unites again when replaced. Merrem[1] and Klencke[2] have seen this. Kleine has never convinced himself of it. In one case it was doubtful whether this union had taken place, or whether, as it usually happens, the piece replaced had become necrosed and exfoliated without being perceived, while the hole in the bone had been filled up by bone newly deposited.

It may be observed further that Heine believes from his experiments that the triangular form of the trephine-hole is more favorable to its complete closure by bony material than the circular shape.

Koeler[3] is the only author who has endeavoured to investigate the healing process after trephining in its separate stages. His observations are indeed very imperfect, but they deserve notice as being the only ones on record. He trephined a dog over the sagittal suture, preserving the pericranium, and observed on the fourth day the dura mater and the edges of the opening in the bones covered with a sticky, gelatinous, reddish material, which gradually increased in quantity and became whiter. In the course of the third week the hole was almost closed by new substance, derived as well from the dura mater as from the edges of the bone. A portion of the outer lamella of the parietal bone exfoliated about this time. About the same time the edges of the wound cicatrized firmly together. The dog was killed at the end of the seventh week. The opening was filled with a material which was cartilaginous in the rest of its extent, and bony on the edges only; this could not be forced out of the opening, but was thicker than the rest of the bone: the pericranium and dura mater were firmly united to it. There was no trace of a suture in it. In the same way, after removal of the anterior wall of the frontal sinus, the edges of the opening were covered in the days immediately following the operation with a glutinous mass, which was shown, by the dryness of the inflamed mucous membrane, not to proceed from that source. It

[1] 'Hildebrand Anatomie von Weber,' I. S., 354.

[2] Loc. cit., p. 199.

[3] Loc. cit.

gradually increased, so that fourteen days after the operation the opening was already sensibly diminished. Its sharp edges also were even at this time rounded off. From the twenty-fourth day the union of the skin with the parts lying below it became so intimate, that soon it no longer allowed the opening to be inspected. The result was a complete closure of the opening, after the eighth week, by a bony material, still soft and resembling cartilage in its centre, which was thicker than the normal skull-wall, and was covered on its outer side by not very thick skin, but had no prolongation of the mucous membrane on its inner surface.

Resections in the substance of any other flat bones except those of the cranium have been performed extremely seldom. Murray[1] excised a triangular piece from the breast-bone of a pigeon, taking away the periosteum. Several weeks afterwards the loss of substance was almost entirely closed by deposit of bone, which was much thicker than the natural sternum, and overlapped the edges of the section in places. He holds the muscles to be the source of the reproduction, and explains from this their intimate union with the new bony material.

After resections from the substance of the horizontal ramus of the pubes and of the symphysis, Heine has observed merely rounding off of the edges of the sections by a deposit of new bone, without any union between them having been effected. After an operation on the tuberosity of the ischium and the ilium, a fibrous union was formed between the cut extremities, with deposition of granules of bone. After the resection of the tuberosity of the ischium, new bony material was deposited also on the os pubis in the neighbourhood; the pelvis was contracted in the oblique diameter.

C. *Resection from the substance of short bones.*—No resections have been performed in animals on the short bones except on the vertebræ. The result of resections from the vertebræ have been hitherto very discouraging.

In twenty-four cats and ten dogs, on whom Heine[2] performed this operation, it had uniformly a fatal result. Two dogs only, not

[1] 'Edinb. Med. and Surg. Journal,' October, 1831; 'Archives génér. de Méd.,' xxvii, 1831.

[2] A. Mayer, "Die Resection der Wirbelknochen bei Knochenbrüchen der Wirbelsaüle," 'Walther u. Ammon Journal,' 38 Bd.; N.F., 8 Bd., 1848.

included in this list, recovered. In one of them, after resection of the arch of the vertebra, when the dura mater was cut through, a portion of the spinal cord protruded. This was cut away, and yet the animal is reported to have recovered without any paralysis remaining. The hiatus left by the removal of the arch of the vertebra was closed by a firm cicatricial tissue, intimately united to the cicatrix of the skin. After resection of a spinous process, the cut end became pointed off, without any formation of new bone having taken place.

After resection from the substance of the horizontal ramus of the lower jaw, without complete division of its whole thickness, Heine observed, two months and a half afterwards, perfect reparation of the defect by new bony material. The cut fangs of the teeth were unaltered.

## III. *Extirpation of Bones.*

Heine is the only experimenter who has performed extirpation of bones. The operation was performed on dogs. In his operations he generally separated the periosteum in the most careful manner from the bone, and left it behind in the wound. His observations show the possibility of restoration of the removed bone by bony material, which indeed does not usually resemble the extirpated bone perfectly in form and size, but still has been found sufficient to re-establish the solidity and usefulness of the limb. The irregular processes which frequently form upon new bones, and usually serve for the insertion of muscles, cannot, to judge from the representations which Feigel[1] gives, be compared without some stretch of fancy with the natural processes and irregularities of the extirpated bone, although a few cases may perhaps be so explained. The joint-ends of the new bones at least had assumed the form of the extirpated articular processes—an observation which applies quite universally, and which Textor also made after resection of the extremities, and by which he refutes the counter-assertion of Caspari.[2]

When the periosteum had been removed with the bone, the reparation by new bone has been found to be extremely scanty, even after a long period. Separate kernels of bone have been found

[1] Loc. cit.

[2] "Ueber die Entstehung der Knochenkrankheiten," 'Graefe u. Walther Journal,' Bd. v.

among the soft parts, and the latter have been soldered together into a firm cicatrix.

The symptoms which followed immediately after the operation have been, considerable swelling and infiltration of the soft parts, with a reddish-brown serous exudation, especially if the inflammation has been raised to a high degree by the replacement of the extirpated bone. Copious suppuration has followed this, and the wounds healed by granulation. If the inflammation have not been very considerable, the periosteum, when examined so soon as the first few days after the operation, is found swollen, of a lively red colour, penetrated with numerous fine injected vessels, and between its lamellæ a brawny, reddish material. Some time later a few bony or cartilaginous nuclei were found deposited on the interior of the periosteum, which gradually enlarged, and in the end united together into a single bony mass, or were joined together by strong fibrous membrane. The new bony material, when examined at a comparatively early period, was entirely solid; later on, traces of a new medullary cavity appeared, partly cellular, and covered over with a delicate reddish-brown membrane, and with bony tissue in its interior containing marrow. Heine has observed this medullary cavity developed, though to a limited extent only, throughout the whole extent of the bone. Usually, after extirpation of a long bone, the new bone is considerably shorter than the one extirpated. After the extirpation of one bone only, in a limb containing two bones, the one left behind has been frequently found to be covered with new bony material, which might be removed with some force, and showed the surface of the bone smooth below it. In these cases also the limb was generally a good deal shortened, while the bone which was left behind assumed a proportionate curvature. Contractions of the neighbouring joints were more remote consequences of these shortenings. After extirpation of both bones of a limb, reproduction of two bones separated from each other has occurred, and these have been found soldered together at a few points only.

The periosteum, frequently thickened, clothed the new bone. The muscles were inserted with it into the bone in tolerably natural order; they were contracted in proportion to the shortening of the limb, and attached as well to the other parts along the whole length, as especially to the irregular prominences of the bone. If perfect bony reproduction had not occurred, the muscles were found inserted also into the fibrous or cartilaginous parts which were covered by periosteum. The play of the muscles was hardly prevented by their being adherent to each other. If processes of the extirpated bone had served as supports or pulleys for particular tendons, these were replaced, if not by new bony processes, yet in this way, that fibrous sheaths had been formed on the new bone, in which the tendons enjoyed a certain degree of motion from side to side. Heine observed after an extirpation of the fibula with its periosteum this state of things in the tendons of the peronei muscles, where they pass round the outer malleolus.

The articular ends of the new bones were found covered on the side turned towards the articular surface of the neighbouring bone with a strong and smooth fibrous or cartilaginous (?)[1] covering. Lying on the articular cartilage of the adjoining bone were found remains of the old articular capsule, or a thin, cellular tissue, which was continuous with a short, strong, fibrous cord passing to the newly formed bone. In other cases a new articular capsule was formed around the contiguous ends of bone, covered with a smooth synovial membrane, and containing a fluid resembling synovia. In a newly formed joint of this kind, between the lower end of the femur, which had been reproduced after extirpation and the upper end of the tibia, even the crucial ligaments were found again. Sometimes a tolerably large space was found between the newly formed bone and the adjoining normal articular surface. In these cases the bone was prolonged into a very strong, but flexible, cord, which was connected by a soft, fibrous tissue to the adjoining articular surface. This was the method also of connexion found between a newly formed rib and the costal cartilage. In rare cases there lay between the articular surfaces of the newly formed and the uninjured bone a meniscus, about a line in thickness, which, however, probably consisted of fibrous tissue.

The above results apply equally to the extirpation of long, flat, and short bones. After the extirpation of the calcaneum, reproduction of bony material took place. This served for the insertion of the tendo Achillis, and articulated with the adjoining articular surfaces, the limb being perfectly useful.

To sum up shortly the results which have been obtained by the different experimenters on the healing process after resection, in respect to the regeneration of bones, and in respect to the tissues

[1] The query is the Author's.—TRANS.

which take part in this process by means of their blood-vessels, we obtain the following results.

1. The periosteum plays the principal part in the repair of the deficiency of bone caused by resection, to such an extent that it is sufficient of itself to form new bony material, which may replace the bone removed. In the cranial bones it is probable that the dura mater takes the part of the periosteum.

2. Nevertheless, reproduction of bone, although only in a slight degree, may take place even without periosteum.

3. This reproduction proceeds—

   (*a*) From the medullary cavity, or from the diploë, in proportion to the extent to which they remain uninjured;

   (*b*) From the soft parts which surround the bones.

4. The substance of the bone itself does not appear to contribute to the reproduction of bone. Klencke is the only author who expresses the opposite view. He also describes that in the process of exudation from the substance of the bone a partial softening of the latter occurs.

5. The exudation necessary for the regeneration of the bone appears to be furnished by inflammation of the parts above mentioned. Irritants, which heighten the inflammation, heighten also the process of reproduction.

6. The exudation is at first reddish, viscid, or gelatinous, and goes through the steps of cartilaginous development before it changes into bone.

7. The newly formed bony material is at first solid, and it is not till after the lapse of some time that a medullary cavity may be found formed in it.

8. It is only in the rarest cases that the deficiency of the bone is repaired entirely, or sometimes even in excess. Still more seldom does the mass of new bone possess the form of that which was removed. If the repair of the deficiency be entirely by bone, still there is a difference in quantity between the new mass and the resected bone, which is compensated only by approximation of the sections of the bone, with corresponding shortening and curvature of the limb. If this approximation has not taken place, or if from other causes the mass of newly formed bone is not sufficient fully to replace the deficiency, either the loss of substance remains permanently, or a fibrous material is laid down in its place, in which separate bony nuclei are often deposited.

## CHAPTER III.

### ORIGINAL EXPERIMENTS AND ANATOMICAL INVESTIGATIONS ON ANIMALS.

Before passing now to the description of my own experiments and dissections of animals, I must preface the chapter with a few words of explanation and apology. I hesitated for some time as to whether it would be necessary, or indeed whether it were worth while, to relate each experiment by itself and give the anatomical details of the dissections belonging to each, and so to make this the preface to my views on the healing process after resection; or whether I should merely set out in order the results derived from these investigations. I have determined on the latter plan; because, having commenced my work on the former, I found it impossible to avoid continual and extensive repetitions; and, even where the healing process was most various, the description of its leading symptoms became tediously monotonous; and I found also, when I had written the following chapter, that it contained, in a complete and elaborate form, all the material which was scattered about in the description of the particular experiments, and that thus nothing was gained for the understanding of the healing process from the enumeration of all the experiments on which my conclusions rest beyond what is contained in the sequel. Fearing, therefore, that to expressly describe each individual experiment would have no effect beyond making my work more voluminous, I expunged that section, and have given at the end an account of only those experiments from which the drawings were made, in order to render the latter more intelligible.

My experiments were performed upon rabbits and pigeons. They relate principally to resections of the extremities and in the substance of bones. Some extirpations of bone are also included in the same experiments. I hoped to discover the chief varieties of the healing process, keeping in view especially the defects of the after-treatment in animals, by so conducting my operation, as—

1st, to bring an articular surface covered with cartilage opposite the cut surface of the bone, and for this purpose I resected the head of the humerus only; or—

2d, to bring the two cut surfaces of one or two bones opposite to one another. For this purpose I resected from the shaft of the radius.

I selected this bone because, after its division, the ulna offers a firm support, which secures as perfectly as possible the immobility of the resected ends of the radius. In order to secure still further the repose of the extremities on which the operation was performed, I always, in rabbits and pigeons, chose the anterior extremity for the operation, because rabbits make less use of it in running than of the posterior extremities, and because in pigeons we find a firm support for the limb operated upon on the trunk, by tying the wings together. It happens also in rabbits that the animals for the most part carry the bone operated upon in a hanging position, and drawn towards the body.

I made the resections of the head of the humerus for the most part on rabbits. The operation is, in the first place, more easily accomplished in these animals than in pigeons, and the anatomical relations of the shoulder-joint in rabbits are much more similar to those of man than is the case in pigeons. In the latter the articular head of the humerus is wanting, at least in the rounded form; the bone is at its upper and very broad end provided with a small, oblong, articular surface, forming a very slight prominence, which articulates with the very small articular surface formed by the scapula and coracoid bone. Besides this the humerus in pigeons is filled with air, and injury of the air-cells which open into it cannot be avoided in the resection of the upper end, a circumstance, however, which produces no morbid change appreciable either during life or on dissection.

The resections from the shaft of the radius and the extirpations of this bone I performed chiefly in pigeons. The bones of the forearm in rabbits lie so close to one another that it is very difficult and requires great caution to resect the radius without cutting into the ulna, or even carrying the incision through the whole thickness of that bone. Thus it happened sometimes that I resected a piece from the radius and the ulna at the same time without intending to do so. In pigeons the bones of the forearm lie so far from one another that the operation can be performed with greater facility. It was for the same reason that I extirpated the radius in these animals. The great interval between the radius and the ulna in pigeons has, however, this disadvantage,—that after the division of the radius the ulna is no longer able to secure completely the immobility of its fragments. I have only once extirpated the radius and the ulna together in a rabbit. The animal died a few days after the operation.

The resection of the head of the humerus in rabbits I performed in the following manner: After the hairs were shorn off I cut through the skin and the muscles on the anterior part of the joint, near its middle line, by an incision about an inch long, running in the axis of the humerus from the edge of the articular surface of the scapula to a point below the articular head. The shining white capsule of the joint thus exposed to view was opened by an incision running transversely across the head of the bone; the head was rotated outwards, and the muscles attached to the smaller tubercle were cut through close to that prominence; then the head was twisted inwards, and the muscles were separated from the greater tubercle. The luxation of the head and its complete separation from the soft parts were then effected with facility by incisions carried behind the bone. Lastly, the head, being fixed by a vulsellum, was sawn off either alone or with a portion of the shaft. The tendon of the long head of the biceps lies so far inwards and forwards, and slips with such facility out of the very flat inter-tubercular furrow, that it often did not come into view at all during the operation, and was never injured. The greater vessels and nerves were hardly ever cut, and the bleeding was almost always quite insignificant.

For resection from the shaft of the radius I penetrated, after the skin was shorn or deprived of its feathers, through a muscular interspace to the bone. The muscles were held aside with fine forceps. When the bone was exposed I either separated the periosteum, after having divided it to the extent of the portion to be excised, taking the greatest care of it, an object which I was able to accomplish pretty well after some practice, or I cut through the periosteum transversely in the parts of the bone to which the saw was to be applied. By a ribbon pushed under the portion to be removed the soft parts were carefully protected, and the bone was sawn through upon it. Splinters of bone which remained upon the sawn surface were removed by the bone-nippers. Bruising of the soft parts can never be avoided without the protection of the ribbon, but it especially takes place when the space between the ulna and the radius is so narrow as it is in rabbits, in whom it occurs to some extent even when the ribbon has been pushed through.

The extirpation of the radius I performed in a manner precisely similar. I did not spare the periosteum in this case. The bone being laid bare, I sawed it through in the middle, and then disarticulated its upper and lower end.

The great vessels and nerves were hardly ever injured in these operations, and the bleeding was always very inconsiderable.

At first I always brought the wound together by the interrupted suture. Perceiving, however, that a firm cohesion of the edges of the wound was attained, but that the suppuration underneath was not diminished, and also that the deficient discharge of the exudation, which was at first bloody and serous and very copious, and afterwards purulent, was the cause of large purulent accumulations, and perhaps of the remarkable mortality of the animals after the operation, I no longer brought the wounds together. The resected ends of the bones were pushed as deep as possible under the soft parts, and I then closed the wounds in rabbits by lightly twisting together the hairs, and it was only in a very few cases that I observed protrusion of the bones through the wound. The proportion of mortality was thenceforth much more favorable, especially when I at first cleaned the wound daily with water, and procured by incisions an exit for collections of serous fluid or of pus in the remoter parts.

Except this there was very little to be done in the after-treatment. A firm bandage which I tried to apply in various ways was never tolerated by the animals, and was soon gnawed and torn off. The only form of bandage which I have not tried, because I unfortunately thought of it too late, is enveloping the whole extremity in plaster of Paris. I do not know whether it would have answered better than those which I did try. They were the following: wrapping the limb and the greater part of the trunk in bandages with or without paste, and with or without splints; applying splints with several rolls of sticking plaster; or enclosing the extremity in a case of gutta percha, secured by pasted bandages. If the bandage adhered, it was generally so firm that I was obliged to remove it on account of œdema and considerable swelling in the parts around it, and from apprehension of gangrene. The animals remained most quiet when I was able to shut them in separate, and as far as possible, darkened rooms. But I was soon obliged to give up this plan, because in these conditions they became more out of health, and died more frequently than in other cases.

I have consequently never succeeded in obtaining an immoveable condition of the parts concerned in the operation, and I do not venture to assert that all the means tried by me have so far fulfilled their aim as to secure a degree of immobility such as would even approximate to that which is possible after resection in man.

Pigeons bear resection much better than rabbits. Out of twelve pigeons none died, while, on the other hand, of forty-five rabbits I lost twenty-one. Death occurred sooner or later after the operation, often from six to seven weeks. I found in these cases generally after resection of the head of the humerus, extensive accumulations of pus in the subcutaneous areolar tissue and the muscular interstices, not only on the limb which was operated upon, but also along the infra- and supra-spinous fossa, on the breast, and thence sometimes even along the whole of the upper extremity which was not operated upon, but more commonly along the abdomen as far as the parts of generation. Almost always there was more or less of recent adhesion between the layers of the pleura, serous exudation into the pleural cavities, adhesion of the pericardium to the heart (the most beautiful instances of *villous heart*), and induration and formation of abscesses, or extensive deposition of tubercles, principally in the upper lobes of the lungs, and sometimes in the muscular substance of the heart. The veins on the limb operated upon, traced as far as the heart, never exhibited morbid changes. The organs of the abdominal cavity were always sound. Only twice I found in the liver the bodies described by Kauffmann,[1] and usually considered as itch-sporules ('psoro-spermien'), in small, scattered, white pustules. After resection from the shaft of the radius death followed much more rarely. In these cases the accumulations of pus were absent, but on the other hand we found changes dependent upon inflammation of the thoracic organs.

When death followed in a shorter time after the operation, no

[1] 'Analecta ad Tuberculorum et Entozoorum cognitionem,' Dissert. inaug., Berol., 1847.

trace of the regeneration of the loss of substance was discoverable in the parts concerned. A grayish or greenish-white viscid fluid covered uniformly the bone and the soft parts in the vicinity of the wound. The soft parts were sometimes rotten and brittle, and infiltrated by the same viscid fluid. If a longer time had elapsed between the operation and the death of the animal, the products of the healing process were always present in the injured parts, but they were for the most part essentially inferior in their development to those which I found in animals which had remained comparatively healthy and had been killed at the same time after the operation. The healing process in such cases was not remarkably altered by the illness of the animal, but was remarkably retarded. A few peculiarities which were found in them do not essentially deviate from the normal phenomena of the healing process, and will be treated of in the sequel as varieties of that process.

## Description of the Healing Process, from original researches.

### I. *Resection of the extremities of bones.*

In most cases the inflammatory phenomena after resection of the extremity of a bone attain a very great height. They usually disappear with the commencement of the suppuration, which remains of a laudable character and moderate, if the secretion have free exit; but, if that is not the case, the inflammatory symptoms persist, and the suppuration becomes very abundant and spreads rapidly. I have never seen union by the first intention. I have indeed observed the union of the wound in the soft parts by first intention when brought together by sutures, but I can only look upon this occurrence as unfortunate, since under the united soft parts the inflammation passed on into suppuration, and thus the further progress of the case was less favorable than it would otherwise have been. Steinlin has observed union by first intention in two cases of removal of the head of the tibia and fibula in the knee-joint. The final results in these cases were no better than in those where healing by the second intention occurs with free exit for the secretion.

In the first few days after resection of the extremity of a bone, and frequently after the first twelve hours, a considerable swelling is observed around the situation of the resection, which fluctuates, and is usually very painful to the touch, and consists partly of the tumefied soft parts surrounding the joint, partly of extravasated blood, but principally of an abundant serous exudation stained with blood. This is especially abundant if the wound of the operation is firmly closed, and quickly subsides if exit is afforded to the fluid. If this is not done, the swelling gradually increases, the exudation infiltrates the subcutaneous cellular tissue, as well as that between the muscles; and a few days after the operation the whole extremity, and often the neighbouring parts also (especially the chest), are found very tense, œdematous, and extremely painful. In rare cases it occurs that during the following days the inflammation subsides, and a more or less complete absorption of the exudation occurs; but usually the latter is converted into pus, and thus gives occasion to the very considerable *infiltration* of pus which I have before mentioned. The swelling becomes about this time of a doughy consistence, and less painful. Later on, in the case of rabbits, the pus, which is thick from the commencement, acquires continually more consistence at the part where it is collected, and becomes dry and crumbly: the swelling has by this time become hard to the touch and gradually painless. In this case there are found occasionally a series of abscesses lying close together, often communicating with each other, and encysted in a firm fibrous membrane. Occasionally the pus find a way to the exterior; and then the skin in the neighbourhood of the opening is ulcerated to a greater or less extent.

Another cause of the *infiltrations* of pus is the extravasation of blood which immediately follows the operation. This comes apparently from the vessels cut through in the operation—it is found, however, to an astonishing extent partly in the subcutaneous cellular tissue, partly in the interstices of the muscles. I have found it almost constantly after resection of the head of the humerus, along the humerus, and in the supra- and infra-spinous fossa, and more rarely in the subscapular fossa also. Its conversion into pus occurs gradually.

In the human subject it seems that the œdematous swelling of the extremities and the *infiltration* of pus occur much less commonly after resection of the *extremities* of bones; still examples of these are found in the histories of cases. Seutin especially contributes a case of resection of the head of the humerus, in which considerable *infiltrations* of pus occurred in exactly the same situations in which I have observed them after the same operation in rabbits, and in which death was caused by pleuropneumonia. Steinlin informs me that he has seen the same appearances after resection of the upper extremities of the tibia and fibula in the rabbit, but not frequently, and always confined to the leg and foot.

The swelling of the soft parts in the neighbourhood of the resected joint gradually disappears. The muscles surrounding the joint, which are partly cut through, partly uninjured, are at first only *loosely united* together; later, about the sixth or eighth day, they are more or less closely incorporated, especially in the parts immediately adjoining the cavity of the wound; and form, by taking an insertion around the articular surface which has not been removed, and into the resected bone below the level of the section, a firm capsule, which, if the wound made in the operation has united, is an entirely closed one.

Immediately after the operation the cavity, which it has occasioned, is lessened by the contraction of the muscles approximating the resected bone to the uninjured articular surface. It is exceedingly difficult to practise measurements of the shortening thus produced in such a way that they shall give an absolutely accurate result. On an average I have found, after resection of the head and a portion of the shaft of the humerus, a piece on the whole six lines long, a shortening of four lines. After a certain time (usually only two or three hours) the muscular contraction appears to subside; at least I have found at that time often no shortening at all, or only a difference of two lines. The cavity, thus increased in size, becomes filled with extravasated blood proceeding from the medullary cavity of the divided bone—this extravasation having a hemispherical rounded surface above (which is supported against the uninjured articular cartilage) covering the section of the bone below, and penetrating a short distance into the medullary cavity. I have seen remarkable differences in the extent of this clot; but I have met with the clot itself in all cases. Sometimes it was only a hemispherical layer covering the section of the bone, sometimes it attained the size of a cherry. This variation appears to depend on the size of the cavity left after the operation. If the shortening of the extremity had been considerable, or the piece of the humerus which was resected only small, the clot was of small size; if the contrary were the case, the coagulum was always found of considerable extent. On microscopic examination it was found to consist of the stiff fibres peculiar to coagulated fibrin, of shrunken red corpuscles, and a mass of pale cells, most nearly resembling lymph-corpuscles, to which elements were added, in the neighbourhood of the medullary cavity, granular and vesicular fat in considerable quantity. This coagulum slowly shrivels up into a reddish-yellow or brownish solid mass, which gradually disappears, apparently by being washed away piecemeal in the suppuration.

Granulations then take the place of the clot, shooting up from the inner wall of the capsule formed by the soft parts around the neighbourhood of the joint. The more luxuriant they are the more perfectly do they fill the cavity. From them, or from the exudation which they furnish, cellular tissue is formed, which, if the granulations have shot up only in a thin layer, is arranged as a membrane covering the inner surface of the capsule formed by the muscles, and thus represents a new articular capsule, on which the muscles are inserted. If the whole cavity have been filled by granulations, they form a firm solid tissue, uniting the cut end of the bone and the articular cartilage, and continuous with the inner surface of the soft parts surrounding the seat of the resection. When the solid tissue adheres only to this surface, as I have often observed it to do, the moveable connexion between the resected bone and the uninjured articular cartilage is formed by the muscles, together with the external layer of the newly formed cellular tissue, which lies nearest to the muscles, while the portion which fills the remainder of the cavity forms, when in large quantity, that which in anatomical examinations of the human body has been called a meniscus. This so-called meniscus, however, may be considerably smaller, and is then found in the form of a tolerably smooth solid plate of cellular tissue, which is stretched transversely across the newly formed articular capsule from one of its walls to the other, between the cut surface of the bone and the uninjured articular cartilage. In other cases this solid mass of cellular tissue is united not only with the muscles but also with the section of the bone and with the articular cartilage. How this union takes place will be shown in the sequel.

Through the difference in the quantity of the granulations there arise other forms of manifold variety on their conversion into cellular tissue. One of the most frequent which I have met with was this, that the mass of cellular tissue appeared to fill entirely the space above the upper end of the resected bone, but that there was still a small cavity in its centre, which is to be regarded as a new articular cavity encroached upon by the thickness of its walls, and which, in regard to its contents, is pretty closely analogous to the perfect newly-formed capsules.

The newly-formed articular capsule, which extends from the origin of the muscles at the uninjured articular surface to their insertion into the resected bone, sometimes encloses the latter, so that the head, which is reproduced in the way I shall presently describe, forms a joint within it with the articular surface, or moves upon the latter at a certain distance; sometimes the lower edge of the capsule unites with the upper end of the resected bone. This difference depends in great measure on the method of performing the operation. Thus, if the bone be separated from the muscles a good deal beyond the part at which it is sawn through, and if the periosteum be preserved on the portion denuded of muscles, but not removed, the first state occurs, viz., that the head of the bone is enclosed in a capsule; if on the contrary the bone is removed just at the part down to which the muscles have been separated, or if the piece of bone which has been exposed below the level of the section has been deprived of periosteum, and in consequence is attacked with necrosis and exfoliates, the new capsule unites by its lower edge with the upper end of the bone.

I have never observed what Steinlin has particularly described, viz., that the remains of the original articular capsule contribute to the formation of granulations, and of the new articular capsule which is developed from them. I have found the remains of the original articular capsule of the shoulder-joint, which are in all cases only inconsiderable, thrust inwards upon the glenoid cavity, at first between the coagulum and the articular cartilage, and later on between the latter and the granulations. At first it is permeated with much fluid, then is found infiltrated with pus, becomes rotten, easily lacerated, and appears to me always to become sloughy, and to be thrown off. The granulations which shoot up from the muscles surrounding the cavity of the joint, consist of nuclei with a dark contour, and of round cells lying close together, with a delicate cell-membrane, nucleus, and nucleolus. The change into cellular tissue is produced by the elongation of the cells into spindle-shaped bodies, which are arranged with their long axes tolerably parallel, and by the union of these bodies into fibres. Between the spindle-shaped cells dark nuclei are found here and there lying in longitudinal directions; I have not been able to trace their development into fibre-cells. The fibre-cells I have found, on addition of acetic acid, to be in small numbers relatively to the newly formed fibrous tissue. I could never perceive a spiral twisting of the former around a bundle of the latter. Neither in the recent fibrous tissue, nor in the fully developed, have I ever been able to detect cartilage-cells in this situation. Thus it is seen that the so-called menisci already described consist exclusively of fibrous tissue. In general, I have observed that the fibres of the fibrous tissue in the parts lying next the muscles, have more of a parallel arrangement, while towards the free surface of the new tissue they are arranged in bundles crossing each other in various directions. The same difference was found in the transverse plates, the so-called menisci, between their free surface and their deeper parts.

If, after not too great inflammation and not too copious granulation, a more or less strong articular capsule is found, the inner wall of this capsule is covered in rare cases with a layer of pavement-epithelium, and its cavity is filled with a fluid which differs from the normal synovia only in having less consistence. I have never found a separate synovial membrane, such as Steinlin describes, which could be dissected off the capsule. Nor have I been more successful in finding the synovial processes (or epithelial processes) which have been found in the bursæ mucosæ, the sheaths of the tendons, and on the synovial membrane of the joints, and which have also been recognised by Steinlin in the joints of new formation. That the cells which I scraped off the inner smooth wall of the capsule were epithelial, I concluded from their polygonal form, their close approximation to each other, and from the universal paleness of the cell-wall and strong prominence of the dark nucleus, which occurred on the addition of acetic acid. The nucleus also frequently separated into several parts. This division of the nucleus, which was observed in the young epithelial cells, is indeed also a property of the nucleus of pus-globules, but a confusion with these was impossible, from the size, form, and regular arrangement of the cells. The fluid contained in the capsule is serous, yellowish, slightly turbid, mixed with reddish points, and stringy. It shows under the microscope, mixed up into a yellowish and rather turbid mass—1, epithelial cells, somewhat shrivelled, obviously separated from the inner wall of the capsule; 2, small brownish granular corpuscles, which most resemble shrivelled blood-globules; and, lastly, fat-vesicles of various sizes. The origin of these two latter elements I am not in a position to demonstrate. I have observed the occurrence of the pavement epithelium and of the synovia in only three cases, more than four weeks after the operation. Two of these are described in the sequel, and furnished the preparations figured at figs. 6—8 and figs. 24—27.

The condition of the tendon of the long head of the biceps muscle, when uninjured in the operation, deserves particular mention. It has been frequently asserted, that the preservation of this tendon, which is attended with some trouble in operations on the human subject, is of no importance for the future usefulness of the extremity, because it will slough and will be removed in the process of suppuration.

I have never seen anything of such sloughing and separation in any case. In examinations soon after the operation, I have found the tendon adherent to the muscles surrounding the situation of the joint, and covered on its anterior surface, which was turned towards the cavity left by the resection, with a thin layer of pus. In these cases it had lost a little of its polish and of its white colour on the surface, and was of a grayish hue. In later examinations, I have found it either covered only on the surface turned towards the cavity by granulations, which were not attached to it, or completely enclosed in them. If the healing process had proceeded almost or completely to its conclusion, I have found the tendon either united with the exterior of the newly formed articular capsule, or of the fibrous cord between the resected end of the humerus and the glenoid cavity; or else enclosed to a certain extent in this capsule by a sheath or duplicature of it. Shortly after the operation, the union with the fibrous tissue is found to be very intimate, and thus the mobility of the tendon much impaired; but later on, the union, probably by the continuous and powerful muscular action which ensues on the recommencement of the use of the limb, becomes much more loose, and the tendon can be moved hither and thither to a greater or less extent. If it is enclosed in the fibrous uniting material, or in a duplicature of the capsule, the inner surface of this sheath is sometimes found polished. I have never found epithelium on this surface, or fluid in the sheath.

From this I am led to speak decidedly in favour of the careful preservation of the tendon of the long head of the biceps muscle in the operation.

In reference to the changes produced in the bone, they are as follows. Next to the sawn surface a thin strip of the bone is usually found, to the extent of about half a line, smooth, pale, and deprived of its periosteum. The latter is usually detached from the bone at its upper end in small torn shreds; and further down, where it is no longer detached, it is reddened, œdematous, and plentifully moistened by a somewhat viscid exudation, which is deposited between the bone and the periosteum in the form of a thin yellowish layer, usually of an annular shape, with numerous minute bloody puncta scattered through it. These changes in the periosteum, which are to be found from the second to the fifth day after the operation, extend to a variable distance along the bone. In most cases they proceed a short way below the point where the muscles are inserted, together with the periosteum, into the bone; but sometimes, when the general inflammatory symptoms had been considerable, I have observed the injection and exudation throughout the periosteum covering the whole bone as far as to the joint lying nearest below the point of excision.

The yellow gelatinous layer proceeds from the inner surface of the periosteum. It is more closely adherent to the latter than to the bone, so that on detaching the periosteum only a slight trace of this material remains on the bone, and this may be readily detached from it, leaving a smooth unaltered surface. On microscopic examination the gelatinous matter consists of a pale-yellow mass, very finely granular, in which are scattered numerous fat-vesicles and small dark rounded bodies (nuclei), each containing a nucleolus, usually clearly marked. These bodies, which are proved to be nuclei also by their relations to acetic acid, rapidly increase in number, and are soon found deposited in greater quantity in the blastema, which has now become clearer and paler, and from which the fat-vesicles have disappeared. Around many of them there is formed a delicate cell-membrane, usually enveloping them pretty closely, the contents of which, generally finely granular, show as a dark border or edging against the blastema, which is now in small quantity relatively to the numbers of the nuclei and cells. At the same period black nuclei, arranged longitudinally, and spindle-shaped cells, occur in the exudation, apparently as the consequence of a second kind of change in the nuclei originally deposited in it. They are found especially numerous in the superficial layers of the exudation nearest to the periosteum; and about this time, viz., after the sixth day, the exudation is found to have undergone changes perceptible to the naked eye. Thus, besides an increase of volume, which is most conspicuous in proceeding from the point where the periosteum with the muscles is inserted into the bone towards the section of the latter, there are found two different substances in the deposit. The one, which lies nearest to the bone, is bluish-white, or frequently slightly reddened, and of cartilaginous consistence; the other is yellowish-brown or reddish, and softer than the former. At the part where they are in contact they present the following arrangement: the bluish-white deposit is slightly tuberculated on its most superficial layer, while the yellowish-red substance covers these elevations and sinks into the depressions between them. Thus, in the middle layer of the deposit, by making sections parallel to the surface of the bone, an appearance is obtained of a series of rounded bluish-white bodies scattered through a yellowish-red mass. As might indeed have been conjectured from examination with the naked eye, the microscopic characters of these two substances are precisely like what Voetsch has observed in the union of fractures of bone with considerable displacement and long-continued mobility of the fragments, in the union of callus material which had been refractured, and in the healing process after resection from the shaft of the radius in a pigeon. Steinlin has obviously seen something of the same kind, but is short and inaccurate in his description. I have also found the same differences in the organization of the exudation after resections from the substance of bones.

The bluish-white material consists of the nuclei and cells above described aggregated closely; between which a slightly fibrillated intercellular substance may be seen in very small quantity. Although the cells are remarkably small, not attaining even later on the size of the cartilage-cells, and never showing endogenous cell-formation, yet this material must be considered as new cartilage in process of formation; and this view is confirmed also by reference to the futher changes which take place in it. The yellowish-red layer of the exudation, on the contrary, consists of the elements of immature cellular tissue, such as I have observed and described in the formation of the tissue of the new articular capsule. If fine sections out of the central layers of the exudation, where the two materials are continuous, are put under the microscope, rounded discs are seen of the small cartilage-cells and cartilage-nuclei, situated close together in a pale basement substance, surrounded by the yellowish-red material of the immature cellular tissue. While, however, in the other parts of the exudation the elongated dark nuclei, and the closely compacted spindle-shaped cells, have a parallel longitudinal course, in the neighbourhood of these discs of growing cartilage, they affect a concentric arrangement, and mingle with the elements of the cartilage in such a manner, that at a greater distance from the mass of cartilage single cartilage-cells are scattered amongst the components of the immature cellular tissue, and nearer to the masses of unmixed cartilage there is found a perfectly gradual passage of the elements of the one tissue into those of the other. This transition of the cartilage into cellular tissue may be observed in any fracture which is examined during the process of union, in passing from the deeper to the superficial layers of the exudation.[1] I have observed it especially well marked in frogs, in whom the apparently extremely late occurrence (or perhaps entire absence) of the process of ossification does not interfere with the perfect development of cartilage-tissue in the repair of fractures. There is only one distinction to be made here. In investigations of the newly formed tissues around the situation of fracture in a bone, I have always observed the transition from the elements of cartilage to those of cellular tissue to be equable throughout the whole mass, and quite gradual; while in those after resection, with which we have to do at present, I have found the transition always limited to that central layer of the exudation of which I have before made frequent mention, and so abrupt that it often has appeared at the first glance as if only single cartilage-cells were strewn about in the immature cellular tissue, and as if the latter were sharply marked off from the rounded cartilaginous masses.

The further development of the two materials above described proceeds also in different directions. The immature cellular tissue is gradually developed into perfect cellular tissue, and is soldered into a single mass with the periosteum, which thus is frequently considerably thickened. The newly formed cartilage ossifies and the bone thus formed is covered by the thickened periosteum. Only at the point of transition from the young cartilage to the immature cellular tissue, transitional formations are also found when the development has proceeded further.

[1] This statement, I believe, is meant to apply only to fractures in the lower animals.—TRANS.

The process of ossification commences very soon. Its commencement occurs at about the same time at which the cartilage reaches the above-described stage of development. In consequence of the very defective development of the cartilage and the very rapid progress of the formation of bone, the healing process after resection of bones offers very little that is useful for the study of the process of ossification. All that I have discovered in long-continued investigations of this subject, leads me to support the views developed by Voetsch. I am not in a position to explain the cause of the very rapid commencement and progress of ossification. I have not seen either the development of blood-vessels, or vessels fully formed, in the cartilage. The layers of cartilage which lie nearest to the bone ossify the soonest; and then the process goes on to the superficial layers. I have constantly observed that in the process of ossification, a finely granular dark opacity of the intercellular substance always precedes the deposit of large, dark granules on the internal surface of the cell-walls. At the limits of the ossification the still unaltered cartilage-cells and cartilage-nuclei are constantly found surrounded by narrow bridges of blackened intercellular substance.

I cannot, however, give an unconditional assent to Steinlin's assertion, that a difference is to be found in this fact between the process of ossification in union by the first intention and that in union by suppuration; since distinguished observers like Koelliker[1] assert, that in the development of bones the ossification of the basement substance slightly precedes, as a rule, that of the cartilage-cells. I myself have never undertaken investigations into the bones of quite young animals; and the fact that in ossification of enchondroma I have seen the conversion into bone occurring first and markedly in the cartilage-cells, which were highly developed and of large size, does not justify me in regarding this as a phenomenon necessarily belonging to the normal process of ossification.

I have succeeded in many cases in clearly observing the development of the bone-corpuscles (lacunæ) out of the cartilage-cells in the manner described by Voetsch. After the shrivelling and complete disappearance of the nucleus, I have seen the lacunæ in the dry bone appearing unmistakably as empty spaces. The disappearance of the cell-membrane I have not seen till a remarkably late period. I

[1] 'Mikroscopische Anatomie,' Leipzig, 1850, p. 358.

have often succeeded, even in the perfectly formed bone, in bringing this membrane into sight again by treating the preparation with dilute muriatic acid. Perhaps the very inconsiderable development and extent of the radiating canals which traverse the basement substance going off from the lacunæ, which I have always remarked, depends upon this. The nuclei, around which a cell-membrane is not formed, are at first enclosed by a finely granular dark material which permeates the intercellular substance. After this they appear to shrivel and disappear, as the nuclei do in the ossified cartilage-cells. This view of the case is supported by the fact that in a preparation of new bony material, treated with dilute muriatic acid in which the basement substance was slightly turbid, and the cartilage-cells had come into sight again in many places, some with shrivelled nuclei, others without any at all, there were no solitary nuclei to be seen, and the close aggregation of the cartilaginous elements had quite disappeared. I believe that I may be permitted to explain the smallness of the number of lacunæ in the developed bone, in proportion to the extraordinarily close aggregation of the cartilaginous elements before ossification, by this disappearance of the free nuclei.

The fully developed new bony material is very porous in its superficial, but more solid in the deeper layers. Later on it acquires greater solidity on the surface also. In the porous material are found large clear spaces, quite empty in the dried bone, which are surrounded by relatively narrow bridges of bony substance. Thus, the new bony material has the appearance of a wide-meshed net. I consider these spaces as the medullary cavities of the bone, but I have not arrived at any definite view as to their development. I think I am in a position to assert in the most positive manner that these spaces do not possess any previously formed element, in the organization of the exudation up to the commencement of ossification, from which they can be developed. The only possible assumption, which could be founded on these premises, would be that they are formed by the coalescence and subsequent disappearance of several cartilage-cells which do not progress to ossification; but for this view I cannot find any support in my observations. I cannot agree to Bidder's[1] view, viz., that they are formed from cartilage-cells which enlarge into maternal cells

[1] "Zur Histogenese der Knochen," Mueller's 'Archiv,' 1843.

surrounded by progeny, because I have never been able to find any trace of endogenous cell-formation in the exudation when it has been organized into cartilage. For the same reason I cannot assume that they are formed from the canals of the cartilage. I have never seen these latter, and from this circumstance I derive a support to the idea that they are altogether absent in that immature cartilage, which attains only so low a grade of organization as that of which we are speaking at present. I am therefore inclined to Koelliker's[1] opinion, that the meshes which I take to be medullary cavities are formed by the absorption of previously formed bone. I have found them to possess exactly the properties described by Koelliker. Their contour is irregular, often presenting an eroded appearance; they are larger than the cartilage-cells, elongated and oval, or angular, but with a generally oval figure. I have never been able to find bone-cells more or less eaten out on their walls, as Koelliker has described; but, on the other hand, have often seen processes of the cssified basement-substance projecting into them. Perhaps, however, some other explanation of the development of these medullary cavities may suggest itself to the reader from the sequel.

The immature cellular tissue which lies next to the cartilaginous material in the central layer of the deposit also takes part in the process of ossification. I have seen in the most indubitable manner, at the places where the above-described transition of the cartilage into the immature cellular tissue occurs, the deposit of the same finely granular dark masses between the elements of the immature cellular tissue as are found in the cartilage; and I believe that we must regard the elongated nuclei of this tissue as the preliminary elements for the formation of the bone-corpuscles, or lacunæ. I have failed to follow step by step their conversion into bone-corpuscles; but this view is supported by the extraordinary length and narrowness of the bone-corpuscles in general in the bony material which is formed from the cellular tissue; and further, by the fact that in treating a preparation of this material with dilute muriatic acid, a considerable development of air-bubbles occurs, the field clears, and shows the clear transparent disc of cartilage, altered as above described, and surrounded by a tolerably clear, very obscurely fibrillated and almost homogeneous material, of a light-yellow colour, in which longitudinal dark nuclei are seen lying in the situation formerly

[1] Loc. cit., p. 363.

occupied by the bone-corpuscles. Between these are merely seen scattered single cartilage-cells. I have found this ossification of the cellular tissue only in the central layers of the new deposit; in the superficial layers of the yellowish-red material of the exudation, I have never seen it. When the process of ossification is terminated, one is able to see, sometimes very plainly, a difference in the colouring of the different layers of the new bony material. Thus, I have found the most superficial layer, adjoining the thickened periosteum, of a brown colour for a great distance, while the subjacent layers become lighter coloured, till they attain a snowy whiteness. The porosity and softness of the bone were equal throughout the different layers, and the large medullary cavities studded all of them without distinction.

The ossification of cellular tissue, or the formation of bone without the transitional stage of cartilage, is no new phenomenon. Virchow[1] has observed it in the formation of osteophytes on the skull, and has lately remarked upon it in a work on the identity of the corpuscles of bone, cartilage, and cellular tissue. I can testify to the general accuracy of the description which he gives of the process in the work first quoted. I have, however, never seen vessels in the formative material, nor have I seen the spaces till a later period, when the bone was fully formed. Besides, I have always found that the nidus, in which the deposit of the finely granular dark matter occurs, is composed of the elements of the immature cellular tissue, and that it is not till this deposit has made some progress that these elements become obscure and disappear, when the material assumes a homogeneous appearance. Finally, I have almost always found it possible to bring the longitudinal dark nuclei into view again by the addition of acetic or dilute muriatic acid—more clearly by the former than the latter.

In normal histology, also, we find the ossification of immature cellular tissue. Koelliker,[2] and Sharpey, whom he quotes, have observed that the increase in thickness of the bones which are formed in cartilage takes place by deposits from the periosteum, which after having been organized into half-formed cellular tissue and simple blasterma-cells, are converted into lamellated osseous tissue, by the absorption into their fibrous substance of salts of lime and meta-

[1] 'Archiv für pathologische Anatomie,' 1847, Bd. i, p. 135; 'Verhandlungen der würzburger med. phys. Gesellschaft,' Bd. ii, p. 158.

[2] Loc. cit., p. 366.

morphosis of their cells into lacunæ. A peculiarity of these deposits of bone is their arrangement into reticulated lamellæ, interrupted by rounded or elongated spaces. This bony material, which is rendered porous by the presence of these spaces, does not become compact till a later period. If the reader will compare the process as described by me with the above; if he will compare the properties of the newly formed bone on the resected extremities, and its subsequent changes, with these lamellæ, which occasion the growth of a bone in its thickness; and finally, if he will remember that at the end of the healing process after resection so considerable a deposit of bone is found around the resected extremity as to stand in no ratio whatever to the deposit found at the commencement; I think he cannot refuse to admit the analogy between the two processes. I, therefore, believe it possible, that in the reproduction of bone on the stumps of resections, as in the original development of the bone, an exudation is deposited which is converted into cartilage and then ossifies, and that by continual deposits from the periosteum, which are organized into immature cellular tissue and then ossify directly, a further increase of the new bone which was originally formed in cartilage takes place.

In reference now to the further processes which take place on the resected end of a bone, and from which, perhaps, the views above propounded may derive still further support, they are as follows:

Contemporaneously with the exudation which takes place on the exterior of the bone, and with the reproduction of bone in that situation, the same thing takes place in the medullary cavity of the bone. The ossification of the exudation which occurs in this situation proceeds still more rapidly than in that which is formed externally; and the part of the exudation which remains still unossified, appears to be so intimately united with the medulla, that when the latter is removed it comes away with it. I have, therefore, no observations to make upon the properties of this exudation at the earlier periods. As soon as the sixth day, and afterwards, a thin ring of bone is to be found on the sides of the medullary cavity, which gradually enlarges, and in the end completely closes that cavity with a plate of bone of greater or less thickness. The upper level of this plug is generally the same as that of the external deposit of bone. While, however, the latter constantly commences at the lower edge of a necrosed portion of the upper end of the bone (the necrosis being a consequence, apparently, of injury of the periosteum, or of its detachment in sawing through the bone,) the deposit of new bone in the medullary cavity is often found lining this external necrosed ring. It is then usually situated with its lower edge exactly on the same level as the upper edge of the external bony deposit. This appearance is exactly in union with the processes observed in peripheral necrosis. Later on, the upper ring of bone becomes entirely necrosed and is thrown off, or else its peripheral layers are exfoliated. We get then a club-shaped, or in the latter case a somewhat pointed, and completely closed end of bone, resembling more or less an articular extremity, but differing from it essentially, besides the difference in shape.

In more rare cases the plug of the medullary cavity is absent. I observed this in one case where a small dry residuum of the blood-clot which originally proceeded from the medullary cavity still adhered firmly to its interior, and filled up its upper end; and again, in a case where the upper end of the bone had become necrosed throughout, and lay quite loose in a hemispherical capsule of new bony material open at the upper end. I have failed to find an explanation for this defective closing of the medullary cavity. Perhaps the blood clot, which may be regarded as a foreign body, and the necrosed ring of bone, kept up the suppuration to such an extent, that the new bony material already formed in the medullary cavity was reabsorbed, an event which Steinlin regards as possible. This view is rendered probable by the fact that the internal surface of the bone in the cases above mentioned had a carious appearance for some distance.

The loss of substance caused by the resection is not restored by new formation of bone; on the contrary, in consequence of the necrosis and exfoliation of the upper section of the bone, the loss of substance is in most cases greater than immediately after the operation. Only occasionally, when the upper section of the bone is necrosed throughout, new bony material encircles this also; having no connexion with the dead bone. In the greater number of cases the deposit of new bone serves only to round off and close up the upper end of the old; and thus an increase of volume is caused only in the thickness of the bone.

The connexion of the new articular extremity of the bone with the parts which surround it is peculiar. The muscles are inserted into the bone only by means of the new articular capsule, or by means of the fibrous uniting material. The upper end of the bone is covered by a layer of fibrous tissue; either connected at its edges only with the new capsule, or on its whole surface with the solid cord between the bone and the opposite articular surface. This connexion takes place partly by means of the granulations which spring from the bone in order to the throwing off of the necrotic ring, and which unite with those which proceed from the soft parts; partly, as it appears, by means of the exudation, which originating in the medullary cavity effects its closure by bone, but on its surface is organized into cellular tissue. I believe at least that I may assume this to be the case, since, even in cases where the separation of the necrosed ring has not yet taken place, I have still occasionally seen the bony material which closes the medullary cavity already covered with a layer of cellular tissue. I have never discovered a trace of cartilage on the upper surface of the cut end of the bone.

The newly formed bony material is at first porous, and encloses the walls of the old bone, which are plainly visible on a longitudinal section. Later on, it becomes more compact, and at length a process of absorption occurs in it, as well as in the portion of old bone which is enclosed in it, by which the wall of the old bone becomes rough and perforated, and at length disappears, whilst in the place occupied by it and in the entire mass of new compact bone the formation of diploic tissue commences. Thus the end of the bone presents, finally, a very fine reticular tissue covered by a lamella of compact substance; on a section, it is seen to be of a reddish colour, and occupied by numerous vascular puncta. Whether the delicate cells contain normal medulla, as the medullary cavity does which lies beyond the newly formed plug, I have not been able to decide. I have found the new formation of bone (except that in the medullary cavity), as well as the first appearances of exudation, always to the extent of the periosteum only; and, judging from the alterations in this membrane, and from the relations between the exudation and the periosteum, I consider the latter as the source of the exudation, and I consider inflammation of the periosteum as the cause of its existence. In all the cases in which the general symptoms of inflammation have been very considerable and extensive, the injection and tumefaction of the periosteum, the exudation, and finally the new formation of bone, have been found very extensive. Thus I have observed this formation extend over the whole humerus, over the articular surface of the scapula, and along its spine into the supra- and infra-spinous fossa. In the cases in which I have resected only the head of the humerus and left the shaft quite entire, and thus have mechanically isolated the periosteum but little, or not at all, on the one hand the consequent inflammatory symptoms were, as a rule, very inconsiderable; and on the other, as Steinlin has also observed, the new osseous formation on the external surface of the bone was either quite absent, or was very scanty; while in these, as in all other cases, the medullary cavity was closed by a bony plug.

The relation between the articular cartilage and the uninjured joint-surface opposite the resected extremity is also dependent on the degree of the inflammation and of the suppuration consequent upon it. When this was slight, I have always seen the cartilage remaining on the articular surface, slightly turbid on its surface, but otherwise quite unaltered. But if, on the other hand, considerable inflammatory symptoms have preceded, I have found that the investing cartilage has either altogether disappeared, or is loosened at the edges, thinned, and very opaque; and often covered with a thin layer of yellow viscid exudation, and roughened. In particular cases a perforation of the bony wall of the articular surface may follow on this; the consequence of which is the simultaneous gradual enlargement of the compact tissue of the articular process, and the passage of pus into the diploic texture of that bone, by which it is destroyed.

Granulations begin to shoot up from the surface of the bone thus denuded of its cartilage, even during the process of exfoliation of the latter; and these unite with those which proceed from the soft parts, and thus either occasion the union of the solid fibrous uniting medium with the articular cavity in its whole extent, or, if a new capsule has been formed embracing the edges of the articular surface, are organized into a covering of cellular tissue for that surface.

The separation or gradual disappearance of the cartilage is accompanied by alterations in its texture, which Redfern[1] has particularly described under the designation of "*softening*" of the cartilages. These alterations proceed from the circumference and the surface towards the centre and the deeper layers. The intercellular substance appears at first yellowish, finely punctuated, as it were, and

[1] 'Abnormal Nutrition in the Articular Cartilages,' Lond., 1850.

opaque; gradually fibres make their appearance in it, which are slightly wavy, and resemble the fibres of cellular tissue, but are frequently broader, and have the same relation to acetic acid as the fibres of cellular tissue. In the cells, which are at the same time considerably enlarged and arranged irregularly, a deposit occurs of a quantity of small darkish bodies, which must be regarded as fat-vesicles. These often fill the entire cell, but occasionally lie in smaller quantity, arranged around the nucleus like a necklace. They either remain separate, or coalesce into one large bubble of oil. Besides these, small dark granulated corpuscles make their appearance, disappearing with a considerable development of air-bubbles on the addition of acetic acid, and cells provided with a well-marked nucleus and nucleolus. The membrane of the cartilage-cells becomes gradually paler, and disappears. Their contents are found either enclosed by a clear transparent areola in the intercellular substance, which is contrasted against that substance, but without any definite contour; or else a similar clear space is found without any such contents; or else the fibrous basement substance lies immediately around the contents of the cells which are poured out into it. In the end a homogeneous fibrous material is found, in which a large quantity of fat-vesicles are scattered about together with some small and generally granular cells. A few washed-out clear streaks pass through it.

In examining the material which covers the surface of the cartilage as a viscid exudation, I have found it homogeneous, dark, and finely granular, without any trace of organization.

Towards the end of the healing process, the adhesions between the muscles surrounding the joint are usually reabsorbed. The muscles are again easily separable at some distance from their insertion into the new-formed capsule or the fibrous uniting material. I have already made the same observation as to the adhesions between the tendon of the long head of the biceps and the parts which surround it. Perhaps, as a consequence of this liberation of the muscles, at any rate always simultaneously with it, a recurrent shortening of the extremity operated on takes place, which, however, I have never seen to so great an extent as that which immediately follows the operation. The degree of this depends of course principally upon the size of the portion of bone removed, and the nature of the new joint which is formed.

The usefulness of the limb operated upon became in many cases quite perfect again—notwithstanding the shortening; in other cases it remained so far imperfect that the animals used the limb operated on only in quiet motion, and in more rapid movements carried it drawn up to the body and pendulous. In a few cases the result was so unfavorable that the animals appeared unable to raise the limb, and dragged it after them on the ground. Excoriations then formed upon the leg. I have never seen the formation of anchylosis in the shoulder-joint. Contractions in the neighbouring joints occurred only in a few cases, and always only in those in which the inflammation in the upper arm had been propagated downwards to the joint lying next below it, and had resulted in suppuration there. I have found in those cases the articular capsule considerably thickened, swollen out like a ball, and containing dry white pus. The cartilages investing the articular ends had disappeared, and the latter were either rough and porous, enlarged, or covered with fibrous tissue, by means of which they were more or less immoveably anchylosed together. Undoubtedly the alteration in the insertions of the muscles involved in the operation is capable of producing contraction, as soon as these muscles come into action again; but I have not succeeded in proving this to be the cause of it in any of the cases which I have observed.

## II. *Resection from the substance of bones.*

The healing process after resections from the substance of bones takes place as often by first intention as by suppuration, if the wounds are brought into accurate apposition. I have never seen any essential differences in the results, dependent on one or the other kind of union. If the union has occurred by suppuration, the preceding inflammatory symptoms have never been so considerable, or the suppuration so abundant, so extensive, or so persistent as in resection of the ends. In essentials the process of union is the same as that of fractures, as the latter is set forth by Voetsch in the work which has been so often quoted.

We find the same alterations in the soft parts which surround the situation of the resection, the same alterations of the periosteum and of the exudation which proceeds from it. In the latter the differences above described are observable from an early period.

I have not succeeded in following the development of ossification in that part which is organized into immature cellular tissue; and do not know whether it furnishes a product of another form in this case also. In the cases where, after the completion of the healing process, the two resected extremities, which are enlarged by the deposition of new bony material and in which the portion of the medullary cavity lying nearest the sectional surface is closed up, are united by a fibrous material (evidently developed out of the immature cellular tissue,) granules of bone are frequently found deposited in this cord. I have seen such granules also after resection of the extremities of bones in the portion of the exudation which is converted into fibrous tissue, but have deferred their mention till this place. Their origin is doubtful. On the one hand it cannot be denied that it is possible that such granules of bone may be portions of the old bone, which are splintered off in the sawing, and become afterwards imbedded in the exudation. Voetsch inclines to this opinion. He found a granule of bone of this kind on the eighth day after resection of a portion from the substance of the radius of a pigeon, in the yellowish-red part of the exudation. Again, these granules of bone may also be formed by the ossification of rounded agglomerations of lowly developed cartilage-cells; and such cells I have found scattered through the immature cellular tissue which is formed from the exudation. This opinion appears to me to have at least as much probability in its favour as the one above mentioned. For the fact that granules of perfectly developed bony substance should be found so soon after the operation cannot militate against it, inasmuch as about the same time a large part of the cartilage formed around the resected ends is already fully ossified. I should have assumed unconditionally the development of these granules of bone out of the discs of cartilage, were it not from an examination of them and of the cellular tissue surrounding, them, on one occasion, which made me doubtful of this. Thus, when I have subjected the newly formed bony material, not too long after the resection, to the action of dilute muriatic acid, I have usually observed, after a copious extrication of air-bubbles, the structure of the cartilage come into view again, more or less altered, after a tolerably long interval. But on the occasion referred to, on making a fine section of one of the granules of bone of which I am speaking, in the preparation of which numerous particles, mostly of small size, were detached, and examining it with its surrounding cellular tissue under the microscope, I saw, contrary to the result of my other observations, the wavy fibres of the cellular tissue running in a perfectly parallel course, and not arranged concentrically around the dark bony material; and I believed that I could also see them, though very obscurely, running through the finely granular masses. In the latter lay small longitudinal corpuscles, with short radiating processes arranged parallel to the fibres of the cellular tissue. When I added diluted muriatic acid to the preparation, the fibres outside the dark portions became pale, and gradually disappeared. The black corpuscles with their radiating processes also disappeared from the dark spots with a considerable extrication of air-bubbles, and in the clear transparent homogeneous material, which was left, only slightly clouded in the situation of the former dark spots, were lying single, round, and elongated nuclei. There was no trace to be seen of any structure resembling cartilage. It seems to me therefore possible that the granules of bone imbedded in the cellular tissue may also originate from an ossification of the cellular tissue itself.

I have never in any case seen perfect bony reparation of the loss of substance occasioned by resection from the substance of a bone. Nor in the preparations which I removed soon after the operation have I found the materials necessary for it. For the cartilaginous cushions deposited on the cut ends were never united together, but always separated by a layer, however delicate, of the yellow soft exudation.

The reproduction of the bony material was reduced to a minimum in those cases in which I had taken away the periosteum together with the piece of bone. It appeared then only around the ends of the bones, which were rounded off by it or ended in a tubercular point, while the medullary cavities were closed in the immediate neighbourhood of the sections. Occasionally, in these cases, after resection of the radius, the ends were immoveably united to the ulna by a new bony formation extending to a variable distance on that bone. I have never seen any bony deposit in the medullary cavity of the ulna. The space left between the ends of the bone was either filled up by a cord of cellular tissue, or was quite empty.

Corresponding to the slightness of the inflammatory symptoms which follow resection from the substance of bones, I have found only in a single case new formation of bone at a considerable distance from the cut ends of the bone; in the rest it was always limited to the neighbourhood of the sawn surfaces of those ends.

Thus, besides the preservation of the periosteum, I have to lay down as a second condition necessary for the bony union of the resected extremities, their perfect immobility. I have not succeeded in determining whether the want of this condition causes only a difference in respect of quantity in the organization of the exudation into cellular tissue and bone, or whether a difference also in quality is connected with it, so that with complete immobility of the resected extremities no organization whatever of the exudation into cellular tissue occurs. In judging, however, from the results obtained by investigations into the healing process after fractures, I consider the former as probable.

Occasionally, after resection of portions of the shaft, the cut surfaces of the ends of the bone are attacked with necrosis, and this may, even in rare cases, extend beyond them. If the necrosis is peripheral, the medullary cavity becomes completely closed by bony material within the necrotic portion, while new formation of bone goes on gradually on the outer surface of the bone—especially on the side of the bone turned towards the wound—commencing originally below the necrosed portion. If the necrosis is total, the medullary cavity of the healthy bone is closed below the line of demarcation, and the necrosed portion is sometimes invaginated by newly formed bone, which originates from the outer surface of the sound bone, and progresses slowly; while, occasionally, the new formation of bone does not overstep the line of demarcation.

The newly formed bony material on the resected ends is at first porous; whiter when dry than the remains of the original bone, and quite solid. Later on it becomes more compact—the remains of the original bone are absorbed, and diploic tissue and a medullary cavity are formed in it, the latter being closed at the cut ends by a delicate lamella of bone.

If the loss of substance left after the completion of the healing process is somewhat considerable (as it was in all the cases in which I operated without preserving the periosteum), there resulted, as Heine has also observed, a bending or a shortening; which, in limbs with two bones, was strongly marked on the uninjured one.

In rare cases, especially if the inflammation had been propagated to the next joint, and had there resulted in suppuration, contractions were developed, which rapidly increased and much interfered with the usefulness of the extremity. In the joints which had suppurated I found the changes mentioned in the former section.

The muscles surrounding the situation of the resection, which at first are firmly united together for some extent, at a later period can be separated again; they are adherent to each other close to the point of resection, and are attached only to the periosteum, which is somewhat thickened, and to the ends of the bone, but also project into the gap which is to be found between the latter.

The utility of limbs with only one bone is of course interfered with by the false joints which are formed; in those with two bones, the one which was uninjured often formed a sufficiently firm support to maintain entirely the usefulness of the extremity.

### III. *Extirpation of bones.*

I have extirpated the radius in pigeons, without preserving the periosteum, six times only. The wounds were closed by a firmly adherent dried coagulum of blood, and all healed by the first intention. No inflammatory symptoms whatever made their appearance in the neighbourhood of the wounds. When I unloosed the wings, from three to six weeks afterwards, the birds flew perfectly well.

In no case could I see a trace of new formation of bone. I felt, through the soft parts, a firm, thin, perfectly flexible cord in the situation of the radius. In the dissection it was often impossible to find even this. The firm cicatrix in the soft parts occupying the position of the radius, which were closely united together, had obviously given the feeling of a cord. In other cases there was found between the soft parts a thin cord-like fibrous material closely united to them, which in one case enclosed the residuum of a yellowish-brown coagulum of blood. The articular surfaces which had been exposed, but not injured, in the operation, were closely surrounded by the consolidated soft parts, and covered with unaltered cartilage.

## CHAPTER IV.

### EXPERIMENTS WHICH HAVE FURNISHED THE PREPARATIONS FOR THE PLATES.

#### I. *Resections of the extremities of bones.*

EXPERIMENT I. (Figs. 1, 2, 3.)

On a full-grown rabbit the head of the humerus and a part of its shaft was excised in the way above described (p. 159), and a piece seven lines long on the whole was removed. The length of the upper arm before the operation, from the acromion to the point of the olecranon, was two and a half inches, and immediately after the operation two inches two lines. Three hours afterwards no shortening could be detected. The animal was cheerful, ran about with the leg hanging and trailing a little, and fed. Gradually the animal drew the extremity so much towards its body that it no longer touched the ground in running. It died on the eighteenth day after the resection. The examination was made immediately after death. I then found the upper arm which had been operated upon three lines shorter than the sound one. At the dissection, a rather hard swelling, the size of a walnut, was found, on the anterior wall of the thorax between the fore legs, which contained thick yellow pus. The lungs and heart were healthy.

No particular swelling was to be seen in the neighbourhood of the joint. The wound was closed, but the soft parts in its immediate neighbourhood were infiltrated with pus. By cutting through the soft parts on the outer side of the joint, a cavity about the size of a pea was exposed, filled with inspissated pus. The resected end of the humerus was situated in this, lying near to the glenoid cavity. The muscles surrounded the bone up to half a line below the level of the section. In their course up to the glenoid cavity, and around that cavity, they were firmly united together, almost cartilaginous in consistence, and thus formed a sort of capsule around the situation of the joint. They were covered with granulations on their inner (free) surface. The surface of the bony section was covered with a white and tolerably firm cap, about two lines in thickness, which separated it from the glenoid cavity. This cap was in intimate connexion with the medullary substance, and lay upon the free edges of the tube of the bone, but without being attached to them. The substance of this cap was found, on microscopic examination, to consist of an amorphous granular mass, of turbid yellowish hue, through which fine fibres ran, crossing each other in various directions. Pus-corpuscles were visible on the edges and in the circumference of the object.

The bone above the insertions of the muscles was white, dry, smooth, and deprived of periosteum (fig. 1 *b*, fig. 2 *b b*). It was very difficult to separate the muscles from the humerus. In doing so the periosteum covering the bone up to the necrotic ring, and a few of the bodies which will be described directly, lying between the bone and periosteum, were torn away from the bone with that membrane. On the exposure of the upper end of the bone, an annular swelling was observed around it, which began close below the part deprived of periosteum, and descended in a gradually decreasing layer, down to about a quarter of an inch below the surface of the section, where it passed imperceptibly into healthy bone. This deposit consisted in its outer portion of a yellowish-red mass, in which, especially at its upper edge, were found imbedded some pale, firm granules, about the size of a pin's head, arranged like a necklace. These again contained in their centre a material of snowy whiteness. The deeper layers of the deposit, lying next the bone, were also white, and (especially below) inseparably united with the bone (fig. 1 *a*, fig. 2 *aa*). At the upper part the whole deposit might be separated from the bone, as was done accidentally in denuding it of the muscles. The bone underneath it, was pale and rather rough.

On microscopical examination, the yellowish-red mass was seen to consist of a number of fine parallel fibres, which became paler on the addition of acetic acid, and gradually disappeared, leaving a number of fine blackish elongated nuclei, lying in a direction which corresponded with the axis of the fibre. Close to the rounded granules which were imbedded in them, the fibres assumed a concentric arrangement around the granules; the number of nuclei increased here to an extraordinary degree; they became smaller and round; and the transition to true cartilage, of which the pale substance of the hard granules consisted, was very gradual. In the cartilage the nuclei were small, rounded, very thickly aggregated together, partly with, partly without, nuclei, and surrounded by a cell-membrane, encircling them for the most part closely, the contents of which were finely granular and rather darker than the intercellular substance, which surrounded it in sparing quantity. At the situation of the snow-white material contained in the white granules, the cartilage was found to be ossifying. In the intercellular substance at this spot a quantity of fine black corpuscles were scattered, which surrounded the still unchanged cartilage-cells at the edges of the ossification. At the situation of the ossification the cartilage-cells presented, on their inner surface, a ring of fine black angular corpuscles. Between these corpuscles minute canals led, in radiating directions, outwards into the intercellular substance. In a few sections the cartilage-cells seemed to have disappeared out of the intercellular substance, so that the latter was disposed around clear spaces, and assumed a network appearance. The nuclei in the ossified or ossifying cartilage-cells were partly shrivelled, partly gone, and thus the bone-corpuscle (or lacuna) which had been formed out of the cartilage-cell was clearly shown as a hollow cavity. On addition of acetic acid the black corpuscles disappeared slowly, with a considerable formation of gas-bubbles; both the finer ones from the intercellular substance and the larger ones from the cartilage-cells. There remained perfectly clear cartilage, in which the cartilage-cells were merely very finely granular and less transparent than the substance forming the ground on which they lay, and partly contained shrunken nuclei, partly were destitute of nuclei. The clear meshes were surrounded by hyaline intercellular substance. On drying the preparation which had been treated with acetic acid, small crystals were formed, in the form of rhombic plates, partly single, but for the most part in twos or threes, and lying either touching each other in the form of a star or crossing over each other. These disappeared again on addition of distilled water.

After the separation of the closely adherent cap from the cut surface of the bone, a ring of porous bony substance, about half a line broad, and extending also about half a line downwards, was found on the inner surface of the free edge of the bone (fig. 2 *c*). This was situated higher than the upper edge of the ring of bone which was deposited on the outside. The medullary cavity was not yet quite closed by it. On making a longitudinal section of the bone, the medullary substance below the inside bony ring was found quite normal. On the outer surface of the bone ran two fine strips of bony substance, which became somewhat thicker as they were traced upwards, beginning from about a quarter of an inch below the surface of the section, and ending about half a line below it, exactly at the level at which the bony ring on the inner surface of the bone commenced.

The glenoid cavity was covered with fat infiltrated with pus. Beneath this lay the cartilage, which was a little roughened and turbid, and thinned over a great part of the joint-surface. On microscopic examination it showed the appearances of softening, which have been before described. At one point, near the centre of the articular surface (fig. 3 *a*), the cartilage was gone, and the bone was perforated. The pus had passed through the opening into the diploic tissue of the articular process. Around the opening a layer of white, newly formed bony material was deposited (fig. 3 *b b b*).

Fig. 1.

Fig. 2.

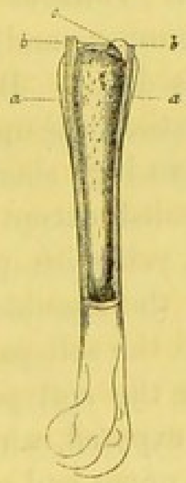
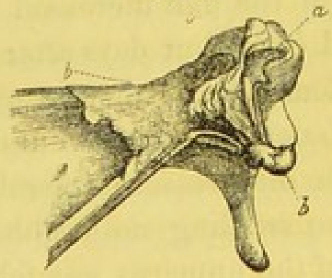


Fig. 3.



Explanation of Figs. 1, 2, and 3.

The humerus of a rabbit, eighteen days after resection of a piece, seven lines in length, from its upper end.

Fig. 1. Lateral view of the humerus.
*a*. New bony material.
*b*. Free edge of the section of the humerus, in a state of necrosis.

Fig. 2. The humerus seen on a longitudinal section.
*a a.* Section of the new bony material.
*b b.* The ring of necrosed bone.
*c.* A ring of new bone deposited in the medullary cavity, which has not yet quite closed that cavity.

Fig. 3. The articulating process of the scapula.
*a.* The articulating surface, perforated, and deprived of its cartilage.
*b b b.* New deposits of bone.

## Experiment II. (Figs. 4 and 5.)

In a full-grown rabbit, the head of the humerus was excised with a portion of the shaft; a piece nine lines long on the whole. The length from the point of the acromion to the point of the olecranon measured before the operation two and a half inches. Immediately after the operation, when the animal was quiet, the same space measured two and a quarter inches. A few hours later measurement gave the former length of two and a half inches. The animal remained cheerful, and dragged the fore foot of the limb operated on after it, leaning little of its weight upon it. Towards the end of the third week, it used this foot a little in running; and after this the usefulness of the foot increased up to its death. Before the animal was killed (fifty-four days after the operation) the upper arm operated on was found to be about a quarter of an inch shorter than the other.

*Dissection.*—The wound was healed except a small part, from which on pressure tolerably thick, yellowish pus escaped. There was no swelling noticeable around the shoulder-joint. The upper end of the humerus was felt through the soft parts rounded off like a ball, and freely moveable. After the soft parts were divided, a newly formed articular capsule was exposed, which passed off from the glenoid cavity, embraced the upper end of the humerus, and was inserted below its rounded end. This capsule contained a little pus. Its walls were on their inner surface somewhat rough, flocculent, and turbid. The muscles which surrounded the joint were firmly united to the outer surface of the capsule. Even at a considerable distance from the capsule, they could not be separated from each other. The tendon of the biceps muscle was only loosely connected to the capsule, and ran on its posterior surface. The upper end of the resected humerus was seen as an irregular smooth ring of necrosed bone, about a line in depth (fig. 4 *c*, fig. 5 *f*). Below this the hemispherical swelling was best marked. It extended about an inch and a half down the humerus, gradually thinning off. It was covered by periosteum, which was prolonged on to the unaltered part of the humerus below the swelling. On the outer side of the bone two kinds of deposit could be distinguished. The one was snow-white, porous, tolerably soft, began as a thin layer, gradually increasing as it was traced upwards, and lay immediately upon the bone. This thin layer stretched up on one side not quite so high as on the other (fig. 4 *b b*, fig. 5 *c c*). The second kind of deposit was brownish-yellow (fig. 4 *a*, fig. 5 *a a*); it was situated over the substance above mentioned, and was in immediate connexion with the capsule. It had not the same limits as the material which was deposited immediately around the bone, and was strongest on the side on which that material was the weakest. On that side it formed a cavity for a depôt of inspissated pus (fig. 5 *b*). A few roundish white masses of bone, some of them separate, some joined together, were scattered about in this deposit; and these had precisely the same properties as the material which lay upon the bone (fig. 5 *d*). Beneath the free surface of the section of the humerus the medullary cavity was filled with pus for the space of about a line, and below this was completely closed by a mass of bone about a line in thickness, which was inseparably adherent to the old bone (fig. 5 *e*). This deposit was continued for a few lines further downwards upon the walls of the medullary cavity. On microscopical examination the yellowish soft deposit and the new articular capsule were seen to consist of fibrous tissue; the white masses of normal bone.

The articular cartilage of the glenoid cavity was turbid, of a yellowish-brown colour, and separated from the edges of the articular surface. On microscopical examination the appearances of softening already described were seen in the superficial layers, and in those lying nearest to its circumference. In the deeper layers of its central substance it was distinguished from healthy cartilage only by a finely granular turbidity of the intercellular substance, by an increase in the size of the cells, and by a copious deposit of vesicles and granules of fat in them. No changes were seen in the scapula.

Fig. 4.

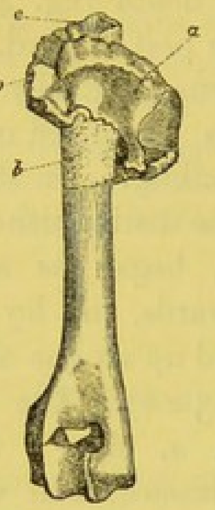
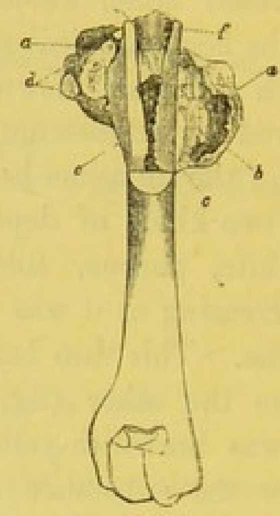



Fig. 5.




EXPLANATION OF FIGS. 4 AND 5.

Humerus of a rabbit, fifty-four days after resection of a piece, nine lines in length, from its upper end.

Fig. 4. Lateral view of the humerus on which the resection was performed.
- *a.* Newly formed yellowish mass, composed of fibrous tissue.
- *b b.* Newly formed bony material, deposited on the old bone, and disseminated through the yellow mass of fibrous tissue in the form of separate granules.
- *c.* Ring of necrosed bone at the surface of the section of the humerus.

Fig. 5. The same humerus; a longitudinal section having been made of its upper end.
- *a a.* The section of the yellow mass of fibrous tissue.
- *b.* Cavity in the latter, which was filled with inspissated pus.
- *c c.* Bony material deposited on the outer surface of the humerus.
- *d.* Granules of bone deposited in the yellow fibrous mass.
- *e.* Newly formed mass of bone within the medullary cavity, entirely closing its upper portion.
- *f.* The necrosed ring of old bone.

## EXPERIMENT III. (Figs. 6, 7, and 8.)

On a full-grown rabbit, the head of the humerus (fig. 6), three lines in thickness, was excised. A splinter obliquely broken off, and adhering to the sawn surface, was cut through with the bone-nippers. The muscles were left covering the remainder of the shaft of the humerus up to the same surface. No shortening of the limb could be observed, either immediately upon the operation or afterwards. The animal remained quite cheerful. Inflammatory swelling in the neighbourhood of the wound was present only for a few days after the operation, and disappeared when the suppuration began, by which the wound, which was closed at first, but opened again afterwards, healed. As early as fourteen days after the operation the animal ran about well, and used the leg operated upon almost as well as the healthy one. It merely trailed it a little. The animal was killed twenty-eight days after the operation.

*Dissection.*—The wound was perfectly healed; the cicatrix in the skin was closely united to the soft parts which lay below it. The humerus was firmly attached to the scapula, but freely moveable. A short, thin, newly formed articular capsule (fig. 8 *e e*) had been developed, which proceeded from the edge of the glenoid cavity, and was inserted on to the upper edge of the divided humerus. The muscles surrounding the joint were firmly united with this capsule; at a short distance from the capsule they could be easily separated from each other; they were firmly united to the edges of the section of the bone through the medium of this capsule. The tendon of the biceps muscle was uninjured, and ran on the posterior surface of the capsule, loosely united to it, but pretty freely moveable. Inside the capsule was found a serous, somewhat ropy, fluid, which showed under the microscope fat-vesicles of different sizes, small granular bodies, and epithelial cells. The inner surface of the capsule was smooth, and covered by a layer of pavement epithelium, which, together with the capsule, also covered the upper end of the humerus. No trace of cartilage could be discovered in this. On the external surface of the humerus (which was entirely covered by periosteum) an extremely thin layer of white, porous, bony substance had been deposited (fig. 7 *a*, fig. 8 *c c*), passing downwards on one side for about two lines, on the other for about six, from the surface of the section of the humerus, and covering the free edges of a portion of that section for a short distance. The medullary cavity was closed for the space of half a line by a firm, rather rough, plate of bone, (fig. 8 *d d*), which was firmly united to the walls of the medullary cavity and to the covering across the latter, derived from the articular capsule. The glenoid cavity was completely covered by healthy cartilage, nor was the scapula altered in any other respect. The lungs and heart were healthy.

Fig. 6.

Fig. 7.

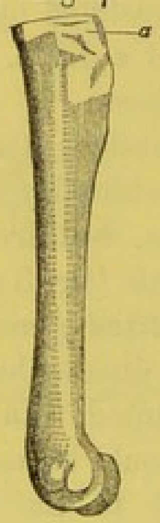
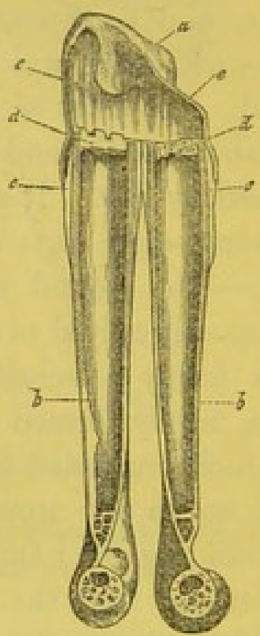



Fig. 8.




EXPLANATION TO FIGS. 6, 7, AND 8.

Preparations from a rabbit, twenty-eight days after resection of the head of the humerus.

Fig. 6. Resected head of the humerus.

Fig. 7. Side view of the humerus.
*a*. Very sparing thin layer of new bone.

Fig. 8. The new articular capsule, cut open, to which are attached the humerus, which has been sawn through longitudinally, and the glenoid cavity, seen from the front.
*a*. The articular surface of the scapula.
*b b*. The sections of the humerus.
*c c*. Newly formed bony material on the exterior of the humerus.
*d d*. Linear portion of the upper end of the section of the medullary cavity, closed by a newly formed mass of bone.
*e e*. New articular capsule.

## EXPERIMENT IV. (Figs. 9, 10, 11, and 12.)

In a full-grown rabbit the caput humeri was excised, with a portion of the shaft. The piece of bone was altogether six lines in length. The wound was united merely by twisting the hairs on its opposite sides loosely together. The length of the upper arm before the operation measured two and a half inches from the tip of the acromion to the olecranon; immediately after the operation a shortening of four lines was discovered, which, however, had almost entirely disappeared four hours afterwards. The animal was at first confined in a small dark place, and did not feed, but sat quite still. On the second day appeared a considerable swelling, fluctuating and very painful on pressure, which occupied the neighbourhood of the shoulder, the whole upper arm, and the external and posterior sides of the forearm. The fluctuation was most perceptible at the back of the forearm, and a small incision in this situation gave exit to a quantity of brownish, watery fluid. The wound of the operation was firmly closed. It was opened again, and then fluid of the same appearance flowed out from it also. The animal was now taken into a larger, light room, and soon began to feed and to run about, in doing which it carried the leg which had been operated on drawn up to its body, and pendulous. The swelling of the limb soon disappeared completely; the wound of the incision and operation healed by suppuration, the latter leaving a small fistulous opening, from which a little thick pus continued to exude on pressure. At the end of the third week the animal began to put the injured leg to the ground in running, but still dragged it very much, and clearly rested very little of its weight upon it. Towards the end of the twelfth week the animal used the leg which had been operated on almost as well as the sound one, and ran so quickly and nimbly that it was difficult to catch it, even in a small place. The upper arm operated on was two lines shorter than the sound one. The animal was killed eighty-four days after the operation.

*Dissection.*—The wound of the operation was completely cicatrized, except a fistulous opening. The cicatrix, as well as the skin on the upper arm, and in the situation of the incision in the forearm, was firmly united to the subjacent fascia. The upper end of the humerus, rounded off into a club-shape (fig. 9 *b*, fig. 10 *a*), was united with the enlarged articular extremity of the scapula (fig. 9 *a*) by an apparently solid and very thick fibrous structure (fig. 9 *c*), to the outer surface of which the surrounding muscles were firmly united. This consolidation of the muscles was found even at some distance. The tendon of the biceps muscle, which had not been injured in the operation, ran through the posterior portion of this fibrous structure, and was not very moveable in it, being pretty firmly united to that tissue. It had lost its pearly-white colour, and was dull and grayish. The fibrous material was attached to the whole surface of the glenoid cavity, which was entirely deprived of its covering of cartilage, and it ran down, in the form of an oval, compact mass, about four lines broad, to the upper end of the humerus, into the outer surface of which it was inserted about two lines below its upper edge. The upper end of the humerus formed a hemisphere, open above, and lay in contact with the lower end of the fibrous mass, but was not united to it by its upper surface. In the club-shaped end of the humerus, the upper end of which thus formed a cavity, there was lying an irregular ring of necrosed bone, completely loose, and surrounded by a mass of new bone (fig. 12). The newly deposited mass of compact bone began as a thin layer seven lines below the upper end of the humerus, and rose up along its outer surface, gradually attaining the thickness of one line, and spreading out into a club-like shape. It was deficient at the anterior side in the neighbourhood of the articulation corresponding to the fistulous opening, so that the necrosed bone was reached with a probe through the latter.

The surface of the deposit was studded with small tubercles, but was otherwise smooth. On a longitudinal section it was found to be no longer clearly distinguishable from the old bone, which had assumed a rather darker brownish hue, and gradually passed into the new. The formation of diploic tissue was shown in it by numerous fine foramina of a reddish colour (fig. 11 *a a*). The medullary cavity of the bone, which was not closed, contained unaltered medulla up to about five lines below the upper end of the humerus, and further upwards thick pus, covering the part of the wall of the old bone which was left, and which was of a white colour and appeared to be carious (fig. 11 *b*), and also filling the ring of necrosed bone.

The articular extremity of the scapula was also covered by a tolerably firm mass of new bone, which was a white colour and tuberculated, extending a few lines along the fossa supraspinata (fig. 9 *a*).

The viscera of the rabbit were quite healthy.

Fig. 9.

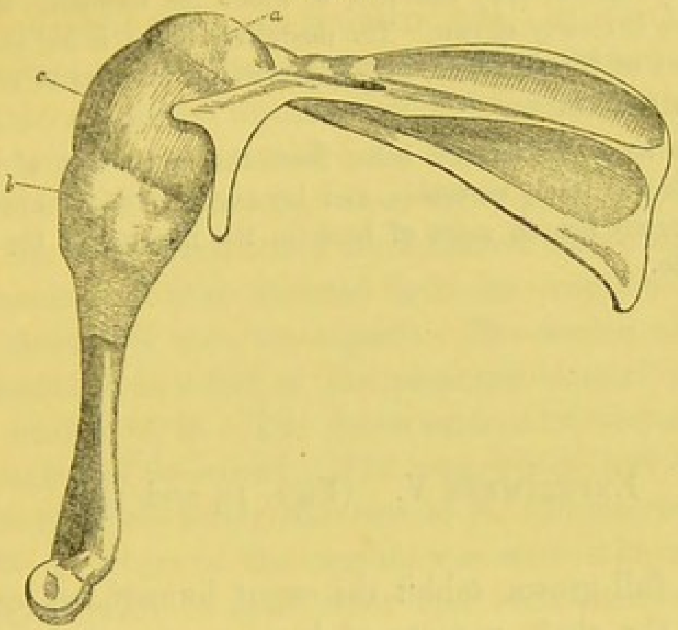



Fig. 10.

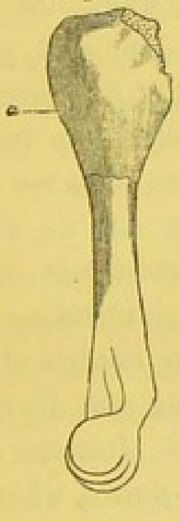



Fig. 11.

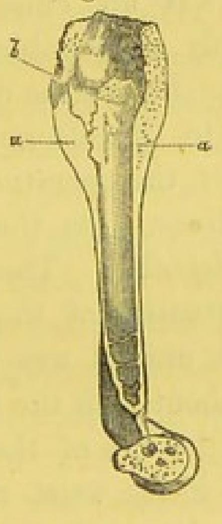



Fig. 12.

EXPLANATION TO FIGS. 9, 10, 11, AND 12.

Preparations from a rabbit, eighty-four days after resection of a piece, six lines in length, from the upper end of the humerus.

Fig. 9. The scapula and humerus united by means of a newly formed fibrous material, which has been cleanly dissected.

*a*. The articular extremity of the scapula, enlarged by deposit of recent bone.

*b*. The end of the humerus, swollen out into a club-like form by a mass of new bone.

*c*. Newly formed fibrous material.

Fig. 10. Lateral view of the humerus.

*a*. The end of the humerus operated on, enlarged into a club-shape by a mass of new bone.

Fig. 11. The humerus, seen on a longitudinal section.

*a a.* Newly formed bony material, in which the formation of diploic substance is clearly shown. The medullary cavity is not closed.

*b.* Remains of the old bone, in the interior of the mass of new bone, probably carious.

Fig. 12. Loose ring of necrosed bone, from the upper end of the humerus, which was freely moveable, and lay enclosed in the upper portion of the newly formed mass of bone in the interior of the fibrous substance.

## Experiment V. (Figs. 13 and 14.)

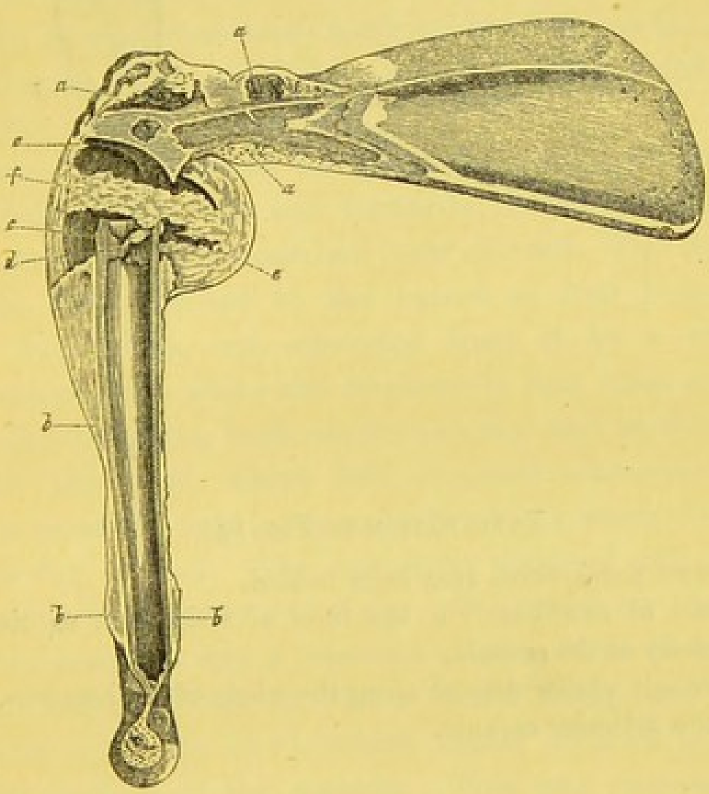
In a large, full-grown rabbit the caput humeri was excised with a portion of the shaft, a piece of bone on the whole six lines in length. The wound was not closed in any way, but the bone merely thrust as deeply as possible beneath the soft parts, and covered over by them. Before the operation the distance from the point of the acromion to the olecranon measured two inches nine lines; immediately after the operation the same distance measured only two inches four lines. On the following day no shortening could any longer be detected. There was a moderate amount of swelling around the situation of the resection, extending down to the elbow-joint. The animal was not again examined; it was cheerful, fed, and ran about with the leg hanging and drawn a little to the body. Towards the end of the fifth week after the operation contraction was noticed in the wrist- and elbow-joints, which gradually increased to such a degree that at the end of the seventh week the animal, keeping the extremity adducted, trod on the point of the arm, which was inclined to the forearm at a right angle pointing downwards. It leant little of its weight upon this, and trailed it somewhat. A little before the animal was killed, which was done on the fifty-second day after the operation, it was ascertained that there was no difference in the lengths of the two upper arms.

*Dissection.*—Around the shoulder- and elbow-joints there was still to be felt a spherical swelling, of a soft, doughy consistence. The wound of the operation was closed, except a small opening, from which thick pus oozed on pressure. On the side operated on a depression had been formed under the skin extending downwards to the breast, and so along the whole belly as far as the pelvis. This was filled with a small quantity of thick, granular pus. In the situation of the shoulder-joint a very firm capsule had been formed, which was bulged out into a rounded form below and behind, was filled with thick, white pus, and surrounded both the glenoid cavity and the resected end of the bone (fig. 13 *e*, fig. 14 *c c*). The muscles surrounding the joint were firmly consolidated with each other and with this capsule, and were inserted into the resected end of the bone on the same level with the capsule. The tendon of the biceps muscle was enclosed in a fold of the posterior part of the capsule, and loosely united to it. The inner surface of the capsule was somewhat rough and flocculent. The pus, which had become inspissated, was tolerably firmly adherent to it. On microscopical examination, the structure of the capsule was seen to be composed of fibres running parallel to each other and somewhat wavy, and of fibre-cells. These elements crossed each other in various directions. Between them were scattered small, rounded, and elongated nuclei. The humerus was covered, from its lower end upwards to the insertion of the muscles and capsule, with a firmly adherent deposit of bone, which in some places resembled stalactites (fig. 13 *b b b*, fig. 14 *b*). This was strongest a little above the lower end of the humerus above the capsule of the elbow-joint, which joint was the seat of the swelling above described, and was filled with thick pus. The upper end of the humerus was swollen into a club-like form. This swelling was found principally external to the new articular capsule. Above the swelling was seen an irregular ring of necrosed bone (fig. 13 *c*), the breadth of which averaged one line. The bony material deposited around the resected end of the humerus was strongest at its anterior side, and surrounded it on all sides like an irregular nodulated capsule. The ossification was perfect, no trace of cartilage being found left anywhere. The new bony material was covered partly by the periosteum, partly by the capsule, as far as it extended over the end of the humerus; they were firmly united to it, sinking into all the depressions between the individual nodules. The upper termination of the medullary cavity was filled with pus; below this was found complete closure of the medullary cavity by a bony material (fig. 13 *d*). This bone, seen on a longitudinal section, was about twice as thick in its posterior as in its anterior half, and was situated in the medullary cavity above the level to which the deposit of bone reached on the outside, with its lower edge exactly on the same level as the upper edge of the layer of bone deposited externally, and therefore corresponding to the ring of bone, which, viewed externally, appeared smooth and necrosed. Below this mass of bone the medullary cavity was filled with perfectly normal medulla, and was not encroached upon at any part. The new bony material was whiter than the old bone, tolerably porous and soft, and showed under the microscope the normal texture of bone, with peculiarly large cavities. A similar deposit of bone had taken place around the articular process of the scapula and along the spine of the scapula in the upper and lower spinous fossæ (fig. 13 *a a a*, fig. 14 *a a*). It was peculiarly copious at the upper edge of the articular process, which was swollen out into a solid ball almost the size of a small cherry. In the new deposit were seen on section numerous small and large cavities of a round or irregular form, filled with inspissated pus. The medullary cavity of the anterior extremity of the scapula was quite unaltered. The cartilage covering the articular cavity was thinned and was entirely deficient at its edges; where it was present, it was pale, turbid, and covered with a white deposit.

Its intercellular substance was opaque, finely granular, and of a yellowish tinge; the cartilage-cells were enlarged, and prolonged longitudinally, and arranged with their axes parallel to each other. Their contents were partly fine, round granules, which must be considered as fat-vesicles, partly from three to five blackish nuclei, with tolerably defined angles, often completely filling the cell. They did not change on the addition of diluted muriatic acid, nor did this occasion the evolution of gas-bubbles. Between the articular surface of the scapula and the upper end of the humerus was situated a smooth cushion, about one line in thickness, which was attached to the capsule and divided it into an upper and lower portion (fig. 13 *f*). Its surface had the same properties as the inner surface of the capsule, and on microscopical examination the only difference which could be made out between it and the capsule was that the fibrillation was less distinct, and that it contained a deposit of numerous amorphous, coarsely granular, masses between the fibres, and in interspaces formed by the crossing of the fibres. This appeared to have depended on an imbibition of pus, which had become gradually inspissated.

Between the layers of the pleura were adhesions, partly of old, partly of recent, standing. The heart was firmly united to the inner surface of the pericardium by numerous long, thin bands of adhesion. At the upper surface of the lower lobe of the right lung there was found a deposit consisting of four hard nodules, varying in size from a hempseed to a pea, which on section appeared granular and of a whitish-yellow colour, and consisted of inspissated pus.

Fig. 13.



EXPLANATION TO FIG. 13.

Preparation from a rabbit, fifty-two days after the resection of a piece, six lines in length, from the upper end of the humerus.

Fig. 13. Longitudinal section of the humerus, the new joint formed after the resection, and the anterior part of the scapula, seen from the front.

*a a a*. New bony material deposited around the articular extremity of the scapula.

*b b b*. New bony material deposited on the exterior of the humerus.

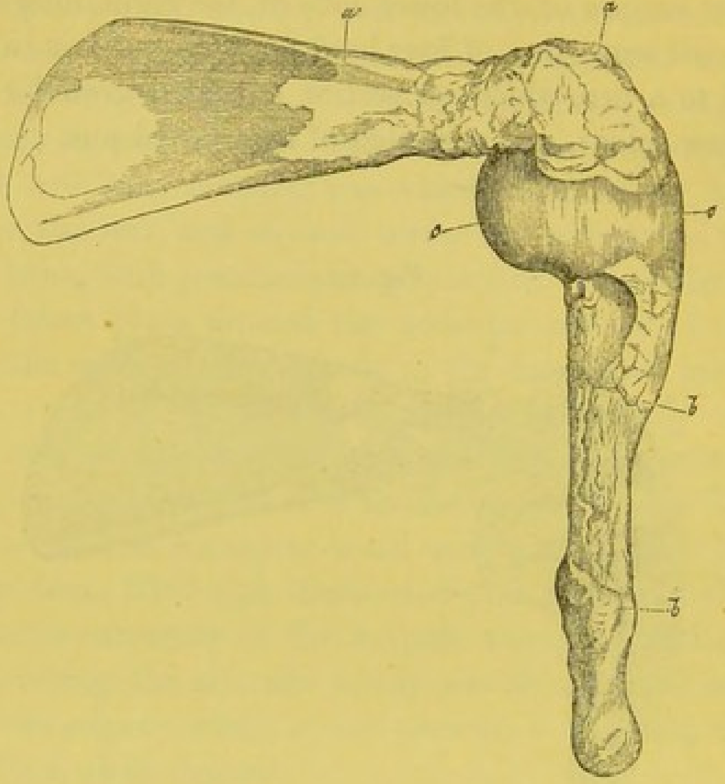
*c*. A ring of the upper end of the bone, necrosed.

*d*. A mass of new bone formed in the medullary cavity, and entirely closing it.

*e e*. Newly formed articular capsule.

*f*. So-called "meniscus" in the articular capsule.

Fig. 14.



EXPLANATION TO FIG. 14.

Fig. 14. The same preparation, seen from behind.

*a a.* Deposit of new bone, in the form of stalactites, on the articular extremity of the scapula.

*b b.* A precisely similar deposit along the whole of the humerus.

*c c.* The new articular capsule.

## EXPERIMENT VI. (Figs. 15 and 16.)

In a small rabbit, not full-grown, the right caput humeri was excised, with a portion of the shaft, a piece on the whole five lines in length. The wound was not united in any way, the resected bone merely thrust under the soft parts. I forgot to take the measurements of the extremity. Three days after the operation a very small obscurely fluctuating swelling presented itself near the situation of the resection; the resected end of the humerus had come out between the edges of the wound for a distance of some lines, and was replaced. The animal was cheerful, and ran about with its forearm drawn in towards its body. Three days later the wound was suppurating; the swelling around the neighbourhood of the joint had diminished, and become pulpy in consistence; the upper end of the humerus again projected between the edges of the wound for about three lines; it was covered with glutinous exudation, and of a pale-brownish colour; it was not replaced. The animal continued cheerful; the wound closed in around the projecting end of the bone; on pressing on the situation of the joint some rather thick pus still appeared by the side of the bone. This was the state of things when the animal was killed, on the fifty-sixth day after the operation. A short time before this it was running about nimbly, it supported itself, however, but little on the end of the leg operated upon, and carried it for the most part pendulous, drawn up against the trunk.

*Dissection.*—The humerus was displaced to a great extent from below and behind, upwards and forwards; between it and the scapula, a firm but moveable union had been effected. The upper end of the humerus was necrosed to the extent of four lines (fig. 15 *b*, fig. 16 *a*); below this, but separated from it by a well-marked line of demarcation, a white and moderately firm mass of bone was formed on the humerus, both on its exterior and in the medullary cavity. The old bone, which had assumed a brownish hue, was lost in this mass of new bone, so as not to be everywhere clearly recognisable (fig. 15 *c c*). The new bony material did not entirely close the medullary cavity (15 *d d*). It passed on the posterior surface of the humerus into a process a quarter of an inch in length, curved from behind forwards, like a bird's beak, and somewhat nodulated (fig. 15 *e*, fig. 16 *b*), which rested with its point against the articular surface of the scapula. This was surrounded by a layer of strong fibrous tissue (fig. 15 *ff*), intimately united to it. The latter extended from the point of the process over the whole of the glenoid cavity, which had lost its cartilage, and terminated on the edge of that cavity. The muscles surrounding the shoulder-joint were consolidated, not only to each other, but especially, and more firmly, to this fibrous tissue. Their arrangement was the natural one, but they were shortened, and those which ran on the anterior and inner side of the humerus were thrust somewhat backwards, corresponding to the displacement of the humerus. The tendon of the biceps muscle had been preserved, and ran (as did the upper end of the muscle) on the hinder surface of the beak-like process. Up to the point where this process came off, the bone was covered by the natural periosteum, but that membrane could not be followed further. Around the articular extremity of the scapula was a deposit of white, nodulated, newly-formed bone (fig. 15 *a*).

The viscera were healthy.

Fig. 15.

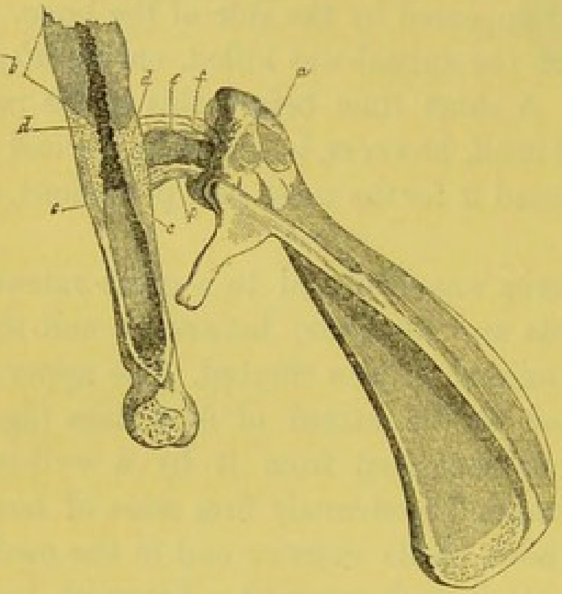
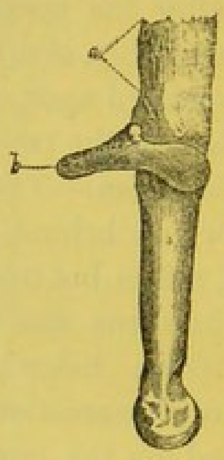


Fig. 16.



Explanation to Figs. 15 and 16.

Preparation from a rabbit, fifty-six days after resection of a piece of the upper end of the humerus, five lines in length.

Fig. 15. Scapula, with the resected humerus attached to it. A longitudinal section has been made of the latter.

*a.* The articular extremity of the scapula, enlarged by the deposit of new bone.

*b.* A portion of the humerus, which was necrosed and projected out of the wound.

*c c.* Remains of the old bone, which pass imperceptibly into—

*d d.* The newly formed bony material.

*e.* A newly formed bony process, which passes off from the posterior side of the humerus, and rests against the articular surface of the scapula.

*f f.* Fibrous tissue, surrounding the bony process in a solid mass, attached to the articular surface of the scapula, and maintaining a moveable union.

Fig. 16. The humerus, seen from behind.

*a.* Necrosed extremity of the humerus.

*b.* Bony process to the articular surface of the scapula.

EXPERIMENT VII. (Figs. 17, 18, 19, and 20.)

On a full-grown pigeon a piece of the upper end of the humerus, nine lines in breadth and five in length, was resected (fig. 17). At the operation the injury of the air-cavities was accompanied by a well-marked hissing from the wound and the escape from it of frothy blood. The wound was not united, but the wings were tied firmly together. The animal remained cheerful, ran about, and fed. As soon as the second day after the operation the wound was closed by a firmly adherent dry clot of blood. The swelling in its neighbourhood was very inconsiderable. Suppuration was not clearly perceptible after this, but a thin, yellowish secretion poured out in small quantity from under the coagulum on pressure. The coagulum having separated and been removed at the end of the third week, the wound below it was found closed by a fine linear cicatrix. When I threw the bird into the air at about this time it fluttered and moved the wing operated on a little, but soon fell to the ground, and then let the injured wing hang loosely down. It was killed on the forty-sixth day after the operation.

*Dissection.*—Immediately on opening the cicatrix a thin membranous capsule was exposed, which was united with it (fig. 18*a*), and which was inserted into the clubbed extremity of the os humeri attaching it to the scapula and coracoid bone. On these bones the capsule covered not only the articular surface, which was completely denuded of cartilage, but also the surrounding muscles to a great distance, so that these muscles were inserted on to the posterior surface of the capsule. On the anterior part of the inner surface of the capsule were inserted the ends of the muscles proceeding from the arch of the shoulder (fig. 18 *d*), which had been cut across in the operation, as well as the upper end of the triceps muscle. The anterior surface of the capsule was not covered by muscles. The interior of the capsule was villous and reddish; its texture had the characters of fibrous tissue on microscopical examination. A rather thin fluid filled its cavity.

The upper end of the humerus showed a deposit of new bone on its exterior (fig. 19, and fig. 20 *a*), beginning five lines below the upper end of the bone, and becoming gradually thicker towards the upper part. It was of a reddish-brown colour, very firm, and ended in a rounded mass of bone of a deep-yellow colour, which lapped over the free surface of the section of the humerus, but did not entirely cover the medullary cavity, and which enclosed a dried, reddish-brown, very hard substance, the remains of a clot of blood connected with the medullary cavity. There was deposit of new bone on the interior of the humerus also, beginning on the same level as that on the exterior (fig. 20 *b b*). This did not entirely close the medullary cavity at any point. It ended at the cut edge of the humerus beneath the deep-yellow mass of bone just mentioned, and was of a reddish-brown colour and great solidity. The two masses of newly-formed bone adhered firmly and inseparably to the humerus, which still was clearly recognisable between them (fig. 20 *c c*). They displayed all the characters of natural bony tissue on microscopical examination. In the deep-yellow mass the ultimate tissue of the bone had a yellow hue, otherwise this swelling was not to be distinguished from the rest of the deposit. The brachialis muscle cut across covered the anterior surface of the clubbed end of the humerus, and was inserted with the capsule on to the upper surface of that bone. There was no alteration in the bones of the arch of the shoulder. The viscera were healthy.

Fig. 18.

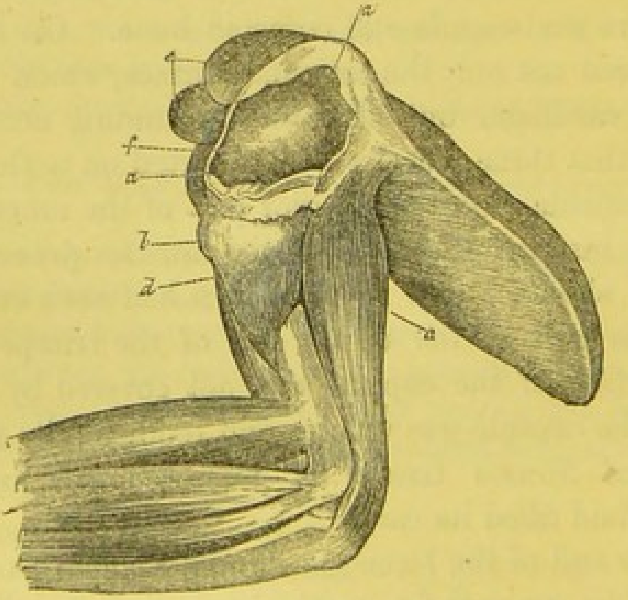


Fig. 19.

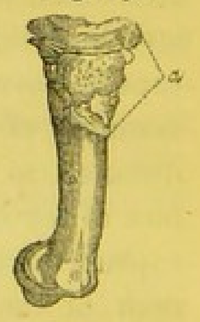


Fig. 17.

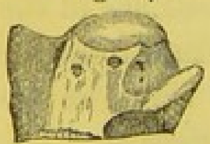
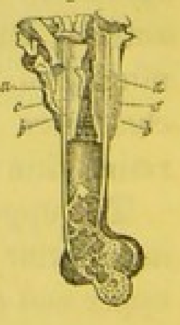


Fig. 20.



### Explanation to Figs. 17, 18, 19, and 20.

Preparation from a pigeon, forty-six days after resection of a piece of the upper end of the humerus, nine lines in breadth by five in length.

Fig. 17. The excised upper end of the humerus, with the openings of the air-cavities.

Fig. 18.
- *a a.* The newly formed capsule, slit open and denuded of muscles in front.
- *b.* The upper end of the humerus, rounded off into a club-shape, to which the new articular capsule is inserted.
- *c.* The triceps muscle.
- *d.* The brachialis muscle. Both these are inserted by their upper, cut, extremities into the new articular capsule.
- *e.* The cut ends of the muscles proceeding from the scapula and the coracoid bone, which are inserted into the new articular capsule.
- *f.* Fibrous tissue, constituting a part of the new articular capsule, which covers the articular surface, deprived of its cartilage, and the bone in its neighbourhood.

Fig. 19. A lateral view of the resected humerus, rounded off into a club-shape.
- *a.* The new bony material.

Fig. 20. A longitudinal section of the same humerus.
- *a a.* A mass of new bone, deposited on the exterior of the bone. It laps over the level of the section, but does not entirely close the medullary cavity.
- *b b.* A mass of new bone deposited in the medullary cavity, which also does not completely close it.
- *c c.* The unaltered old bone.

### Experiment VIII. (Figs. 21, 22, and 23.)

On a full-grown rabbit the caput humeri and a portion of the shaft, forming together a piece eleven lines in length, were excised (fig. 23). A few pointed fragments which had been left on the section of the bone were cut off with the bone-nippers. The length of the anterior extremity, from the point of the acromion to the olecranon, measured before the operation two and half inches. After the operation, when the animal was quiet, the same distance measured two inches. The wound was united by the interrupted suture. The animal dragged its leg after it, but was cheerful.

During the first six weeks it was kept confined in a small, dark room, and sat quiet, feeding well. It was then taken into a large, light room, and soon became lively, and ran about with the fore-leg drawn up against the body. As early as the fourth day after the operation a doughy swelling, of very considerable size, was found in the neighbourhood of the resected parts. As this increased in size continuously during the next two days, the sutures were removed, and the adherent edges of the wound partially separated again. A tolerably large quantity of brownish, watery fluid, and a rather thick, yellow pus, flowed out upon this being done. The space between the acromion and the olecranon could not be accurately measured, on account of the size of the swelling. The animal was not again examined immediately after this. At the end of the fourteenth week I felt around the neighbourhood of the shoulder-joint a doughy but solid swelling, composed of several smaller spherical portions. The wound was firmly cicatrized. Passive motion of the shoulder-joint was quite free, and I believed myself able to feel a new caput humeri through the soft parts. The animal ran nimbly, but carried the fore-leg more frequently than it supported itself on it. The latter was the case in quiet running; but if it were chased, it drew the leg up, and made use only of the three other legs. The rabbit was killed on the hundred-and-ninth day after the operation.

*Dissection.*—The skin in the neighbourhood of the cicatrix and on the whole upper arm was firmly united to the soft parts below it. The muscles also in the neighbourhood of the joint were equally firmly united to each other and to a new and strong articular capsule, which was pouched out above into two hard, spherical swellings. One of these (fig. 21 *d'*) was united firmly to the articular surface of the scapula, which was swollen up to the size of a cherry, and denuded of its cartilaginous covering. The strong fibrous covering of this swelling was continued into a second swelling, lying further forward (fig. 21 *d*), and into the articular capsule. The contents, composed of inspissated and dried pus, passed through an opening about the size of a pin's head in the articular surface of the scapula into the diploic substance of that bone. The pus contained in it was enclosed in a tolerably firm bony capsule, composed of the compact substance of the bone spread out (fig. 21 *a*). This bony capsule was again connected with another swelling, surrounded by a thick capsule of fibrous tissue, containing also inspissated pus, on the posterior and upper edge of the scapula (fig. 21 *d''*). The prominence situated furthest forward (fig. 21 *a*) was connected with the capsule itself by an opening the size of a millet seed, and this capsule was also full of rather thick, viscid pus. It was firmly inserted into the humerus on the healthy bone below its upper, clubbed extremity (fig. 21 *b b*). The inner surface of the capsule, as well as that of the pouches, was rough, opaque, and covered with pus. Its structure was that of fibrous tissue. The tendon of the biceps muscle arose from the upper and inner border of the glenoid cavity, and ran, in pretty firm adhesion with the fibrous tissue round the joint, at first in the grooves between the spherical pouches (fig. 21 *d' d*), and then on the edge separating the anterior and posterior aspects of the pouch situated furthest forward (fig. 21 *d*), down to the humerus. The somewhat thickened periosteum which covered the part of the humerus situated beneath the insertion of the capsule was continuous with the capsule, and passed over the club-shaped end of the humerus, which was situated within it (fig. 21 *c*). The latter was covered on its upper surface with a thin, opaque, yellowish layer of cellular tissue, and was freely moveable in the capsule. On the exterior of the bone there was a deposit of newly formed bony material, which was white, porous, and tolerably firm; it began five lines below the upper end, became a little thicker above, spread out into a club-shape, and closed the medullary cavity above with a thin, irregular lamella (fig. 22 *b b*). On a longitudinal section a slight deposit of bone was visible also on the interior of the humerus; but in this, as in the external deposit, the formation of diploic tissue had made very great progress (fig. 22). The bony material of the humerus which remained was quite rough, and pierced with numerous minute openings. It seemed to be in process of absorption (fig. 22 *a a*). The whole cavity of the bone was filled with healthy medulla, which appeared rather paler at the upper than at the lower part of the medullary cavity. On the articular process of the scapula, along the fossa supraspinata, and close to the spine along the fossa infra-spinata, there was a deposit of white, porous, nodulated new bone (fig. 21 *a a*).

The pleura costalis was united with the pleura pulmonalis for a great distance, and the pericardium with the heart. Otherwise the viscera were healthy.

Fig. 21.

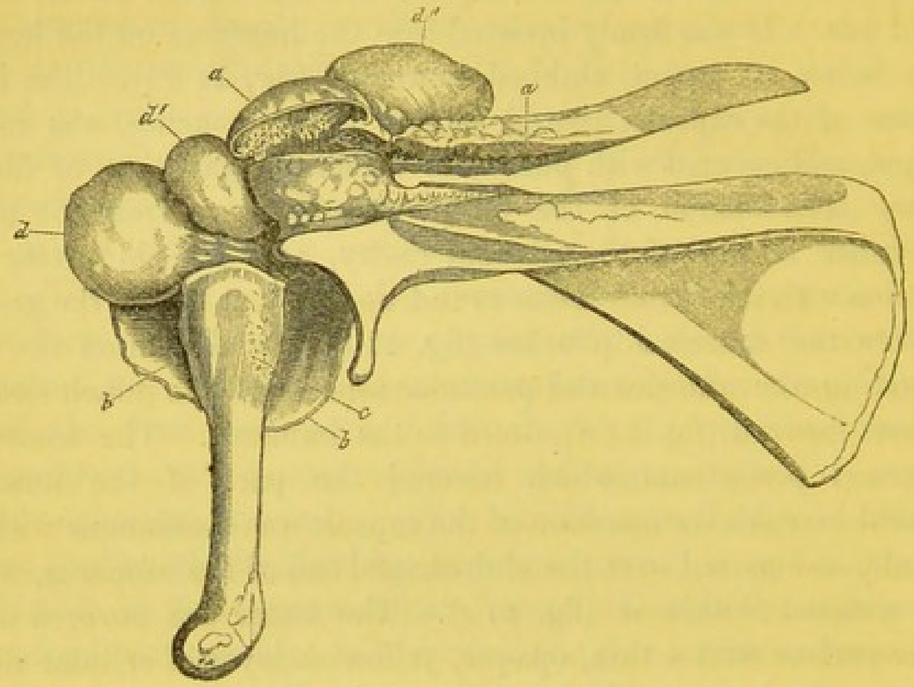



Fig. 22.

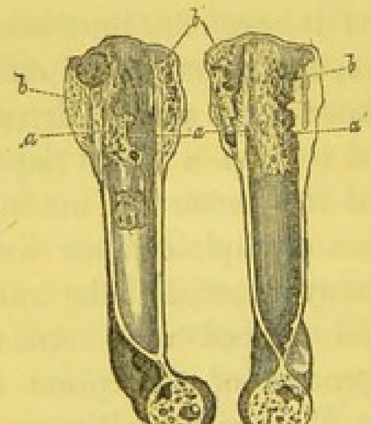



Fig. 23.

EXPLANATION TO FIGS. 21, 22, AND 23.

Preparation from a rabbit, one hundred and nine days after resection of a piece of the upper end of the humerus, eleven lines in length.

Fig. 21. The scapula, new articular capsule, and humerus, connected together.

*a a.* The scapula, through which a section has been carried. It is enlarged by deposit of new bone. The spherical, expanded, articular extremity formed a bony capsule containing inspissated pus.

*b b.* New articular capsule, cut open and spread out.

*c.* Club-shaped upper end of the humerus.

*d d' d''.* Encysted abscesses in the neighbourhood of the new joint.

Fig. 22. The humerus, seen on longitudinal section.

*a a a.* Remains of the old bone.

*b b b.* A mass of newly formed bone deposited in the exterior and interior, a fine lamella of which entirely closes the medullary cavity of the bone. The formation of diploic tissue in it is advanced.

Fig. 23. Portion of the humerus removed.

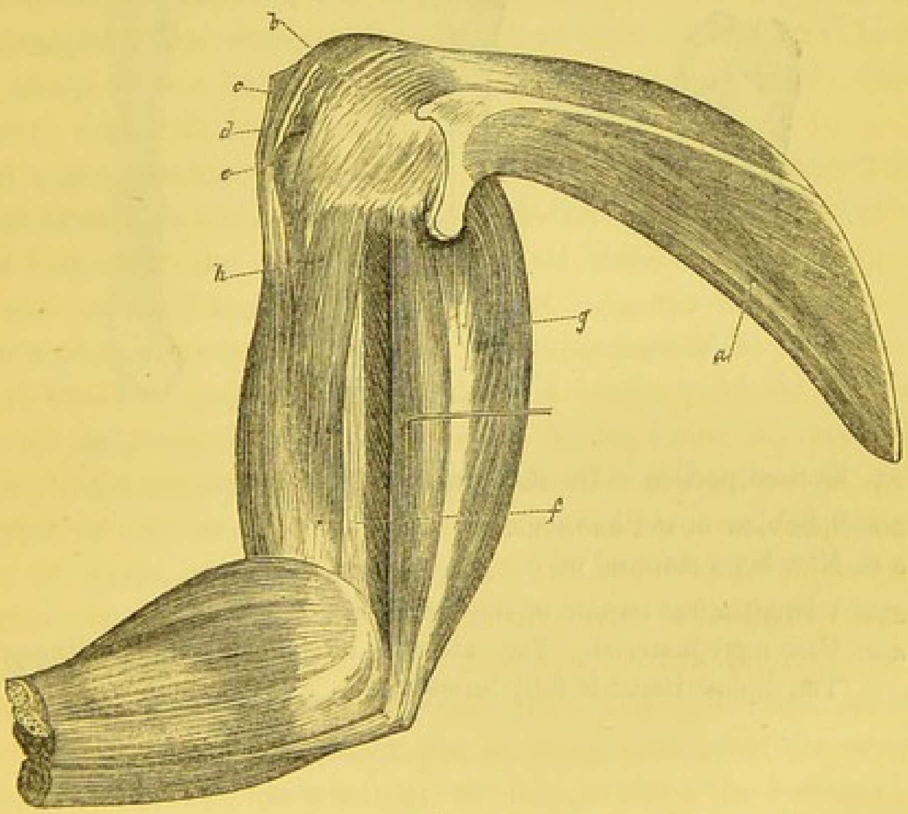
## Experiment IX. (Figs. 24, 25, 26, and 27.)

In a large, full-grown rabbit, the right caput humeri was excised with a portion of the shaft, a piece, on the whole, nine lines in length (fig. 25). The wound was closed by twisting the hairs loosely together, after the bone operated on had been thrust as deeply as possible under the soft parts. The length of the upper arm from the point of the acromion to the tip of the olecranon measured before the operation two inches, nine lines; and immediately after it, when the animal was quiet, in the sitting posture, two inches three lines. The animal was cheerful; it dragged the extremity on the ground slightly in running. Four hours after the operation, the distance between the points named measured two inches seven lines. On the second day a tolerably large and slightly fluctuating swelling showed itself in the neighbourhood of the wound of the resection. Pressure on this caused the discharge of some brown-coloured, watery fluid out of the wound, which was open. This discharge, to judge by the moisture and matting together of the hairs on the leg operated on, was continuous. On the twentieth day after the operation, the length of the upper arm measured two inches seven lines. There was a constant discharge of thick, laudable pus from the wound. The animal was cheerful. In running, it supported itself a little upon the leg, which still, however, trailed a little; if it was chased, it drew the leg up to the body, and ran on three legs. When I next examined the animal, at the end of the twelfth week, the wound was firmly cicatrized, and no trace of swelling remained around it. I thought that I could feel plainly a new articular head, through the soft parts. This was firmly united to the scapula, but moved with perfect freedom. The length of the upper arm measured two inches four lines, while the healthy one measured from the acromion to the olecranon two inches nine lines. The animal ran perfectly well, and both in quiet motion and when chased used the fore-leg operated on as much as the uninjured one. This animal was killed on the ninety-first day after the operation.

*Dissection.*—The cicatrix was united to an articular capsule lying beneath it. This came off from the edges of the glenoid cavity, and was inserted about three lines below the upper extremity of the humerus, which was expanded into a something of a club-shape. The capsule was perfectly closed. The muscles surrounding the situation of the joint were firmly united to the outer surface of the capsule, while at a little distance from it they were readily separable from each other. Over the anterior surface of the capsule the thin remains of the deltoid muscle were to be traced (fig. 24 *b*), and they had a common insertion, together with the capsule, into the humerus. The anterior and upper part of the triceps muscle, which lay nearest to the bone (fig. 24 *g*), and the upper end of the short head of the biceps (fig. 24 *h*), were firmly inserted into the bone together with the lower and anterior edge of the capsule. The tendon of the long head of the biceps muscle (fig. 24 *d*) ran in a fold of the capsule, which was smooth on its interior, and situated on the posterior surface of the latter (fig. 24 *c*), between two tubercles on the clubbed extremity of the humerus, which was enclosed in the capsule (fig. 24 *e*). It was quite freely moveable. The interior of the capsule was smooth, and its walls were covered with a layer of pavement epithelium. I failed to discover any epithelium on the fold of capsule for the reception of the long tendon of the biceps. In the capsule was contained a rather thin, ropy, reddish-yellow fluid, which showed under the microscope epithelial cells, fat-vesicles, and dark, granular bodies. (Qy. shrunken blood-corpuscles?) The cartilaginous covering of the glenoid cavity remained entire, nor was there any other alteration perceptible on the scapula. The humerus was covered with healthy periosteum, thickened over its upper extremity, which appeared to be connected with the capsule at its insertions, and was continued into the capsule over the portion of the humerus which was enclosed in it. The upper surface of the bone was covered by a thin layer of cellular tissue, which passed over at the edges into the periosteum. This cellular tissue was more opaque and not so smooth as the inner surface of the lateral walls of the capsule, and not covered with epithelium. Underneath the periosteum a layer of new bony material was deposited (fig. 26 *a*, fig. 27 *a a*), which was hardly distinguishable from the original bone, and which was thin at its commencement, and became thicker in proceeding from below upwards. It closed the upper end of the medullary cavity perfectly, with a thin lamella. The walls of the remainder of the old bone, as might be seen on section, passed gradually into this material, and were indistinguishable from it, as was also a deposit of bone on the walls of the medullary cavity. A thin layer of compact tissue surrounded the internal layer of the new bony material, which was developed into fully formed diploë. The whole of the medullary cavity was filled up with medulla, which was perfectly normal.

The viscera of the animal were healthy.

Fig. 24.




EXPLANATION TO FIGS. 24, 25, 26, AND 27.

Preparation from a rabbit, ninety-one days after resection of a piece of the upper end of the humerus, nine lines in length.

Fig. 24. Newly formed shoulder-joint, with its muscles.
*a.* Scapula.
*b.* Newly formed articular capsule, over which pass the remains of the deltoid muscle.

Fig. 24—*continued.*

*c.* A fold of the capsule cut open, in which runs—

*d.* The long tendon of the biceps muscle.

*e.* New tubercle on the humerus.

*f.* Humerus.

*g.* The triceps muscle, partly with its natural insertion, partly attached to the humerus, together with the new capsule.

*h.* Short head of the biceps muscle, inserted, by its upper divided end, together with the new capsule into the humerus.

Fig. 25.

Fig. 26.


Fig. 27.

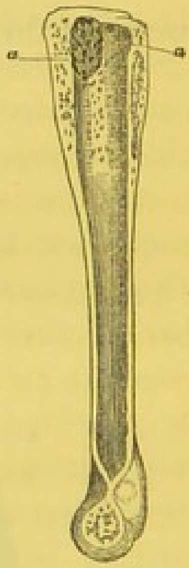



Fig. 25. Excised portion of the humerus.

Fig. 26. Side view of the humerus.
*a a.* New bony material on it.

Fig. 27. A longitudinal section of the humerus.
*a a.* New bony material. The extremity of the old bone has disappeared. The diploic tissue is fully formed.

## II. *Resection from the substance of bones.*

### Experiment X. (Fig. 28.)

In a full-grown pigeon, a piece four lines in length was excised from the shaft of the radius, the periosteum being spared as much as possible. The wound was not united, the wings were bound firmly together, and supported by the trunk. The bird remained cheerful, ran about, and fed. On the second day after the operation the wound was closed by a firm dry, blackish-brown coagulum. A slight swelling existed in the neighbourhood of the wound. The animal was killed nine days after the operation.

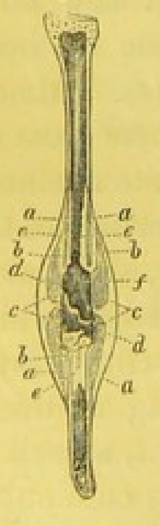
*Dissection.*—The wound was covered by firmly dried blood clot, which could be removed from it with tolerable ease. Under this the wound was found healed, except a small cleft, through which the clot extended down to the deeper parts. Around the situation of the resection was found a swelling of an oval shape, with its long axis in the direction of the limb, and of a tolerably firm consistence. The divided ends of the bones might still be moved a little from side to side. The skin in the neighbourhood of the wound was firmly united to the muscles which lay below it, and these to each other at the situation of the resection, and to the swelling which was situated below them. After they had been dissected off, the cut ends of the bone were seen surrounded by a yellowish-white, flexible material, which united them together.

On a longitudinal section of the bone the following was observed. About three lines above the section of the upper end of the bone there began in the medullary cavity, on both sides of it, a very delicate layer of white, bony substance (*e e*), which in proceeding down to its cut extremity, became gradually somewhat wider, turned round the free edge of the bone, and being rounded off at its anterior end, was continuous with a similar layer of white bone, which, commencing a little nearer the divided end, ran on the exterior of the bone (*b b*). On the lower end of the bone the state of parts was much the same, except that the new bony material was deficient on one side of its exterior, while the bony deposit in the medullary cavity closed it completely (*e*). Almost at the same level with the external deposits of bone there arose on each side of the two ends of the bone four bluish-white swellings (*c c*), which became thicker in proceeding towards the surfaces of the sections. They overlapped these surfaces considerably, and almost touched each other, two on each side, by their free edges, which were rounded off in front. Enclosed among these swellings lay a yellowish-brown, shrunken coagulum (*f*), corresponding in thickness to the medullary cavity, and loosely connected to it, as well as to the parts which surrounded it. This blood-clot was continuous with that which covered the wound, through a narrow fissure which passed through the whole swelling around the ends of the bone on the side looking towards the wound. Again, on the same level with the other deposits there was a capsule composed of yellowish-red and tolerably soft substance (*d d*), which formed the outer layer of the whole swelling, and in the interval between the free ends of the above-mentioned bluish-white enlargements passed in to touch the clot in the centre. The periosteum over both ends of the bone was finely injected for some distance towards each joint, and passed over on to the swelling around the ends of the bone. On microscopic examination, the white bony deposit showed the properties of fully formed normal bone, and the substance of the bluish-white enlargements those of young cartilage. In the hyaline intercellular substance of the cartilage, nuclei were found lying very close together, and partly surrounded by a cell-wall. The yellowish-red substance which enclosed both of these consisted on its surface of newly formed fibrous tissue, with fibres and fibre-cells running in parallel directions; in the deeper layers, nearer the centre, there were elongated nuclei and spindle-shaped cells also arranged chiefly in a parallel direction to the long axis of the bone. Between them cartilage-cells were again found scattered, and were present in greater numbers in several places, aggregated into small round masses, surrounded by the new-formed cellular tissue.

### Explanation to Fig. 28.

Longitudinal section of the radius of a pigeon, nine days after the resection of a piece, four lines in length, from its shaft.

Fig. 28.



*a a a a*. The remains of the old bone.
*b b b*. New bony material deposited on its exterior.
*c c*. A callus of newly formed cartilage.
*d d*. Yellow softer mass, consisting of young fibrous tissue.
*e e e*. Bony material formed in the medullary cavity.
*f*. Dried blood-clot (substantia intermedia).

## EXPERIMENT XI. (Fig. 29.)

In a full-grown pigeon, a piece four lines in length was excised out of the substance of the radius, the periosteum being spared as much as possible. The wound was not united. The wings were firmly bound together, and supported by the trunk. The bird remained cheerful, ran about, and fed. On the third day the wound was found closed by a black, dry, and firmly adherent coagulum of blood. In the neighbourhood of the wound I found a well-marked, club-shaped, solid swelling. The animal was killed on the thirteenth day after the operation.

*Dissection.*—The dried blood-clot was pretty firmly adherent to the wound. When this was drawn away there came into sight with it a yellower and softer portion of the clot, which was prolonged through the wound into the interior of the swelling, and a small quantity of thin, yellow fluid escaped. The wound was healed at its extremities. The spindle-shaped swelling on the bones was almost an inch in length. The cut ends of the bones were slightly moveable from side to side. The skin in the immediate neighbourhood of the wound was closely united to the muscles below it, and these to each other and to the material which formed the swelling. When they had been removed, the yellow, flexible material which enclosed the ends of the bone came into view. At the place corresponding to the wound in the skin this capsule was open, and by pressing the edges of the cleft away from each other the free end of the lower piece of bone (*b*) could be seen at the bottom.

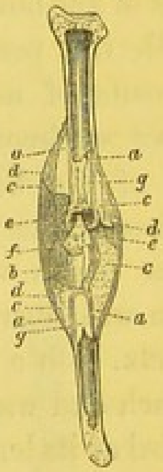
The following was observed on a longitudinal section: On the exterior of the upper piece of bone, and on the surface turned towards the wound (which I shall call the upper surface), about three lines from the surface of the section, and upon the surface turned away from the wound (which I shall call the under), was deposited a bony swelling (*c c*), commencing thin and gradually becoming thicker as it approached the divided extremity. This extended on the upper surface not quite to the section of the bone, while on the under surface it passed a little beyond it. There were two thin lamellæ of bone (*g*) in its interior, beginning on a level with the external deposit on the under surface, which completely closed the medullary cavity at the free end of the bone. Dark-coloured, coagulated blood lay between these two in the medullary cavity of the bone. In the same way there were on the lower end of the bone two lamellæ of bone (*c c*), which began at the same level, and were thin at their commencement and became gradually thicker. The one which was situated on the upper surface adhered firmly to the bone, and terminated in a rounded end about two lines from the surface of the section. That which lay upon the under surface adhered firmly to the bone up to a certain level, like the one above described; it then left it, and ran making a curve outwards imbedded in a yellow, soft material, to a point rather beyond the level of the cut end of the bone. The medullary cavity was completely closed by a mass of white bone from the commencement of the bony swelling deposited on the outside down to about two lines below the free end of the bone (*g*). On the bony swellings, which were deposited externally on the upper end of the bone, and on the bony material which lay on the under surface of the lower end of the bone, there were found three bluish-white swellings (*d d d*), which arose at the same level, and became thicker towards the section of the bone. These terminated in rounded extremities at the same level with the bony deposits. The lower cut end of the radius was deprived of its periosteum for the extent of about two lines, and was smooth and white, and projected into the material which we are just about to describe (*b*). Its medullary cavity was filled with dried blood-clot, a small remnant of which stretched up to the upper cut end corresponding in breadth to that of the medullary cavity (*f*). A yellowish-red soft material (*e e*) originating at the same level with the deposits on the exterior of the bone, formed the whole remaining part of the swelling, enclosing the parts above described, and insinuating itself between the bony material on the outer and lower side of the lower cut end and its necrosed portion. The periosteum was finely injected on both ends of the bone nearly to the epiphyses, and passed over on to the swelling, but could not be followed far upon it.

The new bony swellings showed on microscopical examination the structure of normal bone, with very dark, finely granular, basic substance, and few medullary spaces. The bluish-white swellings had the properties of newly formed cartilage. Its nuclei were for the most part nucleolated, some of them partly surrounded by a very delicate cell-membrane, which enclosed them closely, and they lay very closely aggregated in a hyaline intercellular substance, which was relatively to them in very small quantity. The yellowish-red substance consisted on its surface of delicate fibres, running in parallel directions, in which longitudinal nuclei were scattered. In the deeper layers the fibres were in smaller quantity, and were replaced by spindle-shaped bodies, rounded cells, and longitudinal darker nuclei. Cartilage-cells were scattered about in it, partly separate, partly aggregated into small heaps.

### Explanation to Fig. 29.

Longitudinal section of the radius of a pigeon, on the thirteenth day after the resection of a piece, four lines in length, out of its shaft.

Fig. 29.



*a a a a.* The remains of the bone.
*b.* A necrosed portion of it, not cut through in making the section.
*c c c c.* New bony material, deposited outside.
*d d d.* New cartilaginous deposits.
*e e.* Yellow soft mass, consisting of young cellular tissue, passing in between the lower bony deposit on the right side and the necrosed bone.
*f.* Dried blood-clot (substantia intermedia).
*g g.* New bony material formed in the medullary cavity.

## Experiment XII. (Fig. 30.)

In a full-grown pigeon, a piece four lines in length was excised out of the shaft of the radius, the periosteum being spared as much as possible. The wound was not united, but the wings bound firmly together. The bird remained cheerful. On the third day after the operation the wound was found closed by firmly adherent coagulum, of a blackish hue. A few days later a spindle-shaped, hard swelling could be felt at the situation of the resection. On the twelfth day the bandage which kept the wings together was removed. The bird moved the wing, but did not fly. The swelling persisted. The wings were again tied together. On the twenty-first day the swelling had materially diminished, the ends of the bone were still moveable, but the bird could fly. The wings were again tied together. On the thirty-fourth day after the operation the bird was killed.

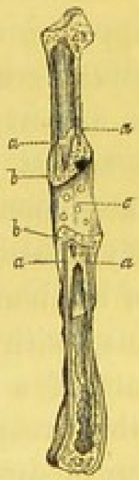
*Dissection.*—The wound in the skin was closed by a delicate cicatrix; there was no swelling in the wing. The resected ends of the radius could be felt through the skin, thickened, and slightly tuberculated, with an interval between them. Each end of the bone could be moved pretty freely. The muscles, which in the neighbourhood of the resection were united together, were dissected from each other, and removed from the ends of the bone, which were swollen and tuberculated. The latter were then found to be covered up to the surfaces of the sections with periosteum, which towards the ends was somewhat thickened. Between the ends of the bone it passed over into a ligamentous material. Underneath the periosteum there were found numerous irregular, small deposits of new bony material (*b b*). They were rough on their upper surface, very porous, and vascular; situated, over the upper end of the bone, only in the immediate neighbourhood of the cut surface; over the lower end, along the whole length of the bone. Their union with the bone was intimate, and its surface below them was also thinned, rough, and containing numerous vascular puncta. On a longitudinal section of the bone the medullary cavity at each end was seen to be closed by new bony substance for about a third of its length (*b*). The latter was porous, of a deep-red colour, which distinguished it from the wall of the old bone and from the external deposit. This external deposit, which was in the greatest quantity nearest the section, and diminished gradually, extended about as far as the bony material in the medullary cavity. It was continued over the wall of the bone and the internal deposit, and thus helped to close the medullary cavity. On its surface the fibrous material was deposited. At the points nearer to the joint ends of the bone, where deposits of bone were found externally, the medullary cavity was not trenched upon.

In the ligamentous tissue (*c*) between the ends of the bones, small whitish bodies, about the size of a pin's head, were found. The chief part of the uniting substance consisted of fibres of fibrous tissue, with very pale outline and wavy, parallel course, between which were scattered spindle-shaped cells and fibre-cells. Corresponding to the small white bodies the section of the mass was opaque, and small pieces of those bodies started out on its being cut into. Here a finely granular deposit was found, in an irregular, but tolerably circular extent, between the fibres, which had become very obscurely marked, and small, longitudinal bone-corpuscles, with radiating processes, lay within it. On the addition of dilute muriatic acid the fibres became very pale, external to the dark spots, and gradually disappeared. At the situation of these dark spots a strong development of air-bubbles occurred; the dark bone-corpuscles, with their processes, disappeared, the whole mass became homogeneous, and clearly transparent; round and longitudinal nuclei showed themselves in it, arranged longitudinally. In the situation of the former dark spots, which continued somewhat opaque, they were darker than in the rest of the mass.

EXPLANATION TO FIG. 30.

Longitudinal section of the radius of a pigeon, thirty-four days after the excision of a piece, four lines in length, out of its shaft.

Fig. 30.



*a a a a.* The remains of the bone.
*b b.* New bony material, covering the ends of the bone, and completely closing the upper portion of the medullary cavity.
*c.* Fibrous material, with bony nuclei scattered through it (the latter are shown diagrammatically).

## EXPERIMENT XIII. (Fig. 31.)

In a rabbit, which was not quite full grown, a piece seven lines in length was excised out of the shaft of the radius, the periosteum being spared as much as possible. The wound was brought together with sutures. The animal ran about after the operation with the leg drawn up, without supporting itself upon it. On the second day a considerable fluctuating swelling was found along the whole forearm, largest in the neighbourhood of the wound, which was firmly closed. Up to the fourth day the swelling continued to increase. The animal sat still, and would not feed. The sutures were removed and the wound reopened, on which a quantity of brownish, serous fluid escaped, and might be pressed out by stroking the limb. On this the swelling disappeared almost entirely. On the ninth day the animal had become cheerful again, and fed. The wound was suppurating healthily. At the end of the third week the wound was firmly healed, and there was no swelling in its neighbourhood. A small interval could still be felt between the cut ends of the bone. The animal used the leg operated on as well as the other. It was killed on the eighty-fourth day after the operation.

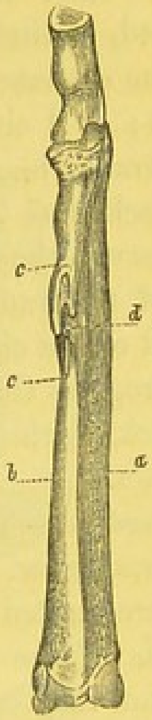
*Dissection.*—Under the cicatrix a small depression could be felt between the ends of the radius. The latter were somewhat tubercular, and immoveable. The cicatrix was firmly united to the subjacent fascia, and the latter to the muscles in the neighbourhood of the resection. The muscles were readily separable from each other, they embraced firmly the tuberculated cut ends of the radius, and dipped down into the depression between them. The ends of the radius were pointed by a deposit of new bone, which was white, porous, and irregularly jagged (*c c*). It replaced the loss of substance almost entirely for the length of about four lines at the lower and about two at the upper end. The medullary cavity was perfectly closed at both sections. The irregular cleft between the ends of the bone (*d*), which was about a line in length, extended to the ulna, with which the cut ends of the radius were firmly united by means of a narrow strip of new bony material, of a white colour. With this exception there was no deposit of new bone on the ulna. The periosteum covered the bone entirely. It was found somewhat thickened in proceeding towards the cut ends, and came off from them together with the muscles inserted into it.

The viscera were healthy.

EXPLANATION TO FIG. 31.

Bones of the forearm of a rabbit, after the resection of a piece, seven lines in length, from the shaft of the radius, eighty-four days after the operation.

Fig. 31.




*a.* Ulna.
*b.* Radius.
*c c.* The cut ends of the radius, covered with new bony material, and firmly soldered by means of this material to the ulna.
*d.* Space between the cut ends of the bone.

## EXPERIMENT XIV. (Figs. 32, 33.)

In a rabbit of middle size, I resected a piece nine lines in length from the substance of the radius, without preserving the periosteum, and united the wound by the interrupted suture. The animal remained cheerful, and at first carried the leg operated on drawn up to its body, but after only a few days again bore a little of its weight upon it. About this time a tolerably large, doughy swelling, very painful on pressure, had formed along the whole forearm, and especially around the situation of the resection and in the neighbourhood of the elbow-joint. The wound was firmly closed. I did not open it, and found a few days later only a slight increase of the swelling, which had become more solid than before. The sutures had cut out. The wound was for the most part united. Thick pus exuded on pressure from the ununited part. When I again examined the animal, at the end of the fifth week, the wound was firmly cicatrized, there was no longer any swelling on the forearm, but about the elbow-joint, which was flexed to a right angle, there was found a spherical, very hard swelling, not painful on pressure, and the size of a small walnut. The joint was moveable only to a very slight degree. In trying to extend it forcibly I felt a solid resistance, clearly depending on callus-material in the joint. At the same time a rectangular contraction of the wrist had occurred, so that the animal touched the ground in running only with the extreme point of the leg. Even this only occurred in quiet motion; if I chased the animal, it drew up the operated limb to a considerable height, and used only the three sound legs. The fore-arm itself was a good deal curved, with the convexity upwards. An interval, the breadth of a finger, was felt between the resected ends of the radius. Its condition remained about the same up to the end of the eighth week. The contraction of the wrist had made such progress that the animal, when it rested on the limb, trod on the back of the paw. It was killed on the fifty-sixth day after the operation.

*Dissection.*—The cicatrix of the skin adhered intimately to the soft parts below. The muscles in the neighbourhood of the resection were united together, and dipped into the hiatus between the cut ends of the radius, which was eight lines in length. In the dissection they came off from the ends of the bone, together with the periosteum, which was somewhat thickened. The ulna (*a*) was considerably bent in a curve, with the convexity upwards. The ends of the radius (*c c*) were rounded off by a small quantity of new bony material, of a white colour, and were firmly united to the ulna by similar deposit (fig. 33 *d d d*). This covered the outer side of the ulna also in a thin layer, corresponding in extent to the hiatus in the bone (fig. 32 *d*). The medullary cavity of the radius was closed at both ends, to a greater extent at the lower than the upper (fig. 33 *b b, c c*); the medullary cavity of the ulna was unaltered (fig. 33 *a a*).

The capsule of the elbow-joint was extraordinarily thickened and hard, and was firmly united to the muscles which passed over it. It had the size and shape of a small walnut. In the capsule dry, thick pus was contained, together with the joint ends of the humerus (fig. 32 *f*), the ulna (fig. 32 *e*, and 33 *e*), and the radius (fig. 32 *g*). They were very much enlarged by formation of new bone, and entirely deprived of their cartilaginous covering. The condyloid process of the humerus was firmly united to the sigmoid cavity of the ulna, by a short, strong, fibrous union, which covered also the other articular surfaces of the bones. On section, the new formation of bone could be recognised as a deposit on a portion only of the radius. On the articular process of the ulna, there was nothing to be seen of the original bone, but merely a homogenous, tolerably firm, but porous mass of bone (fig. 33 *e*).

Fig. 32.

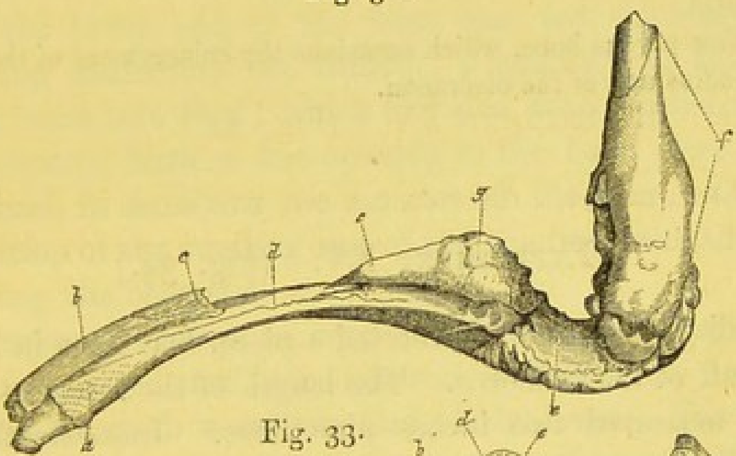
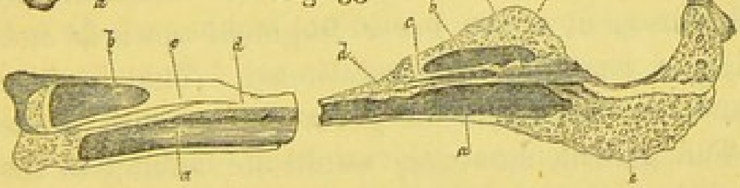


Fig. 33.



EXPLANATION TO FIG. 32.

Bones of the forearm of a rabbit, after the resection of a piece, nine lines in length from the substance of the radius; fifty-six days after the operation.

*a.* The ulna, much curved.
*b.* The radius.
*c c.* The ends of the bone, covered with new bony material, by means of which they are firmly united to the ulna.
*d.* New bony material deposited on the ulna.
*e.* The articular extremity of the ulna, considerably enlarged by deposit of bone.
*f.* Condyloid process of the humerus.
*g.* The head of the radius.

### Explanation to Fig. 33.

The same preparation, sawn across transversely in the centre, and longitudinally by different sections.

*a a.* The ulna.

*b b.* The radius.

*c c.* New bony material, completely closing the medullary canal of the radius.

*d d d.* New bony material, firmly uniting the ends of the radius to the ulna.

*e e.* New porous bone, which occasions the enlargement of the head of the radius and of the olecranon.

## Experiment XV. (Fig. 34.)

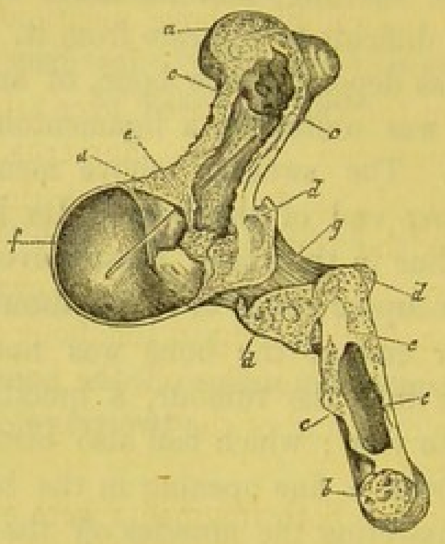
In a full-grown rabbit I resected a piece, five lines in length, out of the shaft of the humerus. The length of the humerus before the operation measured two inches nine lines. Immediately after it, through displacement of the lower fragment upwards and forwards, a shortening of one inch was occasioned. The displacement was reduced, and an apparatus of gutta percha with paste bandage applied. The animal, however, would not submit to the bandage, and gnawed it, as often as I replaced it, so as soon to get it off. The displacement of the ends of the bones thus recurred. An inconsiderable swelling, which had shown itself on the forearm, disappeared, as soon as the wound (at first closed by sutures) was reopened. Union took place by suppuration. The animal remained cheerful, carried the injured limb hanging, or trailed its lower part after it. Shortly before the animal was killed (which was done on the fifty-first day after the operation) the usefulness of the limb was found not to have improved. The two pieces of the humerus, where they had been sawn apart, remained at an obtuse angle pointing backwards, and were firmly united to each other, but moveable without crepitus. Firm callus-material could be felt through the soft parts. A round swelling of the size of a cherry, firm, but not solid, was present at the point of union of the two fragments, stretching backwards; it was slightly moveable, and appeared to be connected with the upper fragment of the bone.

*Dissection.*—The cicatrix was very delicate and firm. The muscles were natural, except that the triceps muscle was thinned, being raised by the swelling, and its fibres spread out to form a covering for it, and difficult to separate from it. On both fragments of the bone there was deposit of new bone, of an irregular tuberculated shape. This was united by a ligamentous material between the two fragments. The swelling above mentioned was united directly to the upper end of the bone. Its firm fibrous capsule, which was about a line in thickness, passed over into the thickened periosteum on the upper end of the humerus. The periosteum on the lower end of the bone was not thickened. On a section being made into the tumour, a quantity of thick yellow cheesy pus came into view; which had also been evacuated, though in small quantity, from a fine opening in the bone close below the articular head, in dissecting the muscles off the bone. On a longitudinal section of the swelling and of the two fragments of the bone, the following was observed:

The corresponding ends of both fragments were enlarged by irregularly tuberculated new bony material (*d d d d*), the end of the upper fragment much more than that of the lower. The medullary cavities of both were closed at their corresponding extremities (*e e*). The new bony material was continued as a narrow strip, which extended, for the most part clearly distinguishable from them, on either side of the fragments, towards their articular ends; and accompanied the upper fragment up to the joint, and the lower to about its middle. In this bony material the formation of diploic tissue had progressed in parts to a great extent, and the remains of the old bone had been in part absorbed. The medullary cavities in both fragments were filled with the same thick cheesy pus as was found in the swelling, and which showed normal pus-cells under the microscope. At the lower end of the upper fragment of the bone there was a cavity as large as a hempseed, which communicated with the medullary cavity by a fine opening. The capsule of this cavity exhibited, under the microscope, smooth fibres crossing each other in numerous directions. To this cavity was connected another and larger swelling (*f*), separated from it by a similar, but stronger, membrane. The corresponding extremities of the humerus, which were covered by new bony material, were partially united together by a short, strong, ligamentous structure (*g*), which externally was inseparably united with the periosteum.

The lungs, heart, and liver of the rabbit were quite healthy.

Fig. 34.



EXPLANATION TO FIG. 34.

Longitudinal section of the humerus of a rabbit, fifty-one days after resection of a piece, five lines in length, out of its shaft.

*a.* The upper end.
*b.* The lower end.
*c c c c.* The remains of the shaft.
*d d d d.* New bony material deposited on the exterior of the bone. The formation of diploic substance has made great progress; the remains of the old bone are in part absorbed.
*e e.* New bony material closing the ends of the medullary cavity after its division. In the upper fragment of the bone this is perforated, and is connected with—
*f.* A circumscribed encysted abscess, the pus from which also fills the medullary cavity. The communication is shown by a fine bristle.
*g.* Fibrous material between the ends of the bone.

## APPENDIX TO CHAPTER I.

I HAVE collected all the instances of dissections after successful operations for excision of bones and joints which I could find on record since the date of Wagner's publication in 1853. The great activity of both English and German surgeons in this branch of operative surgery led me to anticipate, before I commenced the search, a copious collection of authentic cases which would test the truth of our author's theories, and form a valuable addition to surgical literature. The meagre list which I am able to furnish, after a careful search of all the principal German, French, English, and American periodicals and treatises, shows how completely erroneous my anticipations were, and how accurately our author's complaint of the barrenness of this field of investigation applies even to the present day, when all other points connected with excisions have been so diligently studied. It is possible, however, that sufficient time has not yet elapsed since the general adoption of the operation for many opportunities to have been found of dissecting limbs on which it has succeeded. I believe the following list includes all which have been put on record. In arranging them I have followed the classification adopted in Chapter I of Wagner's treatise.

### A. *Excision of the shoulder.*

The cases of excision of the shoulder-joint which appear to have become the subjects of subsequent dissection are only three in number.

The first is to be found in the 'Deutsche Klinik' for 1856 (vol. viii, p. 21) by Herr Reid, of Jena. The operation had been performed one year previously, on account of caries of the head of the bone, with acute pain in the joint. One long incision had been made, and the tendon of the biceps was spared. The patient was in a bad state of health, suffering from the effects of empyema, &c. The scapula was found superficially ulcerated. The case went on well for eight months; the wound healed, except two small fistulæ, and the functions of the arm were perfect, except abduction. Then his health failed, pain recurred at the situation of the joint, and the usefulness of the arm diminished. He died of lumbar abscess, accompanied by tubercular disease in other parts. Dissection of the shoulder showed the ends of both bones enclosed in a capsule, which was lined by a membrane resembling mucous membrane, and covered by a viscid secretion. This capsule was closed, except at two points, where it communicated with the above-mentioned fistulæ. Its walls were formed in part by the remains of the old articular capsule, but principally by the muscles surrounding the joint. The latter were more or less fattily degenerated, and the supra- and infra-spinatus were also infiltrated with pus from the fistulæ. The long tendon of the biceps was traced upwards. It was free up to the resected end of the humerus: here it was firmly united to that bone; and beyond this point a deposit of bone was found in it corresponding to a bony swelling on the inner side of the resected humerus. Above this it was inseparably united to the capsule, and beyond that again could be traced in the form of a band, a quarter of an inch in breadth, bridging over the interval between the capsule and the remains of the glenoid cavity, which was affected with caries. The end of the humerus was a little enlarged and rounded off; on its inner side was a crest of bone, resembling an exostosis. The thicker parts of the scapula, and especially the acromion, were swollen and very porous. Lamellated bony deposits were found in the supra-spinous fossa.

The second case will be found in the 8th vol. of the 'Pathological Transactions,' p. 346. Mr. Hutchinson excised the head and about a third of the shaft of the humerus on account of a tumour described as of the myeloid variety. The tumour recurred (being then of a distinctly cancerous nature) in the wound and in other parts of the body, and the patient died five months after the operation.

The shaft of the bone was itself healthy, and was united to the lower edge of the glenoid cavity by a thick ligamentous band, so strong that the bones could not be separated by any moderate force. This union permitted of free motion in all directions. Springing from the periosteum of the humerus at the point of section, and surrounding the bone and the ligament, uniting it to the scapula, was a large mass of malignant disease. The deltoid muscle had been previously absorbed by the disease for which the resection was performed.

The specimen is in the Museum of St. Bartholomew's Hospital.

The third case is by Professor Heyfelder ('Prager Vierteljahrs.,' xxi, p. 87). It occurred before the publication of Wagner's treatise, and its omission is noticed by Heyfelder in a review of this volume. The details, however, are very scanty. The operation had been performed a year before, on account of caries. Death was the result of tuberculosis. The missing bone had been replaced by a material of new formation; which, where it lay close upon the bone, was firm, and of bony appearance; but, further away, resembled brawny fibrous tissue. The coracoid process was carious, and two fistulous openings led from it through the soft parts.

### B. *Excision of the elbow.*

Of successful cases of excision of the elbow, I have also been able to find only three on record. They are as follows:

Case I ('Lancet,' 1855, vol. i, p. 231).—The patient was a man thirty-eight years of age, who had been operated upon nine years previously by Mr. Syme for diseases of the elbow-joint, and who had made a rapid recovery, and had since been employed as a guard upon the Edinburgh and Glasgow Railway. When questioned as to the use of his arm, he always made the same reply, that he knew no difference between it and the other limb, that he could lift an equal weight with them, and that in swinging himself about from one carriage to another, when the train was in motion, and such other dangerous proceedings, he trusted one limb quite as much as the other. On accurately comparing the mobility of the two joints, it might be observed that the extent of motion was not so great on the side where excision had been performed as on the other; but flexion, extension, pronation, and supination were as perfect as could be desired for all useful purposes. The external aspect of the joint was wonderfully natural, the most obvious deficiency being the absence of the olecranon. The limb was not quite so muscular as that of the opposite side. He died of the effects of an accident.

The ends of the bones concerned in the elbow were removed after death, and a representation of them may be seen in the 'Lancet,' as above referred to. The following is Mr. Syme's description, with such verbal alterations as were necessitated by his references to an accompanying engraving:

"The elbow has a very remarkable appearance; the ends of the bones concerned, though quite different in shape from the normal condition, being yet so adapted to each other as to form a secure hinge-joint. The ulna is devoid of either olecranon or coronoid process, and, instead of embracing the end of the humerus, is received, along with the radius, into the forked end of the os humeri. This form of the last-named bone appears to have been produced by the growth downwards of two processes, one from each side of the cut end of the humerus, which appear to be entirely new formations. The ulna is separated a short distance from the humerus, the interval being occupied by a rather lax and vascular ligamentous union; but the radius forms with the humerus a true articulation, lubricated with synovia; the surface of the radius, where it touches the humerus, is rounded, the corresponding concave part of the humerus fitting accurately to it; these surfaces are in part covered with fibro-cartilage, and partly bare, and of porcellaneous hardness; but it is interesting to observe that a bare part of one bone is always opposed by a cushion of fibro-cartilage on the other. The radius and ulna are also adapted to each other; the tuberosity of the radius, into which the tendon of the biceps is inserted, being received into a concavity in the ulna, formed in part by a growth of the latter bone upwards into a process that curves over the rounded head of the radius, and gives attachment both in front and behind to a strong and distinct orbicular ligament, which is but loosely connected with the radius, and allows of its free play in rotation. To compensate for the loss of the head of the radius, which was removed in the operation, a prominent lip has grown out around the upper margin of the bone at its outer part, which thus has a purchase on the orbicular ligament, like the natural head. Between the radius and ulna there is partly loose ligamentous union, and partly a true articulation, lined with synovial membrane; the expanded insertion of the tendon of the biceps serving to cover the articulating part of the radius, while the depression on the ulna is lined with the nearest approach to pure cartilage that is to be found in this elbow. To the naked eye it looks quite like cartilage; and under the microscope differs from it only in the fact that the matrix is obscurely fibrous. Two strong lateral ligaments join the extremities of the processes of the humerus to the orbicular ligament on the one side and to the ulna on the other. A separate piece of bone (sesamoid) is imbedded in the internal lateral ligament at its juncture with the ulna. The extremity of the prolongation of the ulna upwards is also a separate piece united to the rest by ligament. The anterior ligament of the joint has been cut away; it was extremely strong, so as to compensate for the absence of the olecranon in checking backward movement of the forearm beyond the limit of complete extension; it was attached above to the anterior surface of the humerus, and below to the upper edge of the orbicular ligament, and the anterior surface of the ulna. There was also a strong posterior ligament."

Case 2.—Mr. Bickersteth[1] exhibited at the Liverpool Medical Society the elbow-joint of a female, æt. 42, who died seventy-three days after complete excision had been performed. After the operation she went on well for a week, when symptoms of phthisis set in. The elbow continued to heal as the disease progressed. Sloughs formed on the back, and a small one on the inner side of the elbow. A new joint had been formed, complete in all its parts, except where the slough had formed. All the movements could be readily performed. The tendon of the biceps had not been disturbed. A portion of the brachialis anticus which had been detached had acquired an insertion into a new anterior ligament. The triceps was attached to the cicatrix, to a new posterior ligament, and to the fascia. The interior of the joint was lined by a distinct synovial membrane, divided into two cavities, the radio-ulnar articulation being separate from the remainder of the joint. The structure of the ends of the bones was condensed, the cancelli filled up, and the surfaces presenting an almost porcellaneous appearance.

Case 3.—Dr. Mayer, of Wuerzburg, relates ('Deutsche Klinik,' vol. viii, p. 188) a case of excision of the elbow, in which only the end of the ulna was removed. Nine months after the operation all the movements of the forearm, flexion, extension, pronation, and supination, were perfect. At the above period a bony process resembling the olecranon could be felt given off from the end of the ulna, and connected with the triceps muscle; as could be easily made out in extension of the arm.

[1] 'Association Medical Journal,' 1856, p. 218.

D. *Excision of the hip.*

I have only two cases to add to Wagner's.

Case 1 ('Deutsche Klinik,' 1851, p. 497).—Heyfelder relates a case in which, sixteen months after the unsuccessful resection of the hip, the limb was removed together with the carious portion of the pelvis. I find no distinct description of the anatomical condition of the parts involved in the resection. The limb is said to have been at one time ankylosed to the pelvis, but the union gave way again. The acetabulum was filled with pus and with softened fragments of bone (deposited?), and surrounded with isolated fragments, which were removed partly with the forceps, partly with the finger.

Case 2 ('Glasgow Medical Journal,' vol. i, 1853-4, p. 10).—Dr. Buchanan gives a case in which the head of the femur was removed for caries in a man aged forty-one. The patient died three months afterwards of dysentery. The wound was almost entirely healed up; a small opening admitting a probe alone remaining open. The whole course of the incision underneath was completely consolidated. The cut surface of the neck of the femur and great trochanter were quite sound, being coated with a cartilaginous incrustation. The circumference of the acetabulum, from which the edges had been removed, was studded with spiculæ of new bone, showing the progress which nature had already made towards a cure. The acetabulum was filled up with granulations, but in some points was still rough, the reparative process having not yet extended over the whole seat of the disease. At the upper part of the cavity there was a small isolated piece of rough and porous bone, loose, and evidently in the course of being discharged piece by piece. Around this the bone was rough, but not spongy, while other parts were solid and smooth.

E. *Excision of the knee.*

The successful cases which have been dissected since the publication of our author's treatise appear to be as follows:

Case 1.—A preparation in the collection of St. Thomas's Hospital shows the condition of the limb after successful excision of the knee.

The patient was under the care of Mr. South, but I have not been able to learn the exact time which had elapsed between the operation and death. A very small portion only of each bone had been removed, and the patella left behind. The preparation shows tolerably perfect bony ankylosis between the tibia and femur, there being only a very slight and obscure movement between them. The remainder of the uniting medium (which is of very small extent) consists of fibrous material; there is no cartilage. A good deal of new bone is deposited around the end of the femur. The cancellous tissue is much condensed. There is a considerable amount of periosteal deposit around the patella, by which its extent is much increased. A portion of this deposit is ossified; and the patella is partially united to the femur by bony deposit. There is a small piece of dead bone in the head of the tibia. The front of the internal condyle of the femur is slightly carious, but this is thought to have been a secondary result of prolonged suppuration excited by the dead bone in the tibia. The soft parts have been removed.

CASE 2.—Mr. Henry Smith[1] exhibited, at the Medical Society of London, the bones which had been removed from the lower extremity of a boy who had, two years previously, undergone excision of the knee-joint by Mr. Jones, of Jersey, had entirely recovered from the operation, and died of disease of the liver. A firm bony ankylosis had taken place at the site of the operation, between the extremity of the femur and tibia, in nearly a straight position. The patella also, which had not been removed in the operation, was united to the anterior part of the femur, and its ligament was still attached to it and to the tibia, so that altogether a very firm compact mass of bony tissue occupied the situation of the knee-joint.

CASE 3.—Mr. Jones, of Jersey,[2] amputated the thigh several (apparently about nine) months after excision of the knee for caries of the femur and tibia.

The patient, a girl aged fifteen, was exhausted by discharge from a large abscess in the back, and this, together with the occurrence of frequent attacks of hysteria, caused sloughing of the parts and frequent displacement of the bones.

1 'Lancet,' Dec. 9th, 1854; from 'Edinb. Med. and Surg. Journ.' for 1855, p. 184.

2 'Medical Times and Gazette,' 1855, vol. ii, p. 342.

A portion of the lower third of the femur was found in an advanced stage of necrosis. There was strong ligamentous union between the femur and the tibia, and the patella was partially attached to the former.

Case 4.[1] — A preparation of bony ankylosis in the College Museum, from a patient of Sir P. Crampton.

This preparation is not very exactly described in the College Catalogue. From a card, however, which accompanies it, it appears that the patient survived the operation twenty-seven years. The end of the femur appears to have been sawn through close above the condyles, and is ankylosed at a right angle to the tibia, of which a very thin slice only can have been removed. The tibia appears also to have been displaced a little backwards, and somewhat twisted upon its own axis. A large quantity of porous bone is thrown out around the head of the tibia. The uniting medium between the two bones is solid compact tissue, of an ivory hardness, exactly resembling the compact tissue of the shaft in its neighbourhood.

I am not aware that any detailed history of this case exists, but it is referred to in Mr. Fergusson's 'Practical Surgery.'

Case 5.—The following case, although the patient is still alive, may deserve mention here as showing that bony ankylosis is not always necessary to the success of excision of the knee, but that some degree of useful motion may occasionally be preserved. The case is reported in the 'British Medical Journal,' 1858, p. 1001.

A healthy-looking girl, a housemaid, occasionally comes to King's College Hospital, whose knee was excised by Mr. Fergusson in the summer of 1856. On making her stand with her heels together, the limbs seem of equal length, but, on measuring, the left is found to be the shorter by nearly half an inch. The knee has very much the contour of its fellow; the patella exists, and is slightly moveable; and the patient can flex and extend the knee to a considerable extent. The joint, however, does not admit of lateral motion. In following her occupation she is constantly on her legs, and has to go up and down stairs several times during the day. There is

[1] This is the case referred to in Chapter I, of which the author says he has not been able to find a description.

just a slight limp in her walk. On referring to the case-book, it is found stated that, at the operation, a slice half an inch thick was removed from the femur, and two portions from the tibia, together about an inch and a quarter in thickness.

### F. *Resection of the lower end of the fibula.*

M. Houel[1] relates a case in which the leg was amputated six months after resection of the lower end of the fibula.

All the muscles were lardaceous, and almost fused together into a single mass. It was supposed that the anterior tibial nerve had been divided in the operation, but the cohesion of the muscles made it impossible to determine whether this had been the case.

The superficial layers of the fibula were swelled out and softened to the extent of eight centimetres (three inches nearly) above the point of section. Below this point was found an osteo-fibrous material of new formation, continuing the fibula downwards to the external side of the astragalus; and it articulated with this bone just as the malleolus externus had done, which it represented exactly. Between the superior extremity of this new malleolus and the free surface of the fibula was a false joint offering for examination two cartilaginous surfaces, lubricated by a viscid fluid, and maintained in contact by two thick bundles of vertical fibres. The posterior surface of the new malleolus was in relation with the peronei tendons, as in the normal state; but these tendons had contracted intimate adhesions with this eminence, so that, if the resection had succeeded, they would no longer have had any action on the foot. The tibia was hypertrophied in its whole lower half, which was covered by thickened and injected periosteum. Between the external surface of the tibia and the newly formed external malleolus, the interosseous ligament of the inferior tibio-fibular joint was replaced by a fibro-cartilaginous tissue uniting the two parts intimately. Lastly, the articular surface of the lower end of the tibia was solidly soldered to the upper surface of the astragalus by bony substance occupying the whole extent of the pulley-like surface.

### G. *Wrist-joint.*

CASE I ('Prag. Vierteljahrschrift,' 1858, Bd. lix, p. 12).—Pro-

[1] 'Bulletin de la Société de Chirurgie,' vol. iv, p. 400.

fessor Adelmann relates a case of resection of the lower extremity of both radius and ulna, for caries. The hand was useless afterwards, from the extremities of the bones having become again carious. The forearm was amputated six months afterwards.

The interval which had been left in the resection was found to have been diminished; the lower ends of the two bones had lost the smoothness of their sawn surfaces, which were covered by irregular masses of bone, which, however, did not reach the carpus. Both bones were increased in thickness, and their original figure was quite lost.

Case 2 ('Pathological Transactions,' vol. viii, p. 390).—Mr. Fergusson exhibited a dissection of a forearm from a patient in whom he had excised the wrist-joint six months before death. It is described as follows:

The whole of the bones of the wrist were supposed to have been removed. Dissection, however, showed that the pisiform bone, the trapezium, and a part of the unciform bone had been left. Portions of the radius and ulna were taken away.

The operation was performed through a wound in the soft parts on the ulnar side of the joint. The dissection showed how little damage to tendons had been inflicted. The hand moved freely at the wrist, and there was free use of the fingers and thumb. A small sinus remained on both the radial and ulnar side of the wrist, and on dissection it was found that both of the sinuses communicated with a portion of the end of the radius which was bare. The patient died of phthisis.

I have not been able to find a more detailed account of this preparation, nor the preparation itself, which, however, probably exists in King's College Museum.

II. *Resections from the substance of bones.*

The following are all the cases which appear to bear on this subject:

Case 1 ('Medical Times and Gazette,' 1857, vol. ii, p. 453).—*Excision of the ulna, and dislocation of the upper end of the radius.*—This case is reported in the following words: Samuel

D—, æt. 18, a healthy-looking lad, is now under Mr. Cock's care, on account of an affection not in any way connected with that which forms the main interest of his case. His right arm presents the following conditions: There extends along the inner border of the forearm, almost from the wrist to the elbow, a linear cicatrix, beneath which the parts are fallen in, and the border, instead of being round and full, is concave. The styloid process of the ulna and its whole articular head may be felt in its place, but between this and the olecranon the bone is entirely deficient. The cicatrix marks, no doubt, the incisions by which the shaft was removed, and there would appear to have never been the slightest attempt at reparation. The extremities of both articular ends are irregular, and much in the condition left at the time of separation. The olecranon is about an inch long, the shaft being abruptly deficient, with the exception that a very slender spicula, about two inches long, extends forwards from its inner border. The lower head of the bone is about half an inch long, and ends abruptly. The radius is dislocated forwards over the inner condyle of the humerus, and has there very free motion, being restrained only by membranous bands. The arm is thin, and the state of its bones in the respects adverted to is very easily made out. The lad states that he is right-handed, and always uses the affected arm. He is accustomed to wheel a barrow, to lift heavy weights, &c. Its defect appears to be of remarkably little inconvenience to him. As to the history of the original disease, it appears that he was treated in St. George's Hospital, at the age of four, for necrosis of the bone, and that four operations for the removal of sequestra were performed.

Case 2.—*Resection of a portion of the shaft of the ulna.*—In the 'Deutsche Klinik,' 1855, p. 145, will be found a case in which Robert resected a great part of the ulna, leaving the periosteum—a piece five and one third inches in length, through the coracoid and olecranon processes, but not opening the joint,—on account of chronic periostitis, complicated with bleeding from the interosseous artery. The movements of the arm, including rotation, were almost perfectly restored. The patient died eight months after, of apoplexy. The whole of the bone had not been regenerated. The cicatricial tissue between the ends of the bone consisted of a membrane which, close to its origin from the upper section, contained a small plate of bone. The hiatus was considerably shorter than the portion of bone removed—the latter having measured eight centimetres, while the former measured only five. Thus it was seen that there had been growth of bone from each sawn extremity, as was proved also by their altered form. Thus, the lower fragment of the ulna ran up into a flat-pointed process, twenty-five millimetres in length, seven in breadth, and four in thickness, which appeared to have come off from the medullary cavity of that bone. This lower portion was approximated to the radius at its upper end. The reproduction of bone was more considerable at the upper end—a piece five centimetres long having been deposited on the outer, and one two centimetres in length on the inner side. The fragment had changed its position, the new deposit of bone passing down upon the radius; to which it was intimately united by fibrous tissue, and formed a sort of false joint, which interfered with the rotation of the radius. The new deposit on the interior of the bone passed over to the head of the radius, forming a process which supported it, as it were, and was covered with cartilage so as to form a perfect joint.

The articular surfaces both of radius and ulna were united to that of the humerus by false membranes, but not so as to hinder motion.

CASE 3.—*Resection of the greater part of the shaft of the tibia.*—Professor Adelmann ('Prag. Vierteljahrschrift,' 1858, Bd. lix, p. 44) relates a case in which Herr Bechtold resected the whole shaft of the tibia, from three fingers' breadth below the condyles to two fingers' breadth above the malleolus.

Three quarters of a year afterwards a "cicatrix of regeneration" had formed from one epiphysis to the other; but in spite of the uninjured fibula, shortening of more than two inches had occurred, compelling the patient to wear a high-heeled shoe.

CASE 4.—*Resection of a piece out of the shaft of the tibia.*—Professor Adelmann. ('Prag. Vierteljahrschrift, 1858, Bd. lix, p. 45.) The operation was performed on account of a penetrating ulcer of the soft parts involving the bone, with a view of relieving the tissues of the parts, removing entirely the diseased bone, and giving the patient a chance of the healing of the ulcer. A piece of bone six inches long was excised. The ulcer healed temporarily, but broke out again. The limb remained useless, and the leg was amputated eight months afterwards. There was no trace of formation of callus-

The stumps of the tibia had become pointed off at both ends, but this state was produced, not by the deposit of callus material on the ends of the bone and subsequent ossification, but by absorption of portions of bone from the upper and lower ends of the tibia. The interspace between the ends of the tibia was filled by a fibrous exudation-substance, attached to the neighbouring muscles, which were partially atrophied, and intimately blended with them. This rendered it difficult to dissect the separate muscles and vessels.

Case 5 (Busch, 'Chirurgische Beobachtungen,' p. 260).—A man, æt. 50, in good health, suffered trephining of the tibia, which was much hypertrophied, close below the tuberosity, on account of necrosis. The soft parts were separated by a crucial incision, and the thickened periosteum rasped away. This separation of the periosteum extended further than the trephine-hole, so that there remained a portion of exposed bone around the latter uncovered by periosteum. In the progress of the case the periosteum and soft parts around this ring of bone became inflamed and swollen, and on the fourth day after the operation a well-marked development or extension of vessels into this exposed bone could be seen, forming a finely injected network running towards the trephine-hole. Two days later these vessels were hidden, and the exposed bone covered, by a reddish, gelatinous exudation almost up to the edge of the section, and on the following day fine granulations had been formed from this exudation. Thus the process was as follows: In the ring of bone, which was connected with the periosteum only by its outer circumference, and was itself uncovered, a well-marked hyperæmia had occurred, furnishing an exudation from which the newly formed granulations were developed. These granulations reached almost to the edge of the section, and where they ceased a small ring of bone became necrosed. Granulations also sprang from the sawn surface apparently unconnected with those which arose from the medullary cavity, and after the exfoliation of the above-mentioned necrosed portion and of a few small sequestra from the medullary cavity, the hole was quite filled up by the union of the granulations from these three sources, and in the end a perfectly solid substance was laid down, which filled up the trephine-hole and united it to the skin.

(He applies this and similar observations to show that granulations sprang from the substance of the bone itself, and thus to refute

Wagner's idea that regeneration takes place only through the periosteum or medullary membrane.)

Case 6.—In the 'Deutsche Klinik,' vol. viii, p. 201, is an interesting case reported by Mayer, of Würzburg, in which he removed the arch of the seventh dorsal vertebra, which had been depressed upon the spinal marrow by direct violence six months before, and had become united in its new situation by callus. Paralysis had not come on till some time after the injury. It was relieved, but only slightly, by the operation, and the patient died three weeks afterwards.

The cord was found broken up at the seat of the injury. The spinous processes of the fifth, seventh, ninth, and eleventh dorsal vertebræ had been fractured; the process above the seat of the principal fracture was united by callus, but the others, as well as the fracture of the spinous process, showed no trace of formation of callus, while the lateral fragment of the seventh vertebral arch was displaced upwards and inwards, and united with the upper half of the body of the vertebra, which had been fractured across.

Case 7.—In 'Guy's Hospital Reports,' 1857, p. 364, there is an account of the dissection of a man who had been trephined fifteen years previously by Mr. Cock. The operation had been followed by exfoliation of a portion of bone. The case is worthy of perusal on account of its intrinsic interest. In relation to the wound in the bone it is said: "As regarded the original wound, it was not replaced by the growth of any new bone, but the trephine-opening was filled up by a tough membrane, composed of the integument on one side and the dura mater on the other. These were firmly blended together, and formed a sufficiently strong protection to the brain. They were strongly united to the edges of the opening, the latter being rounded, with smooth edges, and little more than an inch in diameter. At its upper part there were two depressions, whence probably the diseased bone had proceeded, and there was considerable evidence of ostitis having occurred all round the site of the trephining, particularly at its front part. Here, over the left protuberance of the frontal, the bone was more than twice as thick as the corresponding part of the opposite side. For about two inches around this opening the dura mater was closely adherent, and upon removing it the inner surface of the skull was seen to be covered with a number of bony points or granulations. Immediately in front of the trephine-hole there was a depression in the bone, which extended upwards and downwards for a length of three inches. It was caused by a ridge of new bone immediately in front of it, and might have been the site of a fracture which took place at the time of injury; from the great change, however, in the structure of the bone, it was impossible to prove this satisfactorily.

### III. *Extirpation of bones.*

Case 1 ('Wiener Wochenschrift,' 1855, p. 513).—Dr. Robert, of Coblenz, extirpated the entire fibula, on account of acute inflammation, with central necrosis in parts. The case did well.

He says: "The peculiar resistance felt in resection-wounds at the commencement of bony reproduction was first perceived fourteen days after the operation at the lower angle of the wound, as a broad, hard mass, gradually becoming thicker and extending further upwards. This new formation of bone had, at the eighth week, when the wound was cicatrized, extended upwards only to the extent of one third of the removed bone, and when I saw the patient last, on the 23d of February, 1849, one year after the operation, the regeneration of bone had proceeded only to half the length of the tibia. The head of the fibula could be plainly felt in the form of a rounded ball, from which a yielding cord extended to the upper point of the regenerated bone."

Case 2.—In the 'Medical Times and Gazette,' 1857, vol. ii, p. 453, is the report of a case in which Mr. Savory removed the whole, as it is supposed, of the shaft of the radius on account of necrosis in a boy, æt. 9. An incision having been made over the centre of the diseased bone, it was divided and drawn out in two pieces. The periosteum was found to be separated from the bone, and was left behind. The articular extremities remained untouched. The shaft had in all probability separated at the epiphyses, from the extremity of each of which new bone had been thrown out, so as to encase the ends of the necrosed shaft for an inch or more.

When examined eight months after the operation, the bone could be felt from both ends growing to within about an inch and a half of each other, the two points being free, moveable under the skin, and apparently connected by a fibrous cord. The boy said that they continued to grow towards each other, but not so rapidly as they used to do. The lower end of the ulna was very prominent, in consequence of the hand having fallen over towards the hollow left by the removal of the radius. The movements of the hand were nearly perfect, pronation and supination being effected by rotating the humerus. When the humerus was grasped above the elbow these movements were stopped. The size of the regenerated bone appeared much less than that of the original radius. It had been hoped at one time that the two portions would have grown into and united with each other, but this prospect was lost, or at least delayed, from necrosis having attacked a portion of one of the fragments. It seemed, therefore, uncertain whether the whole of the bone would be regenerated.

Case 3 ('New York Journal of Medicine,' new series, vol. x, p. 135).—Dr. Compton excised both radius and ulna on account of extensive compound comminuted fracture, followed by sloughing. The bones were disarticulated at the elbow, and removed entire, except a small portion of the lower end of the radius. A great portion of the periosteum was detached from the bones and left in the wound. The operation was followed by the formation of several abscesses connected with spicula of bone which had been left in the wound. On recovery, the arm was two or three inches shorter than the other, and was "perfectly firm." It remained at a right angle with the humerus and could be flexed or extended, so that the hand moved through eight or ten degrees of the arc of a circle. The patient had entire use of the hand, could both open and shut it, and grasped objects firmly. (*From the 'New Orleans Medical Register.'*)

Case 4 ('Moniteur des Hôpitaux,' 1856, vol. iv, p. 828).—In a clinical lecture by M. Thierry, reported as above, the following words occur:

"You saw here the other day a man, about forty-five years of age, who had already submitted to the operation of resection of the os calcis, necessitated by the necrosis of that bone. The calcaneum was reproduced, but, unfortunately, this bone of new formation was struck with gangrene like that which preceded it, and we were obliged to extirpate it a second time." (Here follow some details of the operation, which is said to have been long and painful.)

Case 5.—Maisonneuve ('Comptes rendus de l'Académie,' &c., May, 1856) resected the whole of the lower jaw on account of fibrous tumour. The wound united by first intention. Soon after the operation (when the case was reported) a firm tissue was deposited in the place of the resected bone, in which, as the periosteum had been spared, it was hoped that bone would be deposited.

Case 6.—In the 'Gazette des Hôpitaux,' 1856, p. 604, is the account of an operation in which M. Guerin resected the second and third metacarpal bones—the former in its whole length, the latter from just below its upper end. M. Guerin says, "There was no reproduction of bone, nor could there have been any, for the periosteum was not preserved."

Case 7.—*Excision of the entire radius.*—In the 'American Journal of Medical Sciences' for April, 1858, p. 363, is the account by Professor Carnochan of an excision of the entire radius, in which the patient recovered entirely the use of his arm and hand. Examination externally, some time after the operation (apparently about five years), seems to have shown no reproduction of bone, a depression existing along the original site of the radius. All the movements, including pronation and supination, are said to be performed without difficulty.

Case 8.—In Dr. Williamson's 'Notes on the wounded from the Mutiny in India,' p. 109, will be found the account and representation of a case in which he excised the entire ulna, an inch and a half of the extremity of the humerus, and also the head and neck of the radius, on account of disease following diffuse inflammation. The wound healed by first intention. Four months after the operation, the man could bend his forearm, raise his hand behind his head, and lift a twenty-eight pound weight from the ground; he could also pronate and supinate the hand; there was no anchylosis of the wrist-joint, and he could use his fingers well. Nothing is said as to reproduction of the removed bone.

THREE MEMOIRS

ON

# IRIDECTOMY

IN CERTAIN FORMS OF

# IRITIS, CHOROIDITIS, AND GLAUCOMA.

BY

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MDCCCLIX.

# TRANSLATOR'S PREFACE.

It was originally intended to have published the following translations without the addition of any remarks, trusting that the importance of the subject and the celebrity of the author would sufficiently counterbalance any imperfections in the translation or difficulties in the original. Finding, however, that a former translation of mine[1] did not appear to have been generally understood, and that even in Germany a series of works had appeared necessary as introductions,[2] I have thought it advisable to commence by calling the reader's attention to a few points.

German ophthalmology has especially distinguished itself of late, by the attention it has paid to the anatomy and physiology of the organ of vision, and by the frequent, almost constant, application of facts drawn from those branches to practical purposes, and especially to the examination of cases. As examples, we may quote the ophthalmoscope, oblique illumination, the use of prismatic glasses, &c. &c. Hence the English reader, who is necessarily more or less unacquainted with these recent discoveries, must expect to meet with many and great difficulties. I may perhaps be allowed to mention, that I propose to publish shortly, as some slight aid in that direction, a work on the ophthalmoscope, that may serve as a guide to its use and as a *résumé* of what has been

[1] Dr. A. v. Graefe, "On Unilateral Cataract," in the 'Med. Times and Gazette,' 1857, vol. ii, p. 269.

[2] Such is the 'Klinische Analyse der Motilitätsstörungen des Auges,' von Dr. Alfred Graefe, Berlin, 1858.

already discovered by its assistance; in it I shall also include the subject of oblique illumination, &c.

The difficulties in the present papers do not, however, seem very formidable, and I hope that the explanation of a few points may enable the reader to peruse them with pleasure and profit.

By *exclusion of the pupil, pupillary exclusion,* or *synechia posterior totalis,* is meant adhesion of the whole of the free margin of the iris to the capsule of the lens.

The eye may be divided geographically into two *hemispheres,* an anterior and a posterior, an *equator,* an *anterior pole* at the centre of the cornea, and a posterior at the macula lutea. *Central fixation* is when the eye is so directed, that a line drawn from the object through the centre of the cornea would strike the macula lutea; should it strike elsewhere, it is called *excentral fixation.*

The extent of the *field of vision* is determined by placing the patient at a definite distance, say a foot, from a black board, on which a cross is then drawn with white chalk directly opposite his eye; on this cross the patient must fix his eye steadily throughout the examination; the chalk is now moved slowly upwards, downwards, &c., so as to determine by repeated trials how far it can be distinguished, and at each of these points a mark is made on the board; lastly, by connecting these points, we have a drawing of the field of vision as measured at a foot distance.

As to the *operation of iridectomy,* I need only remark that the eye should be firmly fixed by seizing a fold of conjunctiva with forceps, that the operation should be slowly performed, and that it is often much facilitated by the use of chloroform.

65, Piccadilly, Manchester;
*October,* 1859.

ON

# IRIDECTOMY

AS A

MEANS OF TREATMENT

IN

# CHRONIC IRITIS AND IRIDO-CHOROIDITIS.

By Dr. A. v. GRAEFE.[1]

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The dangers of iritis in general have materially diminished since the introduction of a bold use of mydriatic remedies in the acute form. Treatment by antiphlogistics, mercury, or by other methods of considerable repute, though insufficient to effect a complete cure of the disease, continue important auxiliaries, and in many cases it is impossible to apply mydriatics without their previous employment. Mydriatics, however, are indispensable to the complete success of our treatment. In most cases it is not the single acute attack of iritis that threatens the power of vision, but the frequent recurrences, which sometimes produce fresh pupillary exudations, and sometimes exclusion of the pupil (Abschluss der Pupille) or other injurious consequences.

The frequency of such recurrences, and the gradual supervention

[1] Translated, with the author's permission, from the 'Archiv für Ophthalm.,' Bd. ii, abt. 2, S. 202. Berlin, 1856.

of certain complications (amblyopia amaurotica ex choroiditide chronica, and finally atrophia bulbi) led to the supposition that most cases of iritis depended on internal dyscratic causes. We cannot deny such an etiological relation in certain cases, especially the connexion of iritis with syphilis, so firmly established by experience. But we must maintain, that in most cases of chronic iritis the recurrences depend on no internal causes, but on *residua of the first attack.* These form the predisposing causes for later inflammations. Colds, congestions, &c., may indeed serve as exciting causes, but the true foundation of the disease lies in the eye itself. I will not attempt to decide in what way the iritic exudations produce their pernicious secondary action; they may operate through obstruction of the circulation by contraction of the cicatricial tissue, or dragging of the iris when it can only imperfectly follow the impulses of contraction. Putting this question aside, however, I consider the fact firmly settled, that the existence of posterior synechia is in most cases the true cause of the tendency to recurrence. Iritis cured without posterior synechia seldom evinces any tendency to recur. Iritis with slight and extensible adhesions sometimes recurs, but in comparatively few cases. Iritis with many broad adhesions, resisting all artificial mydriasis, will very generally recur, and there is scarcely any exception to this rule when synechia posterior totalis—a perfect exclusion of the pupil by exudation—has occurred.

For a number of years I have thoroughly proved this exceedingly important connexion. Formerly in cases of double (not syphilitic) iritis, I often treated one eye antiphlogistically and the other either simply by mydriatics or by mydriatics with antiphlogistics. Sometimes both sides recovered without posterior synechia, and then no special tendency to recurrence was found in either eye. Sometimes, however, the eye treated antiphlogistically recovered with posterior synechia, and recurrences were frequently observed in it, whilst none occurred in the eye treated by mydriatics. The converse never took place. It is two years since I last tried this experiment, for the advantages of the mydriatic treatment were so obvious that I could not reconcile neglect of it with my sense of duty. But when patients who had suffered from periodical attacks of double iritis came to me with synechia posterior, I still applied to but one eye methodical instillations of sulphate of atropia, and by that means frequently succeeded in tearing through adhesions which had existed for many years.[1]

In the eye treated with the atropine no recurrence took place, but all succeeding returns affected the other eye. When I became fully convinced, this practice also was abandoned, and in such cases I always ordered double instillations of atropine. Still we often fail in tearing through the synechiæ, especially in old cases, and only succeed in stretching them to a greater or less degree. Here we invariably find that the eyes in which the broadest, least extensible synechiæ remain, are also the most liable to recurrence, and we can frequently show that these attacks proceed from the divisions of the iris affected with the broadest synechiæ. Corresponding to these we find the first injection of the subconjunctival vessels, the first hyperæmic coloration of the iris, &c.

Persons who have recovered from iritis are often affected by periodical ciliary neuroses, which in many cases depend on posterior synechia. After instillations of sulphate of atropia the pains cease,

[1] This has been unjustly doubted. After the first instillations I have very often delineated the form of the pupil in persons who had suffered from iritis many years previously. I have frequently seen projecting angles vanish one after another, and the edge of the pupil return more and more to its natural roundness. After so long a duration this can only take place in the tongue-like, prolonged adhesions, known as pointed synechiæ. In broad adhesions the surface of union is so great that the power of the mydriatic is insufficient. Many patients feel the synechiæ tearing. They have sensations of pressure in the frontal and temporal regions, and sometimes below the eye, at the ala nasi. These sensations increase to a certain extent, and are then suddenly alleviated. Sometimes they have occurred in my presence, immediately after the application, and I could discover that a synechia had actually been torn. In two instances patients, who were perfectly ignorant of the nature of their affection, perceived a tearing sensation just before the pain ceased. Besides, when we consider the anatomical relations, it does not appear extraordinary that such synechiæ can generally be torn, for the tissue is not separated in its continuity, but simply loosened from an extremely slender adhesion. By experiment on the dead, we may further convince ourselves that the slightest stretching with the forceps is sufficient to break through this union, even in broad synechiæ. When the surface of adhesion is very small, as in the narrow-pointed synechiæ, excessively little resistance is made to the rupture. Besides, it is known to every observer that synechiæ may spontaneously separate during the movement of the pupil, even months after the iritis. This occurs in the same way by separation from the capsule; the exudations then remain at the edge of the pupil as pointed processes, which do not adhere to the capsule, but freely follow the motions of the pupil.

but return as the pupil contracts. A methodical use of mydriatics, causing extension of the synechiæ, often permanently cures the disease.

Here the affection seems to have entirely arisen from the dragging of the iris-tissue by the adhesions. Ciliary neurosis is seldom, if ever, observed accompanying anterior synechia, where there is an apparent similarity; the real conditions, however, are so dissimilar that the same causes may easily produce different effects. The difference is especially observable in the circulation, where almost opposite conditions are evinced: in posterior synechia we generally find long-continued hyperæmia of the iris; in the anterior, obliteration of the vessels, atrophy of the tissue, &c., in the dragged portion. My present intention is to determine fundamental principles with regard to the object of my treatise; and, in the first place, I shall assert, *that the principal cause of the recurrence of iritis is the existence of synechiæ, especially when broad and inextensible.*

I shall not here specially consider the mydriatic treatment; I have no doubt that the opposition it still encounters entirely depends on insufficient examination. It is absurd to recommend a fixed dose of the mydriatic in all cases of iritis, and even the best sulphate of atropia ought not to be employed in every case, and in all stages of the disease. The application of Atropinum sulphuricum is generally sufficient in slight iritis, *i. e.* iritis with not much injection of the subconjunctival vessels, nor much swelling of the subconjunctival cellular tissue, nor much lachrymation, and with only slight opacity of the aqueous humour and pupillary space. The severity of the pain is by no means a contra-indication, but rather one of the most decided indications for this treatment; for the most severe ciliary neurosis often diminishes when the pupil dilates, and in such cases the mydriatic is supported without difficulty. It should be applied daily, six, eight, ten times, or oftener, at intervals of five minutes; and notwithstanding the irritation, both the pain and the other symptoms are generally alleviated, and, at the same time, the subconjunctival injection diminishes with remarkable rapidity. Even after the first application the pupil begins to dilate, although far more slowly than in the healthy eye. The margin of the iris gradually separates from the exudations[1] in the pupil, and these

[1] This cloudiness, or "plastic exudation," which occurs in the commencement of iritis, really forms a distinct membrane. This is proved by the performance of paracentesis.

wither in the most satisfactory manner, as might naturally be expected, since they are nourished by the iris, and must atrophy when the source of nutrition is withdrawn. Such a result, however, could not be obtained by the best resolutives and antiplastics.

Where there is *acute iritis*, with profuse lachrymation, chemotic swelling, and cloudiness of the aqueous humour, an entirely different treatment is indicated. Atropine (gr. iv to f℥j water) must be instilled twenty to thirty times, to produce even a limited action on the pupil; sometimes it slightly enlarges, but a genuine mydriasis seldom takes place. Sometimes the desired dilatation is obtained by a very bold use of the mydriatic. From these cases, however, *no rule* can be drawn.

Frequent applications during the height of the inflammation sometimes so much increase the irritability that no therapeutical effect is produced. In such cases, I am in the habit of employing three methods to diminish the irritation as rapidly as possible.

1. Bloodletting, by leeches applied to the temples or nose, and incisions of the chemosis with Cooper's scissors, sufficiently deep to unload the subconjunctival vessels, which are intimately connected with the iris.

2. Paracentesis, which must never be neglected when there is much diffuse cloudiness of the aqueous humour.

3. In very acute cases, and in those attended by excessive exudation, I employ mercurials. The extremities are rubbed every two hours with Ung. Hydr. Cinereum, and every hour I give from a half to one grain of calomel, until the first indications of salivation appear.[1] When the irritable condition has decidedly diminished, which must ensue in two or three days, I commence the use of mydriatics, and so vigorously as positively to tear synechiæ which have already formed. This is the period during which the special object of treatment must be unreservedly followed; and in general, the mydriatics act much more readily than before, partly owing to the diminished inflammatory irritation, and partly also to freer absorption by the cornea.[2] My usual custom is to apply the atropine

[1] In addition, I apply a suppurating blister behind the ear, and believe that it is of use; but from having always employed it in combination with more active treatment, I have been unable to gain so clear an insight into its action in these cases as I have in many forms of corneal exudation, &c.

[2] The latter cause alone is insufficient to explain the more powerful action of mydriatics after depletion. This is proved by a fact I have often witnessed.

from six to fifteen times, sometimes twenty to thirty times a day. The pupil must be kept dilated some weeks after the inflammation has perfectly ceased. It need scarcely be mentioned that the choice of the mydriatic is of essential importance. It is, in fact, owing to the substitution of sulphate of atropia for the extract of belladonna that this method of treatment in acute iritis has come into more general use. It is also very necessary that the preparation should be well made, since it is to be applied so often, and the eye is already in so irritable a condition. This is of less importance in cases where it is only applied once or twice a day, and its action is not opposed by internal irritability. In such cases the most various preparations may be employed. But, as I have already elsewhere stated, even the best-prepared sulphate of atropia becomes unbearable to the conjunctiva after very long-continued use; and if circumstances should still render its application necessary, the tone of the conjunctiva must be altered. This is best effected by solutions of acetate of lead, or dilute solutions of nitrate of silver.

Although I can easily understand that some practitioners are not successful in the mydriatic treatment of acute iritis, because they proceed without discrimination, still I cannot understand how any can yet consider it irrational. In inflammation of a muscular tissue, what indication is more urgent than to keep it quiescent, at the same time relaxing its most irritable and most threatened parts—in the present case, the pupillary margin? Is there a method more likely to induce reabsorption of exudations than to deprive them of their source of nourishment? Finally, does not the diminution of intra-ocular pressure, facilitating the choroidal circulation, afford an especial safeguard against the complication with choroiditis[1] which is so much to be dreaded?

The method itself is by no means irrational; it is only its improper use that can justly incur blame, as when it causes excessive

Atropine has been applied in cases of iritis or corneal exudation, without inducing any dilatation, but many hours afterwards it has ensued upon the application of leeches. All remains of atropine had previously been so carefully removed that it was impossible any could have been left in the conjunctival sac, and hence it must have been absorbed before the use of leeches, its action having been temporarily latent, owing to the excessive inflammatory irritation.

[1] Ophthalmoscopic examination has shown that after iritisopacities are by no means uncommon in the anterior part of the vitreous humour. Evidently these must be ascribed to the anterior division of the choroid having participated in the inflammation.

irritation of the external parts in cases of very intense inflammation, or when an improper mydriatic is applied. The empirical success of mydriatics has appeared to me so evident that it has scarcely seemed necessary to dwell any longer on its beneficial action, either in iritis or in corneal affections that are rapidly spreading. On a former occasion (A. f. O., Bd. i, Abth. 1, S. 223) I was the first to mention the latter circumstance, and I purpose entering more fully upon it at some better opportunity.

A second law is connected with the preceding one, namely, that *the exclusion of the pupil is the point from which the further complications proceed, especially chronic choroiditis* (with progressive amblyopia, and in the end atrophia bulbi). By *exclusion* of the pupil I understand simply the total adhesion of the pupillary margin with the capsule—synechia posterior totalis. The pupillary space, properly so called, may be almost free from exudation; or scanty exudations may adhere to the border of the pupil, whilst its middle portion transmits light perfectly. When the pupil is entirely obstructed by exudation, we no longer term it *exclusion*, but *closure* of the pupil; thus the latter involves the former, whilst the former may exist independently of the latter. The operation for artificial pupil, since its first introduction, has been employed in cases of closed pupil, simply for the purpose of making an aperture through which the rays of light may freely pass into the eye; I purpose introducing it in cases of pupillary exclusion also, not in order to afford a new passage for the light, but to prevent secondary mischief, namely, chronic choroiditis. The above-mentioned law is important as the link that connects all these considerations, and its proof is to be found in a series of facts, which, that I may avoid as much as possible any systematising tendency, I will communicate in the same order in which they presented themselves in my clinical studies. About four years ago, a man came to me whose left eye was perfectly blind from irido-choroiditis. The eye felt rather soft, and the iris was closely applied to the cornea, whilst its inner margin was drawn backwards so as to form a slight depression. The pupil was much diminished in size, and occupied by a white membrane. The tissue of the iris was much changed, and some distended vessels ran in its fibre-work, which was of a dull, dirty colour. The entire absence of any quantitative sensation of light, and the atrophy of the globe already induced, left no doubt about the presence of internal complications (chronic choroiditis with separation of the retina). The sight of the patient's right eye was very weak, so that he could only recognise large objects, and guided himself with difficulty. An examination showed evident effects of iritis—synechia posterior totalis. The somewhat contracted pupil was to a considerable extent filled with pigmented exudation, but the centre was nearly free from them, so that the deterioration in vision could not be entirely ascribed to the condition of the pupil, but must have proceeded from a complication with commencing chronic choroiditis. The iris itself was of a greenish colour, and the knob-like protuberances visible here and there upon its surface clearly indicated the commencement of a similar projection to the one, that had advanced so far in the left eye.

The history showed that the disease had begun in both eyes with simple iritis. The patient was first attacked by a severe inflammation, with ciliary neurosis, which had retrograded after an antiphlogistic and mercurial treatment; vision indeed was restored, but there still remained some redness of the eyes, great sensibility to light, and pain in the forehead and temples. At frequent intervals this condition of irritability became so acute as to pass into a state of inflammation, sometimes through colds, and sometimes without any known cause; after which the vision gradually diminished in acuteness, and on the left side entirely disappeared. For eight weeks previously the patient had not been affected by any visible inflammation of the right eye, yet the sight had continued to deteriorate. I suspect that it was since that period that the iris had gradually arched forwards. Since antiphlogistics had been already employed as far as the patient could bear, and I could not expect any benefit from a longer use of the mercurials, vainly tried for many months, I trusted entirely to the mydriatic treatment. But not the slightest change occurred in the pupil, evidently owing to the adhesions being too firm and extensive. This form of disease commences with iritis, rapidly leads to synechia posterior totalis, gradually induces a projection of the iris towards the cornea, and in the end terminates in chronic choroiditis and atrophy of the globe. It has been freely discussed in literature and in the clinic, under various names, and with the supposition of different dyscratic causes. All observers have agreed that the prognosis must be considered unfavorable from the moment, when the above-mentioned disorganization and projection of the iris appear; and many persons, perceiving the unsatisfactory course of the disease, have been led to infer some deeper disturbance as its source, such as the tubercular process.

The failure of all treatment induced me to make an artificial pupil in the patient's right eye, and, though led by very vague ideas to adopt this course, I believed that the relaxation of the tissue of the iris, the escape of exudation situated behind it, and the discharge of blood from its vessels and the choroid, might act favorably: besides, I apprehended no danger from an operation that is so generally harmless. The pupil was formed close to the inner side; there was only a small amount of aqueous humour in the anterior chamber, and it escaped very imperfectly when the lance-shaped knife was drawn out, and even when the forceps were introduced.[1] As I seized the iris with the forceps and tore its tissue,—in such cases the adhering pupillary margin generally remains with the mass of exudation,—a quantity of yellowish fluid was discharged from the wound; it was simply the exudation lying behind the periphery of the iris. On opening the eye the following day, I saw with delight that the iris no longer projected, but that it lay in its normal plane, separated from the cornea by a tolerably deep anterior chamber. It was still of a greenish hue, but the fibre-work was already not so dull as before; some blood in the process of solution lay at the bottom of the anterior chamber. Eight days after the operation a more careful examination was made; the pupil formed a large coloboma, only separated from the normal pupil by a small bridge of pupillary margin, which had adhered to the exudation; the adjoining part of the artificial pupil was filled with brownish exudation, or perhaps, to a considerable extent, by remains of the pigment-coat; the periphery alone seemed free from it. The iris had almost regained its original colour; the only difference that could be detected was a slight tinge of green; it lay in its normal plane. The anterior chamber seemed of considerable depth. The patient could count fingers at the distance of a room, and recognise letters

[1] This generally occurs in synechia posterior totalis, for the iris with the exudation-membrane forms a complete partition between the cavity of the globe and the anterior chamber, so that the intra-ocular pressure cannot be transmitted to the cornea, as normally, but only to the partition just mentioned. Hence the contents of the chamber will either not escape, or only imperfectly; or, to speak in more exact terms, the escape will cease when the tension of the iris balances the pressure, and when, consequently, all positive pressure ceases in the anterior chamber.

of large print. How was this improvement of the vision to be explained? It could scarcely proceed from a change in the entrance of light, for although an additional free space had been gained through the peripheral portion of the artificial pupil, still the natural pupil was also tolerably transparent in its centre, and obviously must allow a clearer perception than that portion of the periphery. I could not, however, be satisfied with mere reasoning on so important a point.

I therefore covered the whole artificial pupil as far as the pupillary edge, and convinced myself that this scarcely affected the power of recognition, and that when the artificial pupil was entirely unemployed, the patient saw through the central one infinitely better than before the operation. The next idea that suggested itself was, that through tearing away the iris-tissue, absorption of the exudation in the pupil was promoted, just as after artificial mydriasis, and that eight days having elapsed since the operation, the central pupil had become clearer than it was before. It is true, that with the naked eye I perceived no difference, but I did not consider that sufficient to justify my forming a conclusion. Possibly some slight cloudiness caused by exudation had cleared away, and this, though very slight, might previously have caused much dissipation of the light; but the addition of a new pupillary space, and the consequent conditional comparison as to the degree of blackness, rendered it very difficult to form a decisive opinion; and I was unable to come to any conclusion by means of ophthalmoscopic investigation, then only in its infancy, because the increased amount of light passing through the larger pupillary space might easily induce error about the relative transparency of particular parts. It was not until subsequently, after I had sufficiently practised oblique illumination, that my views on this point became clear. As to this case, I shall only add that, without the use of any medicine, the vision of the operated eye continually improved, that the patient learned to read small print (No. 4 of Jäger's specimens of type), that for the last four years he has never been attacked by iritis, and that he now fills a post requiring good eyesight. I have since repeatedly examined him; the exudations that obstructed one division of the artificial pupil have much diminished, and the tissue of the iris has become normal.

The inefficacy of all other treatment, and the success of this one operation, emboldened me to perform it in many similar cases. I should at an earlier period have published the results, had it not seemed advisable to watch for a long time the cases which had been operated on, so as to ascertain the permanency of the results.

Similar cases to the above were at first the only ones so treated. The operation was sometimes performed on both eyes, in cases where the irides were pushed forward, yet without marked amaurosis. The best possible results constantly followed; the anterior chamber was re-formed, the iris resumed its normal texture and position, the eyes continued free from inflammation, and there was an important increase in visual power.

Gradually I convinced myself, by oblique illumination, as previously hinted, that the increased power of vision *was in no way dependent on reabsorption of the pupillary exudations, but was entirely to be ascribed to an improvement in the choroidal complications.* I must admit that all cases were not equally decisive, for sometimes the central pupil was so covered with exudation that the artificial pupil served for the principal entrance of light; obviously such cases could throw no light on the subject.

Amongst other cases there were two especially instructive, in which the whole of the artificial pupil was blocked up by the remains of the pigment-coat,[1] so as not to allow the transmission of light; on the other hand, the natural pupil showed not the least change three weeks after the operation, although only containing scanty exudations, which I had previously very accurately examined by oblique illumination; and yet the iris recovered its healthy appearance, re-formation of the anterior chamber took place, and an extraordinary improvement of vision. In one of these cases the serous exudation behind the iris was not held back by the pigment-coat, but flowed out through the wound, as usually occurs. I suspect that some minute apertures, visible at the extreme edge of the periphery, though useless for the transmission of light, yet had allowed the escape; whilst in the second case, the pigment-coat at first prevented the discharge of the exudation. This was proved by its surface being pushed forward so as to form small elevations; probably it had been strengthened by a layer of pigmented exudation. Here for the first week no improvement took place, and

[1] A proof that only the tissue of the iris had been excised. This is most likely to happen in the cases in question of chronic iritis. The greater part of the serous exudation is indeed situated behind the pigment-coat, between it and the capsule, but there is also a thin layer of exudation between the tissue of the iris and the pigment-coat.

hence I determined to reopen about half the wound, and seize the periphery of the pigment-coat with fine forceps. At the moment of seizure, yellowish serum escaped from behind it, and I removed my instrument without excising any portion, for I wished to ascertain whether the formation of a considerable division was required, or only the escape of the exudation, with a restored communication between the anterior and posterior chambers. The latter proved to be the fact, for the desired action followed; though the tear which had been made opposite the edge of the lens appeared by oblique illumination very trivial.

At a later period, constantly becoming bolder, I even performed the operation in cases where, after previous iritis with pupillary exclusion, atrophy of the globe had far advanced, in consequence of secondary choroiditis. Sometimes the periphery of the iris was closely applied to the cornea, so as to present some difficulty during the operation. Various changes often occurred in the pupil after its first formation; often it was nearly filled with pigmented exudation, at a later period it sometimes even contracted gradually into a small slit, and almost closed. But I always found some improvement in the colour of the iris, and the restoration of an anterior chamber, to a greater or less extent. This excited the hope that a repetition of the operation might ultimately lead to success. Thus, in some cases, by iridectomy repeated three or four times, I have attained results I had previously considered perfectly impossible. Even when the globe has become to some extent atrophied, it recovers its healthy tension, the tissue of the iris being at the same time rendered normal and the anterior chamber restored. I have treated in this manner, at my clinic, a large number of cases in which the globe had become very soft, and much flattened by the action of the recti muscles, and which were ultimately perfectly refilled. A patient still visits me, to whom long since I gave, and that from full conviction, a certificate of incurable blindness, on account of atrophy of both globes. Now, the operation having been performed six times, his vision weekly improves. He can count fingers at the distance of some feet, and distinguish all large objects and letters of the largest print; whilst formerly he had long been limited to a dull, quantitative sensation of light. The iris, which was very disorganized, now appears almost normal, the anterior chamber has been re-formed, the volume and tension of the globe have much increased, and there is only a slight trace, where the rectus inferior is situated, of the flattenings previously visible in all four directions. Yet, at the same time, the lens is very opaque, and the natural pupil is closed by a white membrane, so that, in short, his present vision is almost proportional to the condition of the refractive media.

That an atrophied globe could be refilled would indeed appear somewhat enigmatical if, according to former ideas, we were to consider it as a positive disease of nutrition; but, as we have already often urged, it is in such cases simply a symptom of choroidal stasis. The choroid is the secreting organ of the vitreous body, and if its circulation stagnates, the reproduction of the vitreous body will necessarily fail, and its volume will diminish. In chronic choroiditis, instead of the normal, an abnormal fluid will be given out for the purpose of nourishing the vitreous body, so that the latter will vary chemically and quantitatively from its healthy condition.[1] It is evident that, when atrophy has exceeded a certain extent, the eye cannot resume its original form. Then effusions of blood or serum generally proceed from the choroid (probably to restore the balance of pressure), rendering a perfect recovery impossible. But a certain degree of atrophy of the globe from choroidal stasis is curable, as is well known to all attentive observers, and as the present observations abundantly prove. Besides, we know that in actual iritis, for example, the globe is often softer than in the healthy eye, and that this symptom retrogrades as the inflammation disappears. It is evident that the diminished resistance is owing to imperfect secretion (connected with choroidal hyperæmia) of the fluid of the vitreous body, for in the volume of the aqueous humour there is no change capable of affording an explanation.

I need scarcely mention that, in regard to the success of our treatment, the prognosis becomes more unfavorable as the atrophy of the globe advances; indeed, I have repeatedly observed scarcely any result in very advanced atrophy with such antecedents. There is a certain limit beyond which a restoration of the choroidal circulation is impossible, because the permanent changes of inflammation, namely, atrophy of tissue and obliteration of the vessels have already proceeded too far. Hence we derive the principle that the operation should be performed as early as possible.

Other reasons make it advisable. The presence of serous exuda-

[1] We cannot at present give a more accurate account of these conditions, owing to insufficient knowledge as to the reproduction of the vitreous body.

tion behind the iris causes in time cloudiness of the lens, leading to the development of cataract. This must not be confounded with those circumscribed opacities in the layer of *intra-capsular cells,* which follow almost every inflammatory affection of the iris. The latter do not necessarily lead to the formation of cataract, and occasionally disappear at the same time as the exudation in the pupil. From what I have observed in some cases this seems to me extremely probable, and I have most decidedly observed it in experimenting on animals. It scarcely requires mention, that the prognosis is rendered much more unfavorable when cataract is developed under these conditions, because all methods of treatment are attended with so much risk. Reclination is out of the question when there is chronic choroiditis. Discision is uncertain, for the capsular wounds dilate with great difficulty when iritis has previously occurred, and any swelling of protruded portions of the lens may re-excite inflammation. Only extraction remains, and even here the hardly won success may be entirely lost, if the healing process should proceed unfavorably.

It seems superfluous to strengthen the preceding observations by detailed reports of cases, especially as most of them were observed in my clinic, and in the presence of many competent colleagues, and have also been to some extent published (*vide* Rothmund, 'Beiträge zur künstlichen Pupillenbildung,' München, 1855). On the other hand, it may facilitate the general introduction of these views, if in a short summary we consider the various diseases to be treated, and the manner in which the operation acts.

The disease which has been termed irido-choroiditis is one that presents many different aspects, and we must particularly distinguish two opposite groups, in arranging our cases with reference to our present object.

*1st class.*—The disease begins with iritis, and without proper treatment pupillary exclusion results, whether with or without a certain amount of exudation into the pupil is of no importance. The existence of pupillary exclusion is partly proved by mydriatics not producing the least reaction of the pupil, and partly by oblique illumination, which reveals a circular border of pigmented exudation connecting the tissue of the iris on every side with the capsule. If for any reason paracentesis be performed according to the usual method of operating, in which no artificial pressure is applied to the cornea, the imperfect escape of the aqueous humour will furnish a further but superfluous proof. Vision remains perfectly good in a few cases even after exclusion of the pupil has occurred; as the rule, however, bulging of the periphery of the iris takes place, at first partially, in the form of knobs, and then by degrees affecting the whole; an amblyopia being at the same time developed, for which the condition of the pupil no longer accounts. Delicate opacities of the vitreous body are sometimes shown by the ophthalmoscope. The globe becomes softer; in short, all the symptoms prove the supervention of choroiditis. Most authors bring forward the erroneous opinion that the exudation behind the iris, and *pressing it forward,* is *solid.* It is true, that there are pigmented exudation-membranes behind it, especially near the pupillary margin, but the bulging is explained by serous exudation behind the periphery, as may be deduced from the preceding communications. Nor does an examination of the cases collected give any support to the opinion that this form of iritis depends on some special condition of the constitution; it only differs from ordinary iritides, such as occur after colds, or without any apparent cause, in the very rapid formation of synechia posterior totalis, without much exudation in the pupil—a result that is not attributable to any peculiar quality of the disease, but for the most part to a defective treatment or one commenced too late. The arching forwards of the iris is simply a consequence of the pupillary exclusion, and of the serous exudation on the posterior surface. Hence it loses its specific character, just as the form of the pupillary distortion previously did. The question naturally arises, why exclusion of the pupil sometimes does not induce bulging of the iris? I cannot answer satisfactorily. Differences in the circulation of the iris itself may partially account for the dissimilarity of cases, for the vessels sometimes are obliterated to a considerable, and sometimes only to a slight extent; there is occasionally, however, even when the synechia posterior seems to be complete, still a communication between the anterior chamber and the layer of fluid situated behind the periphery of the iris, the fluid passing through the exudation which adheres to the pupillary margin, or through some very small apertures, occasionally formed in the atrophied tissue of the iris.

*2d class.*—Choroidal changes commence the disease, iritis occurring as a secondary complication. I have already pointed out (A. f. O., Bd. i, Abth. 1, S. 367) that extensive retinal separations, arising through hæmorrhage or serous effusions from the choroid, generally excite in their progress a reactionary inflammation of the internal membranes, and consequent exclusion of the pupil. Cataract often occurs at the same time as the iritis; it sometimes precedes it, and thus we have cataracta accreta in combination with pupillary exclusion. In general, central capsular cataracts are also formed, and extend over the greater part of the pupil—an important diagnostic sign, as from their presence[1] we can conclude with the greatest probability as to the existence of retinal separation. In these cases, also, arching forwards of the iris generally commences after the occurrence of pupillary exclusion, then atrophy of the globe, and eventually the appearance of the disease may very closely resemble the one described above. The differential diagnosis of the two forms of the disease is the more important, because their prognosis is very different. The history demands especial attention. In the latter form the disease begins with characteristic symptoms of retinal separation; contraction of the field of vision generally commences at the upper part, gradually advances, and eventually leaves but little power of recognition, which is usually in the direction of outwards and downwards, combined throughout with partial, oblique, and distorted vision. Inflammations only appear at a later period, and are, as a rule, attended with little irritation, owing to the previous atrophy of the vitreous body and diminution of the intra-ocular pressure. In the former group, on the contrary, the disease commences with well-marked inflammations, which periodically recur, and are generally accompanied by ciliary neuroses; at the same time the power of vision is at first tolerably good, then gradually impeded by a uniform haziness, but without contraction of the field of vision. It is unfortunate that here, as in other cases, the history is often deficient. Its value varies extremely, according to the patient's power of observation and accidental circumstances. Owing to the disease generally commencing on one side, the disturbances of vision often completely escape the patient's notice, and

[1] Of course such capsular opacities must not be confounded with pupillary exudations. Their exact determination is generally impossible where extensive iritic deposits have been cotemporaneously formed. Capsular opacities, in the form of separate lines, proceeding from the periphery, and projecting into the region of the pupil, occur in all forms of cataract, especially in very old opacities, and are in no way characteristic; but large, white, capsular patches, embracing the pupillary space, the lens being at the same time as yet imperfectly clouded, give, with the greatest probability, the diagnostic sign mentioned.

it is, consequently, very important to possess, for still later periods, *objective diagnostic signs*. These depend in part on the examination of the tissue of the iris, which usually suffers more when the disease begins with iritis, than when with separation of the retina. Examination of the lens, when possible, may assist. Indeed, as already stated, the formation of cataract usually precedes, or at least accompanies, the irido-choroiditis, in cases of previous retinal separation; whilst in the former group opacity of the substance of the lens is developed only at a very late period, when projection of the iris has far advanced. Practically, however, the patient's *power of perceiving light* (Lichtschein) is the most important sign. An examination, made according to the principles given in the A. f. O., Bd. i, 2, S. 257, discloses a very different condition in the two groups; though the perception of light is much less in both than would be proportional to the anterior opacities, still it is by far the least in cases of retinal separation. In these cases, also, the light is much better perceived by the upper than by the lower portions of the retina. When there is separation of the retina, and the pupil presents a free entrance for the light, the patient will be quite unable to perceive the light of a lamp which is placed in the upper part of the field of vision; in the present case, however, owing to the diffusion of the light, the superior portion of the retina will be affected, whatever be the position of the lamp; and yet there will usually be a quantitative difference in accordance with the situation of the object. This criterion, also, is lost when there is total blindness. The primary effect of secondary choroiditis is usually exudation into the vitreous body. In these cases of complete loss of vision, retinal separation has occurred as a secondary affection, even though the disease began with iritis; all treatment is useless.

To return to the treatment. I have found that iridectomy only effects a radical cure in the *first group of cases*. I have often tried it also in irido-choroiditis, resulting from retinal separation, and have generally seen any existing irritation relieved. Under certain circumstances, I might even recommend it for these cases (at the same time cautioning the patient with regard to the future result), and should be especially inclined to advise it when a sympathetic affection of the other eye threatens to break out during the long-continued irritation of the eye first affected (*vide infra*). But no real restoration of vision can ever be expected; more true is the principle, that extensive separations of the retina lead to perfect amaurosis, with atrophy of the globe, provided reactionary inflammation of the internal membranes has once been induced. On the contrary, we can depend upon the action of iridectomy in the former cases, and with the greater certainty if the perception of light be good (*vide* loc. cit.), and the atrophy of the globe not too far advanced. The best and most certain results, however, are obtained where there is total adhesion to the capsule, yet no prominence of the iris. It is true that the advantages of the operation under these conditions appear somewhat dubious to the young practitioner, as in general the vision is still moderately acute, and frequently even small print can be recognised; and besides, it is not absolutely certain that secondary choroiditis will be developed. Notwithstanding this uncertainty, however, I cannot recommend delay if the other eye has become amaurotic through the effects of the disease, for the possibilities of success might be materially lessened by the occurrence of choroidal complications or the formation of cataract. Besides, I can dispel the natural fear that the vision may suffer from the operation. I term this fear natural, because, under the circumstances, certain dioptrical irregularities cannot be avoided. In particular, the pupillary margin, adhering through pigmented exudation, will remain in its former position, and separate the artificial from the central pupil; and when the pupils are excentric there will be imperfect accommodation, which might occasion double vision. Pigmented exudation will be deposited on the capsule in the more central part of the artificial pupil, and might in some degree dissipate the light; even the greater size of the pupil, its periphery being opposite the edge of the lens, might have some influence by causing dazzling. But, practically, these doubts are unimportant, assuming that no extraordinary dimension be given to the artificial pupil. We can provide against these contingencies, and any possible disfigurement, by placing the pupil entirely beneath the upper lid, when the patient will still see through the central one. Thus we obtain the desired action on the chronic iritis, without in any way altering the dioptrical relations. I employ this mode of operating when the middle of the central pupil is perfectly clear, but in all other cases I form the pupil on the inner or lower side, and have never seen the vision impaired, even in patients able to read the print No. 1 of Jäger's specimens.

The question arises, whether patients on whom iridectomy has been performed, on account of synechia posterior totalis, remain really free from recurrences of iritis? I must answer affirmatively for by far the majority of cases, and after what has been already stated, I should not return to this point had there not appeared an apparent contradiction with the principle that the recurrences of iritis are usually owing to posterior synechiæ. Certainly these are by no means entirely separated through iridectomy, for the pupillary margin, not falling within the reach of the operation, continues to adhere to the capsule. *A priori*, I myself should scarcely have believed that the formation of an artificial pupil would prevent the injurious action of the remaining adhesions, yet this has been amply proved by experience, and to some extent we are entitled to seek for a sufficient explanation. By excision of a part of the iris, the tension in the muscular structure must be materially altered; hence the tendency to inflammation is so far diminished, that the adhesions no longer cause disease. But I believe the change in the circulation is of still greater importance. Without referring to the immediate hæmorrhage and escape of aqueous humour, the size of the iris is to a certain extent diminished after the operation. Now, if the chamber be afterwards refilled, and apparently in a normal manner, the diminished iris must relatively secrete more aqueous humour than before, and thus the vessels of the iris must be constantly relieved to a greater extent. The condition must somewhat resemble that caused by the periodical repetition of paracentesis; the antiphlogistic influence of the artificial pupil will be, however, far greater, for in this case the relief is continual, whilst in the former the vessels become temporarily congested (ex vacuo) after the sudden escape of the aqueous humour. I have elsewhere stated my views as to the action of both constant and periodical relief of the vessels in inflammations, and my opinions are unchanged in any material point. Still, I do not imagine that I can give an exact explanation of the action of iridectomy in chronic iritis. I have simply endeavoured *to establish a fact*, and shall be perfectly satisfied if my suppositions give an impetus to investigation, and lead to the discovery of a better explanation. So much on *iridectomy in total adhesion to the capsule.*

Where there is already *prominence of the iris*, there are almost always signs of a commencing choroidal amblyopia, and even when absent they may be confidently expected, so that the operation should never be delayed. On the supposition that a large and solid mass of exudation was situated behind the iris, some difficulty in operating might be feared, but provided there is still a small anterior chamber, this is by no means the case, for the iris, which is pressed forward by serum, readily passes between the blades of the forceps. As the effects of iridectomy in such cases have been already fully explained, I shall only add some general observations on the process itself.

1. What is the real nature of the so-called secondary choroiditis? As already mentioned, the ophthalmoscope occasionally reveals very delicate diffuse opacities of the vitreous body; sometimes, however, we conclude that it is clouded, only from the uniformly dull appearance of the back of the eye. Where a clear definition is possible, the retina presents no abnormal appearance. In the choroid, especially towards the equator of the globe, the great vascular trunks are extremely large; yet I consider this less important than the development of the chorio-capillaris, of which the finely stippled meshes (in the direct image) entirely disappear, so that an uniform redness is spread over the stratum of external vessels. Hence hyperæmia of the chorio-capillaris with morbid imbibition of the vitreous body must be regarded as the point of origin of the secondary choroidal affection, and indeed I believe that organic changes in the venous layer do not occur until the disease has made considerable progress; otherwise we should find traces after the disease had retrograded, owing to iridectomy. Hence we perceive the possibility of perfect restoration. Of course, at a later time, the effusions, retinal separations, &c., are too extensive; and thus the prognosis is essentially changed.

2. It is also a question whether the exclusion of the pupil and the choroidal affection are essentially connected? It might indeed be maintained, that choroiditis results entirely from extension of the inflammation, as would naturally ensue, owing to the vascular continuity between the iris and choroid. But how is it that this extension of the inflammation cannot be prevented? It, I believe, depends on the exclusion of the pupil, as the recurrences of iritis depend on the presence of posterior synechia. As proofs, we have the action of iridectomy, after which the choroidal affection spontaneously diminishes, and also our experience that the changes in the choroid seldom occur, when the treatment is otherwise correct, provided we obtain even the slightest dilatation by means of mydriatics, and so break through the posterior adhesions.

3. We yet require a thorough analysis of pupillary exclusion, considered as a mechanical agent, and though, notwithstanding some

previous investigation on the subject of intra-ocular pressure, I may yet be unable to give any decided explanation, this much is certain that, when the pupil is excluded, the pressure both in the posterior parts of the eye, and in the anterior chamber must change —an alteration that may materially affect the circulation. On the other hand, it is also possible that, through stoppage of the communication with the anterior chamber, the fluids do not pass to the cornea in a normal manner, and that thus the conditions of secretion and diffusion become abnormal. This view seems supported by the fact, that when exclusion of the pupil has been formed, serous fluid collects behind the iris. After the performance of iridectomy in this state I have never exactly seen *recurrences of iritis;* I have, however, observed some cases of imperfect resolution. In these instances, I have noticed a large accumulation of pigmented exudation in the artificial pupil, which has gradually lessened through the contraction of these and still more recent effusions. But as there was evidently some improvement in the texture and colour of the iris, it was clearly indicated to repeat the operation on an adjacent spot; for the result of this proceeding, I refer the reader to my previous remarks.

The suspicion has been expressed, that the disease may be only *interrupted,* but not *cured.* In general, when vision has not been entirely lost, the *choroidal complication* recedes by degrees. This has been partly proved by ophthalmoscopic investigation, partly by testing the acuteness of vision. The vitreous body continues to clear for many months, and generally becomes completely transparent; it is only occasionally that opacities are left. On the other hand, the formation of *cataract* is a secondary result, which must not be passed over in silence. I have already mentioned that, where there is serous exudation behind the iris, the substance of the lens generally becomes clouded. If the projection is recent, and but to a small extent, it is not certain we shall find any opacity of the lens when we make an artificial pupil; but if it has existed for a long time, and has far advanced, we shall rarely find a lens perfectly unaffected. These opacities, which generally proceed from the central layers[1] of the lens, may by oblique illumination be clearly distinguished from those intra-capsular opacities accompanying iritic deposits, to which I have so often alluded. It is surely unnecessary to mention the possibility of confounding it with an accidental

[1] I have once seen a perfectly typical stratum-cataract (Schichtstaar) developed after exclusion of the pupil (*vide* A. f. O., Bd. ii, Abth. 1, S. 273).

cataract—one caused by the operation for artificial pupil, for such a case might be distinguished by the wound in the capsule, its rapid development, &c. This opacity of the lens may remain long stationary after its cause, the exudation, has been evacuated, but it may also continue to gradually develope, so that after some years the improvement in vision is again lost. Then extraction of the cataract becomes necessary and to effect this the artificial pupil must generally be enlarged by removing an adjacent piece of the iris, either at the same time as the extraction or some weeks previously. Whenever possible, the centre of the flap-incision should be opposite the middle of the artificial pupil, for then the edge of the lens passes with greater ease through the corneal wound. Even in young persons the linear incision is seldom indicated in these cases; for the cataracts, which occur after iritis, even when they do not contain a hard nucleus, are always viscous, and are enclosed in a firm capsule, probably thickened by deposit, so that they do not readily pass through a linear wound. It is evident that it is not very pleasant to extract under such circumstances, and yet the results are more successful than would, *a priori*, be expected. I believe that extensive statistics would show results not much inferior to those of extraction under normal conditions—an apparent enigma explained by the presence of the artificial pupil. We know, that in the unfortunate termination of extraction, suppurative inflammation of the portion of the iris bruised during the exit of the lens forms an essential factor, indeed sometimes the point of origin; and it necessarily follows, that the injury done by the operation will in general be far less when this part of the iris is absent. It is chiefly owing to the occurrence of turbidity of the lens, with which the ulterior formation of cataract is connected, that I advise the immediate employment of iridectomy in pupillary exclusion, but consider it indicated even before serous exudation has collected behind the iris.

Most difficult is it to determine the indications and prognosis of the operation, when atrophy of the bulb has been already induced. Here, the pupillary space being entirely obstructed, we can only estimate the changes in the deeper parts by examining how light is perceived.[1] If the perception of light is very slight, so that the patients can only just perceive a very bright lamp, held close before them, we must not expect from the operation any improvement in

[1] By this means we are even able to recognise improvements in atrophied eyes from the use of internal means. During a treatment by the sublimate I have repeatedly observed an increased quantitative perception of light.

the vision of the affected eye. If the perception of light is of moderate range, so that a bright lamp is perceived at the distance perhaps of four to ten feet, and a medium lamp close at hand, the most important point is to ascertain whether all parts of the retina are equally sensitive, or whether there are differences indicative of secondary retinal separation. In the latter case the prognosis is always unfavorable; in the former, on the other hand, the operation, repeated according to circumstances, affords some hope. If the light is better perceived, so that a medium lamp can be recognised at the distance of a room, and also the light and shadow of a lowered lamp a few feet off, and at the same time the excentric impressions are symmetrical, some improvement may be reasonably expected. It is evident that the degree of atrophy must also be taken into consideration. If it is more concentric, *i. e.* if the flattenings in the direction of the recti muscles are not conspicuous relatively to the diminution of the eyeball in size; if, in a word, the globe is tolerably regular in form, the prognosis is more favorable than in the inverse case. For we may then conclude that the sclerotic has contracted concentrically during the chronic choroiditis and diminished secretion of the vitreous humour, and that after its new position of equilibrium has been established by corresponding modifications of tissue, the form of the globe has continued, even when improved choroidal circulation allowed a more abundant secretion of vitreous humour. On the contrary, when the flattenings are much marked, the sclerotic itself exercises no pressure on the contents of the globe, and hence the diminished volume must be entirely ascribed to the insufficient action of the choroid.

The first form of atrophy is especially developed in youth, when the sclerotic is more elastic. We know, that when morbid processes have occurred during the years of childhood, especially soon after birth, the affected globe sometimes remains small, but regular, which is generally expressed in practice by saying that the development of the bulb has been arrested. I have even succeeded in tracing a similar connexion in many cases of microphthalmus congenitus. Certainly this disease more often depends on fœtal diseases than on arrests of development. In two cases of microphthalmus congenitus, lately under observation, I found, by means of the ophthalmoscope, large choroidal deficiencies in the equatorial region, just such as are found (as atrophic patches) after circumscribed choroiditis has run its course in adults. I performed tenotomy for strabis-

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mus, on one of these eyes, in a child aged two years; on the second, in a child aged ten months, I made an artificial pupil on the inner side, on account of a large central capsular cataract. So far as could be ascertained by trials of vision at so tender an age, neither eye seemed very weak-sighted; in the latter, the ophthalmoscopic examination could not be made previously to the operation for artificial pupil.

I have once even had occasion to make an artificial pupil in an eye, which was probably affected with the results of irido-choroiditis at birth. I partly suspect this from a medical report extending from the earliest infancy, partly from the history, according to which the patient was always restricted to an inconsiderable perception of light, and partly because the diminution in size was far advanced, yet perfectly regular. The individual, a delicate girl of eighteen, presented symptoms which showed that internal inflammations were still continuing in both eyes. Both globes were very much lessened, but at the same time regularly round, the muscular veins extremely developed, and the aqueous humour muddy. The greater part of the pupil was filled with a shrivelled, calcareous cataract, which adhered to the margin of the iris; after the use of mydriatics it presented (as seen through the muddy anterior chamber) a slight, tolerably distinct projection inwards. The mydriatic treatment, and various other means, having been unsuccessful, vision also having continued to diminish during a year, and finally having become reduced to a dull, quantitative perception of light, I resolved to form a pupil in the left eye, and was much astonished at the excellent influence gradually exerted over the whole eye. The case appeared to me the more instructive, because in the eye which had not been operated on I had a constant representation of the previous condition. Three months after the operation the subconjunctival veins had almost perfectly retrograded, the anterior chamber was clear, the pupil perfectly transparent, except that it was covered to a slight extent by the calcified and floating lens, whilst in the right eye all remained in its former condition. The vitreous body, which could now be readily examined through the large pupil, was somewhat muddy for from six to eight weeks, but then perfectly cleared. There were no appearances of disease in the retina, excepting that the vessels were very small; the papilla nervi optici a little smaller and whiter than usual, and the central artery especially very delicate (symptoms of an imperfect development of the optic nerve and retina). The choroid, tolerably uniformly deprived of its layer of pigment, presented no essential changes, except a few places in the equatorial region, where the tissue was atrophied. Only four weeks after the operation the patient could count fingers. Now, she exercises the eye with convex glasses, in recognising figures and letters of large size. The volume of the bulb has not in the least changed.

Having proved the curative action of iridectomy in those forms of irido-choroiditis which are preceded by iritis and pupillary exclusion, I tried it in other and very different conditions, which, for the sake of completeness, I shall successively enumerate; in doing so, however, I shall be obliged somewhat to repeat myself.

In the first place, I shall mention the cases already adduced, where irido-choroiditis resulted from retinal separation. As already remarked, there was no special improvement in vision, but, on the other hand, the internal irritation was alleviated, a point that was often of importance to the healthy eye. In most cases, the greater part of the artificial pupil was filled by a cataract of previous formation.

Secondly, I operated on those cases of irido-choroiditis well known to all observers, but very variously named. In this form the symptoms of irritation are not very severe; there is diffuse haziness of the aqueous humour, with no great amount of pupillary exudation, without contraction, often even with dilatation of the pupil. In this stage of the disease it has been termed descemetitis, hydromeningitis, aquo-capsulitis, iritis serosa, &c., to which symptoms, contemporaneously or at a later period, there are added haziness and softening of the vitreous humour, (very fine floating opacities), great tremulousness of the iris and crystalline lens, generally terminating in retinal separation, cataract, &c. Guided by the anatomy of former days, this species of disease has been supposed to be an inflammation of the serous tract lining the whole interior of the eye, and even if no part of this conception still remains—for the hydromeningitis is an iritis, and the hyaloiditis is a choroiditis—still (by the delicate nature of the commencing exudation, their suspension in the fluids, the absence of firmly adhering exudation, &c.) this form of disease is sufficiently distinguished from other forms, for it to occupy a distinct place in nosology. The rapid appearance and disappearance of the diffuse opacities are to some extent characteristic. I have sometimes seen the aqueous humour become turbid and again clear within an hour; I have seen it become clear, both spontaneously, as after sleep, and after treatment such as bleeding, incisions into the layer of subconjunctival vessels, diaphoresis, &c. The opacities of the vitreous body never clear away so rapidly. Since, as the rule, success may be attained by other means in the first stage of this disease, I only performed iridectomy in some old or desperate cases, and as their number merely amounted to six, I have been unable to come to any decision, but am inclined to repeat the trial, from the results in two instances having exceeded all expectation. Only I should recommend a very gradual withdrawal of the instrument, as the greatest care should be taken to prevent too rapid escape of the aqueous humour, because separations of the retina and intra-ocular hæmorrhages are very liable to occur. This precaution is equally important in paracentesis.

Thirdly, I have operated in sclerotico-choroiditis. I mean cases in which sclerotico-choroiditis posterior had gradually extended to the anterior parts, and had induced a total ectasis[1] of the bulb (hydrophthalmus), haziness of the vitreous body, and atrophy of the choroid. I have not seen any injurious effect from the formation of an artificial pupil, but neither have I been convinced of any curative action, so that at present I cannot recommend imitation in similar cases.

Fourthly, I operated for extensive corneal affections, with and without iritis. I was induced by certain cases in which the corneal disease not having run its course, it was evident that an artificial pupil would ultimately be required, and owing to other circumstances the operation could not be delayed till the affection of the cornea had ended. Instead of the operation inducing any redevelopment or aggravation of the disease, I almost constantly remarked that after the formation of an artificial pupil, the filling up of the corneal ulcers, and the clearing of the opacities, as far as was possible, proceeded with extreme rapidity and success. Years ago this led me to the idea of performing iridectomy, with the design of *shortening the duration of corneal affections.* Of course this treatment must not be employed in cases where the corneal lesions may be expected to heal without injury to the central pupil; but only where total

[1] Ectasis, according to Nysten, is a word proposed by Graefe to denote all diseases characterised by a condition of dilatation; introduced by Breschet into general use under one form—phlebectasie—it has, I think, so found its way into some English works.—TRANS.

destruction of the cornea is to be feared, as in spreading abscesses with infiltration of pus (eitersenkung), or where the recovery which may be expected renders an increased size of the central pupil desirable, as when we can foresee the formation of large cicatrices in the centre of the cornea. I disapprove of iridectomy when the corneal disease depends on a blennorrhoic affection of the conjunctiva, for by curing the blennorrhœa the corneal process has always a very favorable termination, at least in a relative sense, and at a later period we can better determine the condition in reference to forming an artificial pupil. Besides, owing to the presence of blennorrhoic secretion, the wound might endanger the eye, and it would also interfere with the application of caustics, a point never to be neglected. For the same reason I am opposed to it when the corneal affection depends on diphtheritis, or an acute granular process; on the other hand, the operation is advisable in idiopathic diseases of the cornea. In very extensive central abscesses, with infiltration of pus and hypopion, filling half the anterior chamber, I have often combined iridectomy with evacuation of matter from the anterior chamber, when the only object was to save the eye,and I have been highly satisfied with the result in this and similar cases. How is this favorable influence of iridectomy to be explained? Does it arise simply from the puncture of the anterior chamber? It might be so, where the anterior chamber is annulled or diminished for some time after the operation, through the continued escape of the aqueous humour, for only under these circumstances do we find that paracentesis exercises that curative action on corneal lesions which has been so often praised (*vide* A. f. O., Bd. i, 1, S. 224). But in the present case this is only a most exceptional occurrence, for the wound, which is placed on a healthy portion of the corneal margin, quickly closes. Excision of a piece of the iris must necessarily influence the secretion of aqueous humour. Though we have already attempted to prove that the remainder of the iris relatively secretes more, still a perfect compensation is not probable, and hence a certain diminution of the intra-ocular pressure may be readily admitted; besides I have sometimes found, weeks after unilateral operations (under the usual indications), that the eye on which I had operated still was softer to the touch than the healthy one. I suspect that this continued diminution of intra-ocular pressure explains the curative action of iridectomy in corneal lesions, and that in this respect it is allied with the mydriatic treatment and paracentesis. Further, I must not omit to mention that in acute and deeply penetrating corneal lesions iritis is often unnoticed, and that it is very difficult of control, owing to the affection of the cornea. Central corneal abscesses with hypopion are often accompanied by iritis, a complication that, under such circumstances, should always be suspected when the pupil does not yield to an energetic application of mydriatics, though, at the same time, the eye is not very irritable. I consider this suspicion justified by the fact, that in these very forms of corneal disease atropine is more readily absorbed into the anterior chamber than in others (*e.g.* diffuse, interstitial, or deep exudations). Besides, after atropine has been applied, the existence of iritis can sometimes be shown by irregularities, little indentations of the pupillary margin, &c. Indeed, I believe that it is precisely the combination of iritis with central corneal abcesses that explains the occasionally unsatisfactory termination of the latter. Iridectomy is beneficial in both respects.

Fifthly, I have operated in cases where the lens had become swollen, with the view of preventing its injurious effect, both after discisions and accidents. Elsewhere I have indeed maintained that the extraction of the swollen lens by the linear operation is the best course to pursue; but there are exceptional cases, where iridectomy must be performed instead, before, or at the same time. After accidents we often find the iris wedged into the cornea, the pupil being exceedingly distorted and diminished in size, combined with traumatic cataract. I presuppose that the swelling of the lens is moderate in amount, and that it is only threatening to the eye because the pupil is very narrow, and hence the pupillary margin is irritated by the projecting parts of the lens. Under such conditions we meet with the outbreak of iritis, and yet we cannot perform a linear extraction, for, without referring to the impediments possibly presented by the iris, the imbibition of the lens is yet incomplete. In such cases I have often enlarged the pupil by iridectomy a few days after the injury, and then had no further occasion to interfere with the natural process of reabsorption, owing to the swollen lens no longer exercising an injurious influence on the iris. In other cases, where the imbibition of the lens has already far advanced, excision of the iris should be combined with linear extraction of the whole, or of its softened portions. These are no theoretical propositions, but methods I have tested in numerous cases. If the lens has become very swollen, and iritis has already commenced, no time must be lost in performing iridectomy, which, according to circumstances, must be combined or not with the removal of the lens. The degree of inflammation can never be considered a contra-indication. In truth, there is no treatment which, under such conditions, has so decisive an antiphlogistic action as iridectomy. Superficially considered, it might seem absurd to interfere with the iris, and not at the same time with the lens, which acts the part of a foreign body, but the danger is produced through the pressure exercised by the swollen lens on the iris, and hence the chain of injurious effects will be interrupted by the operation on the iris, even though the original cause remains. It is, of course, far more satisfactory to remove, at the same time, the crystalline lens; but I cannot too often repeat that no force should ever be used in attempting removal by a linear incision; the softened portions of the lens readily escape when the operation is properly performed; the removal of portions of the lens, which are not softened, and which adhere with extreme tenacity, by repeated introductions of Daviel's scoop (curette), &c., is dangerous, and also in some respects unnecessary, because these portions do not afterwards affect the eye. The operation for artificial pupil is employed after discisions as after accidents. In young persons a swelling of the lens, producing iritis, is usually accompanied by a softening of the lens, of such a character that we receive the most assistance from linear extraction (*vide* A. f. O., Bd. i, 1, S. 255). In elderly persons, on the other hand, the tendency to iritis is so great, that loosening of the cortical substance, even to a moderate amount, readily excites chronic iritis. In consequence I have avoided, as far as possible, operations of discision in adults, for I cannot agree with the experience of English authors, especially of Jacob, as to the excellent action of keratonyxis in partially softened cataracts, even of old persons. The occurrence of iritis, even though chronic, operates most powerfully in preventing reabsorption, for the capsule, thickened by deposit, is incapable of expanding or contracting. It matters not what future treatment of the cataract be intended, iridectomy should at once be performed. In some cases we may form the artificial pupil at the upper part of the iris, as previously mentioned.

For a similar reason, iridectomy may be indicated in cases where a small foreign body, such as a fine chip of metal, has pierced the cornea, and is firmly fixed in the iris. All hope of its becoming encysted, &c., must be abandoned, when the irritable condition is of some continuance; we must then excise, at the same time, both the foreign body and the adjacent portion of the iris. This is far safer practice than to attempt to extract simply the foreign body. I advise the latter method only when the foreign body is of considerable size; in other cases, it is generally impossible to remove it alone. In fact, after the escape of the aqueous humour, a fold of the iris invariably falls within the grasp of the forceps, and it is scarcely possible to extract, without seizing the iris, a metallic splinter that can hardly be seen. When such an improper proceeding is employed, hæmorrhage into the anterior chamber generally occurs, the body can no longer be seen, and we entirely fail in our object; even if we eventually succeed in extracting it, after having, in various ways, injured the anterior surface of the iris, inflammation generally ensues. I have already sufficiently called attention to the fact, that vision is practically unaffected by the formation of an artificial pupil, and the advantages of preventing iritis are most important. With similar curative views, iridectomy may be applied even to flap-extraction. I do not mean, when posterior synechiæ positively require an enlargement of the pupil, but when the conditions are in every respect of an ordinary nature. Excision of a contused portion of the iris will generally be advantageous, for it often excites deleterious inflammations in cases of extraction where the exit of the lens has been attended with great difficulty. Hence after the removal of the lens I make an artificial pupil at the upper part, not only on account of prolapsed iris, inaccurate position, &c., but in the not unfrequent cases where the iris has been violently contused during the passage of the lens. Iridectomy must not be delayed until symptoms of inflammation have appeared, for it is most critical to operate on the eye at such a period after previous flap-extraction; it is better to perform it immediately after removal of the lens. For those who employ the upper section the ultimate change of position of the pupil is of no importance, for by proper manipulation the displacement of it upwards is only slight, and not as when there is a considerable prolapsus iridis, or when a piece of the iris is excised owing to its slipping before the knife. The natural pupil preserves its central position, being only continued by a small coloboma in the direction of the corneal incision; this coloboma too is covered by the upper lid. The experience of most observers is in favour of the opinion that the cases of operation in which the iris is excised by the fault of the operator do not terminate more unfavorably than normal cases, although the performance of the operation is much complicated by the hæmorrhage, &c. Certain persons have suggested to me the idea of forming a pupil at the upper part some weeks previous to the operation, and I can only oppose it because it would be superfluous in an infinite majority of cases, and would not be very compatible with the limited period which the patients could remain, &c. On the other hand, it might be defended on the ground of security and prophylaxis.

Lastly, I have performed iridectomy even in a perfectly blind eye, simply on account of the other one. Chronic iritis, certainly, in the mass of cases, affects both eyes, and I believe the irritation in the iris of the one eye, caused by adhesions of the pupil (*vide supra*), is the main cause of the disease of the other eye. Hence we find, that in cases of iritis terminating in extensive pupillary adhesions both eyes are often affected, but that otherwise the disease is generally restricted to one side. And since iridectomy is the best means of stopping the irritation of chronic inflammation in pupillary exclusion, we have also in it a very important means of preventing sympathetic disease of the other eye. I could, if necessary, adduce many instances in support of this fact, which is not without importance in reference to nosology. I first remarked this action in a case where one eye was affected by pupillary exclusion, bulging of the iris, and choroidal amblyopia, and the other by more recent iritis and by very partial adhesions Yet three or four attacks of iritis had already recurred. I then made an artificial pupil on the former eye, because I still hoped for some improvement of its vision, and was much delighted to find that from that time the patient's second eye remained perfectly free from iritis. Since then I have very often performed the operation, even where there was no longer any quantitative perception of light; and I have, in some cases, been perfectly convinced of the beneficial influence exerted over the other eye, thus confirming my previous impressions. I designedly say *in some cases*, because only particular combinations could afford direct proof. If the second eye is still healthy, the only question can be as to a *prophylactic action*, which it is impossible fully to prove, as it is *not absolutely certain* that the second eye will also become diseased. If, however, the second eye is also seriously diseased—thus, if there is union of the whole of the iris with the lens—we have an obvious cause for further disease in this eye, and one which, as regards iritis, is more directly influential than the sympathetic action of the first eye. The only decisive cases were those in which iritis periodically attacked the second eye, yet without producing any structural change, or only to so slight an extent as to be insufficient to account for the further development of disease. Many practitioners will doubt the prevalence of such sympathetic inflammation, and be inclined to attribute its occurrence in both eyes to constitutional causes. I do not deny the frequency of such a connexion, but I would warn my colleagues not to have immediate and unnecessary recourse to this opinion, as it leads to neglect of the local conditions, which are more under our control. No experienced observer of the present time can doubt that irido-choroiditis, resulting from an accident, not unfrequently induces a sympathetic affection of the second eye. And we arrive at a similar conviction as to internal inflammations of spontaneous origin, when we carefully consider the manner in which they spread. Even irido-choroiditis of traumatic origin may be occasionally treated by the formation of an artificial pupil, when a sympathetic affection threatens the second eye. Of course, proper discrimination must be used in such cases; for, as the rule, it is clearly indicated to extract a swollen lens, or to puncture the vitreous body, or to remove the cornea or the anterior portion of the globe. I should consider it unnecessary to perform total extirpation of the globe for traumatic irido-choroiditis, with the view of preventing a sympathetic affection of the second eye; and I only mention the proposition, because I hear that it has been introduced by some of our English colleagues.

Before leaving this subject, I may be permitted to add a few remarks on the *manner of performing the operation* under the circumstances referred to, and on its immediate effects.

In regard to the method of operating, I have always employed iridectomy, or the method of tearing the iris, claimed by Desmarres as his own discovery, and which does not differ very essentially from it.[1]

Irido-dialysis is falling more and more into disuse—a natural result of its offering no greater advantages than iridectomy, and yet being

[1] Desmarres, in my opinion, merits our gratitude, not so much for having distinguished this method as for having shown that, in regard to the performance and prognosis of the operation, it is of little consequence in cases of synechia whether the free pupillary margin is brought out, or the tissue of the iris is torn in its continuity.

attended with important disadvantages and dangers. This point has been so fully treated by Desmarres, that it seems unnecessary to add anything further. I may, however, briefly refer to an apparent advantage of irido-dialysis, as on this account it has still its advocates; it affords broader peripherical pupils, such as are wanted where only a small marginal portion of the cornea is available for the transmission of light. But, without considering the very uncertain success of dialysis under these conditions, where we generally find the tissue of the iris atrophied, we can, through iridectomy, readily obtain pupils in the most external part of the corneal margin. Nothing more is required than not to penetrate at the junction of the cornea and sclerotic, but at the distance of half a line from this point, into the sclerotic itself, and to give the lance-shaped knife such a direction that it may pass into the anterior chamber exactly at the point of union. That this is by no means difficult appears from the fact that the origin of the iris, as Arlt especially has urged, does not lie on the posterior wall of Schlemm's canal, but in the very thickness of the tensor choroideæ.[1] If the knife is thus passed into the sclerotic, no opacity whatever is caused in the adjacent portion of the cornea; and this is of especial importance when the healthy portion of the cornea is extremely small; the pupil extends, of course, as far as the extreme edge, so that at a later period, by oblique illumination or the ophthalmoscope, the tops of the ciliary processes are seen projecting into the pupil. It is true such pupils will be a little less broad than those obtained under favorable conditions by dialysis. But some weeks afterwards they can easily be enlarged to any extent, by similarly excising an adjacent piece of the iris. Besides, it is seldom necessary to enlarge the pupil, provided, in drawing out the knife, we act on the internal wound, and not on the external, already relatively too large. And even the inconvenience of repeating the operation should not in-

[1] The older surgeons had already remarked that they could puncture the sclerotic tolerably far back, and still introduce the lance-shaped knife into the anterior chamber; but, according to their accounts, they generally first passed the knife into the posterior chamber, and then transfixed the iris from behind forwards. I am decidedly opposed to such a proceeding, transfixion of the iris from behind forwards being very unsafe, because the iris, being moveable in the aqueous humour, does not offer sufficient resistance; besides, when instruments are introduced into the posterior chamber, all control over them is lost, and the margin of the lens, &c., may be wounded.

duce us to prefer the hazardous irido-dialysis to iridectomy, so certain as to its results, and attended with so little danger.

We generally find great structural changes in the iris when irido-choroiditis is still active; if its periphery is pushed forward by serous exudation, as already stated, it can readily be seized; the more central portion, however, adhering through pigmented exudation, remains in its former position, and I would dissuade from using any violence in extracting it, because the advantages are not proportional to the danger of wounding the capsule and of thus causing traumatic cataract. In other cases the iris is so thickened by exudation into its tissue, that it becomes quite stiff, and unadapted to form a fold. I then employ *straight, pupillary forceps, with sharp teeth,* which, instead of following the ordinary direction, I apply to the iris somewhat perpendicularly; according to my experience, such an instrument is of very great service under these conditions.

Whilst in leucoma adhærens the formation of an artificial pupil causes little or no hæmorrhage into the anterior chamber, in irido-choroiditis the bleeding is often very severe. This is readily accounted for by the excessive vascularity and by the pressure. In the former case the free margin of the iris is frequently seized, so that the small quantity of blood flowing from the incision for the most part escapes externally. The vessels are also not dilated, and the muscular power of the iris is tolerably normal, which must have some influence on the retraction of the cut vessels; finally, when the globe is filled in a normal manner, the sclerotic continues to exert pressure on the contents after the whole of the aqueous humour has escaped; this must necessarily have some influence in limiting the extravasation. If, in synechia anterior, instead of the free margin of the iris being seized, it is torn in its continuity, the blood from the wounded surface does not indeed escape externally; it is the rule, however, in these cases, for both the vessels and the tissue of the iris to become very much atrophied, through being dragged towards the corneal cicatrix. On the other hand, in irido-choroiditis there is hyperæmia, partly of an inflammatory, partly of a mechanical nature. The muscular action of the iris (and with it the power of retraction in the vessels?) is impeded by the deposition of lymph; even the membranes lying behind the iris not unfrequently become vascular, and all these tissues are torn in their continuity. Besides, in this case hæmorrhage is very much promoted by any existing diminution of pressure, which is still further increased by the escape of the aqueous humour. This is particularly the case when the eye has become somewhat atrophied; then the sclerotic ceases to exert any pressure, and after the vessels are opened, a process of suction occurs, so that it is useless to try to remove the blood by the introduction of Anel's stilette, &c., a method which is perfectly successful after hæmorrhage in leucomata, &c. To prevent any increase of hæmorrhage, I am rather inclined to apply, soon after the operation, a bandage, so as to produce slight compression, and this, after half an hour or an hour, I gradually loosen, and finally remove; at a later period the relations of pressure become equalised by transudation, and no longer by extravasation. It is generally said that bleeding into the anterior chamber is not of much consequence, and, in ordinary circumstances, I perfectly agree with that opinion, as the blood is rapidly absorbed in a healthy aqueous humour, and without causing any reaction; but the conditions are of quite a different character when there are internal inflammations. Effused blood often continues long unabsorbed in cases of iritis and irido-choroiditis, especially when the aqueous humour is somewhat clouded; not only are the endosmotic relations between the blood-corpuscles and the surrounding fluid essentially altered by its saturation with exudative matters, but even the conditions of reabsorption are no longer the same, and finally the flakes of blood, which remain for a long period, seem to act as mechanical irritants, and to serve as the starting-point for fresh exudations when they pass into the pupil. Hence severe hæmorrhages, filling the whole anterior chamber, are very troublesome in some cases of iritis and irido-choroiditis, and success will sometimes be frustrated by them. We cannot always succeed in avoiding them, but since for the most part they arise, so to speak, ex vacuo, I consider it very desirable to exercise a little pressure even during excision, and afterwards to apply the compressing bandage already recommended. I must also mention the *severe pain* sometimes produced by seizure of the iris; whilst this is most exceptional under ordinary conditions, here it occurs almost invariably. This pain, which is partly situated in the bulb, partly radiating as ciliary neurosis into the forehead, temples, and nose, occasionally continues for some hours after the operation.

I have never seen a more violent degree of iritis ensue after the operation; on the other hand, there sometimes follows, however, especially when severe hæmorrhage has occurred into the chambers, by a very marked state of congestion, of which the symptoms are lachrymation, slight chemosis, moderate swelling of the lids, and hyperæmic coloration of the iris; this always forms an essential difference from the usual state, in which the formation of an artificial pupil excites no reaction whatever; and even here it is only occasional, principally occurring when we are compelled to operate in very acute cases. Still it seems advisable to allude to it, that those who may hereafter imitate my example may not be astonished if the allaying influence of iridectomy, of which I have spoken so highly, should not in all cases immediately follow the operation. Fortunately the state of congestion is temporary, and even when excessive it yields to moderate antiphlogistic treatment, and then, in general, the desired curative action on the internal inflammation gradually appears in the course of a few weeks. After the operation for artificial pupil, all other methods of treatment usually act more favorably than before; so that, when pupillary exclusion has once formed, I seldom begin to employ other remedies, such as mercurials, until after I have operated.

Lest I should be charged with one-sidedness, I must, in conclusion, remind the reader that I have by no means intended fully to consider the treatment of iritis and irido-choroiditis. I have never aimed at supplanting, by mydriatics and iridectomy, other methods of treating these diseases; and every unprejudiced person who has followed my clinical practice and lectures will bear witness how much I value an energetic and properly conducted antiphlogosis, especially at the commencement of the disease. Above all, I am far from wishing to depreciate the importance of mercurials, and I recognise with the fullest conviction their great value in dangerous internal inflammations. My sole object has been to recommend to my colleagues a proceeding which I think I have tried with the necessary scepticism and circumspection, believing that they will find in it a source of numerous successes and the curing of many otherwise incurables.

ON

# IRIDECTOMY IN GLAUCOMA,

AND ON

# THE GLAUCOMATOUS PROCESS.

By Dr. A. v. GRAEFE.[1]

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I.—To the report on the curative effects of iridectomy, already published in the 'Archiv' (B. ii, Abth. 2, S. 202—257), I am about to add another of a highly gratifying character, for it refers to a comprehensive category of diseases hitherto incurable. The present communication would much sooner have been issued, had not the insidious nature of the affection demanded extreme care in judging of the results, and long-continued observation. Hence it is perfectly possible that iridectomy, as a remedy in the glaucomatous process, is already well known to most readers of the 'Archiv,' the subject having been discussed in my clinic through two sessions, communicated to many of my colleagues both orally and by letter, and very widely imitated. The best amends for my delay will be to specify the indications and prognosis as accurately as possible; otherwise, indeed, I would not give publicity to these observations, lest those who may adopt my views should not prove equally successful, and I should bring into discredit a method which is

[1] Translated, with the author's permission, from the 'Archiv für Ophthalm.' Berlin, 1857.

happily becoming naturalised in practice within its proper limitations.

II.—When we recommend medicines or modes of operation, it is especially necessary to define the disease in reference to which they are recommended. The absence of general agreement constitutes an hereditary evil of therapeutical science, only to be cured by slow degrees, just as a sanguine predilection for medicines gradually yields to an intelligent analysis of the indications of treatment. I feel the necessity of agreement the more acutely, because the affection in question has ever seemed one attended by confusion and misunderstanding.

The name glaucoma formerly indicated a vague, expressionless symptom—a sea-green, bottle-green, or dirty-green background of the eye, seen through a fixed, dilated pupil. When greater exactness was required, efforts were made to discover definite, material changes, sufficient to account for this symptom, but they terminated most variously and contradictorily. Whilst some imagined in glaucoma a peculiar degeneration of the refractive media, and especially of the vitreous body, others referred the origin of the disease to the choroid, others again to the retina; and as each of these views was contradicted, some gave up the seemingly futile attempt to localize, and considered glaucoma a disease of the whole globe. The latter hypothesis obviously attests only the incompleteness of our knowledge, for, owing to the great variety of the tissues of the eye, an exact pathology requires as accurate localization as in diseases of the abdomen or thorax. No one can doubt that in the course of the glaucomatous process most tissues of the eye become diseased, but it is equally certain that they are attacked at different periods, and that in consequence we have to distinguish the primary from the secondary changes. Of all the opinions brought forward certainly that one had the most numerous and powerful followers, which explained glaucoma as an inflammation of the choroid, with effusion between it and the retina. This view seemed to be favoured by pathologico-anatomical facts first collected by Schröder van der Kolk, and afterwards especially by Arlt. Notwithstanding, it was still open to controversy which of the changes were primary and which secondary or quite accessory. Most of the preparations were taken from far-advanced cases, and hence, at the time of dissection, did not present the typical appearances of glaucoma; and with the exception of a few instances brought forward by Arlt, there had been no examination during life, a point which is almost indispensable for fixing the glaucomatous origin.

Finally, more than five years ago, there appeared Helmholtz's immortal discovery, destined to throw so much light upon many obscure cases, especially upon amaurotic affections. This naturally excited the hope that the question of glaucoma would also be decided. But, unfortunately, this expectation was not so speedily to be gratified; it rather appeared as if glaucoma would remain an insoluble mystery, even when examined by the new instrument. The immediate results were of a purely negative nature, proving the non-existence of those effusions suspected to lie between the retina and the choroid. The diagnosis of such effusions, formerly possible only when they were very extensive, so as to produce the so-called hydrops subretinalis, had been so much aided by the application of the ophthalmoscope, that they could not possibly be overlooked; yet they were never seen, provided typically pure cases of glaucoma—and such, of course, were necessary—were employed in the investigation. Such cases were, in general, somewhat advanced, for in the specially acute period of the process, it is seldom possible, owing to the diffuse opacity of the refractive media, to determine with certainty the details of the back of the eye. Hence it could no longer be supposed that subretinal effusions caused the glaucomatous blindness; either they had no connexion whatever with the disease, or were developed at an advanced period, as a secondary affection. Neither could the diffuse cloudiness of the aqueous and vitreous humours sufficiently account for the blindness caused by glaucoma; for the opacity is never so great as to explain the entire loss of perception; besides, at times, if not prevented by the formation of cataract, it may be seen spontaneously to disappear, without any corresponding power of vision being restored. The changes in the internal membranes, apoplexies, and, at a later period, partial atrophies of the choroid and retina, did not by any means constantly occur, and were also developed to a far less extent than in chronic retinitis and choroiditis. Hence it must follow that these structural changes did not directly cause the occurrence of the blindness. Since, however, a peculiar alteration in the entrance of the optic nerve was always apparent in well-marked glaucoma, the attention of all investigators was directed to this point, as the probable source of the disease.

III.—Three facts were ascertained as to this peculiar condition of the optic nerve.

1. A change in form, first brought into notice and delineated by Ed. Jäger (see his book on 'Cataract and Cataract-operations,' plate viii, fig. 34). He believed that this appearance was caused by an arching forwards of the papilla. The error had such an appearance of probability, that it was universally believed, till I found an opportunity (see A. f. O., B. ii, Abth. 1, S. 248, 249) of correcting it. The mistake was almost certain to be discovered after Dr. A. Weber (A. f. O., Band ii, Abth. 1, S. 141-6) had carefully discussed the origin and solution of an analogous error in the instance of a rabbit affected with sclerectasia posterior. The conviction that the glaucomatous optic nerve does not project, but is hollowed out, has since then acquired complete certainty. I refer any one still unconvinced to the anatomical description of a glaucomatous optic nerve, promised by Professor H. Müller for the next number of the 'Archives.'

2. A peculiar condition of the retinal vessels within the limits of the papilla. This has been well represented in Jäger's first plate, and explained by Liebreich (see A. f. O., B. i, Abth. 1, S. 375) as caused by the form of the optic nerve. Since the concavity has been shown, this explanation certainly requires some slight modification, yet it remains essentially correct.

3. Pulsation in the arterial trunks, already mentioned by Ed. Jäger in reference to diseased eyes, and adduced by me (loc. cit., p. 376) as pathognomonic of the glaucomatous process.

IV.—When the changes in the optic nerve were perceived in glaucoma, there naturally ensued the task of connecting them with the symptoms previously known of circulatory and trophic disturbances. The solution of this problem presented the greatest difficulties. Even if the affection of the optic nerve were really the first cause of blindness, still the remaining complex group of symptoms could not result from it, as a secondary affection. We see glaucoma, in its most typical variety, sometimes occurring in previously healthy eyes in the form of acute inflammatory attacks. Besides, a causal relation of the lesion of the optic nerve with the other alterations, of the refractive media, &c., could scarcely be imagined. In amaurotic cases we observe the most advanced metamorphoses of the papilla, extending even to perfect atrophy of the optic nerve and retina, without the other parts of the eye being affected; even the most exquisite granular exudation processes in the papilla usually only lead to changes of the retina. This may be readily explained by the nutrition of the retina, which is independent of the other membranes of the eye. Indeed, this opinion is almost disproved by the fact, that the papilla is not convex, but concave. Had the former been the case, we should probably have had to consider the question of a swelling caused by exudation, which we all formerly believed to exist, and which might possibly induce further disease of the globe. But since the papilla is concave, we can scarcely imagine any increase in the size of the optic nerve. Retraction of the substance of the optic nerve after any previous exudative processes might certainly cause a retraction of the papilla, but no such previous condition of swelling can at present be shown which might justify the hypothesis. Hence the degeneration of the optic nerve cannot be justly considered as the source of the remaining symptoms, and yet the pathogenesis of particular cases seemed to favour this view. Sometimes, during a long period, only the lesion of the optic nerve was observed, whilst the other symptoms of glaucoma did not occur until a later period. In comparison with the former statement, these cases, however, have been continually becoming less frequent, just as we have gained increased familiarity with the methods of observation, and I now venture to maintain that, on a very minute examination, the other glaucomatous signs, such as increased intra-ocular pressure, may be perceived even in the earliest periods, but they are less prominent in the insidious forms, so that errors in diagnosis may very readily be made. To prevent any misapprehension, I must at once remark, that there is a small but incontestable category of cases, in which the affection of the optic nerve alone exists, and continues unaccompanied by any other symptoms. My previous statement refers entirely to the cases in which the external symptoms of glaucoma are developed at a later period. I am obliged to urge this, because the affection of the optic nerve might otherwise be imagined, as formerly by myself and others, to be a first and original stage of the glaucomatous process. In general, *three different groups of cases* require consideration. In the first the whole sequence of glaucomatous symptoms at once arises; and in due time, but consecutively, as will hereafter appear, the degeneration of the optic nerve is visible by the ophthalmoscope. In the second the lesion of the optic nerve is at all events the first striking material symptom; the other glaucomatous signs, however, can be shown, though at first but little marked, until at a later time they attain their typical development. In the third group there is throughout only the degeneration of the optic nerve. It will be one object of the present communication to estimate these three groups of disease in their opposite nosological relations, and either to unite or separate them.

At the time of my writing the above-cited essay on glaucoma, the generation of the ophthalmoscopic signs was still completely veiled in obscurity. The identity in the form of degeneration of the optic nerve seemed to justify us in including all these groups under the head of glaucoma, explaining the differences of development by the unequal action, in different directions, of a common extra-ocular cause—arterial atheroma. Certainly, the first service rendered by the ophthalmoscope towards understanding glaucoma was not of a very gratifying nature; instead of the simple and comprehensive doctrine of glaucomatous choroiditis, the disease was transferred to a part apparently unconnected with the rest of the evolution; even the term glaucoma showed this influence, for it now acquired a much more extended signification, and was for some time applied to cases not previously known under that name. If it had ever been possible to agree about glaucoma, it was certainly impossible at the time of the first ophthalmoscopic elucidations.

V.—There were only two ways of discovering the connexion of the lesion of the optic-nerve with the other glaucomatous symptoms; first by pathological anatomy, and secondly by the most exact clinical observation. Since my opportunities were very insufficient for the anatomical examination of fit cases, I was restricted to the latter method of study. I especially watched those cases in which the appearance of glaucoma was developed after repeated acute internal inflammations (ophthalmia arthritica). For the time I neglected the question as to what internal membrane the origin of inflammation should be referred, and adhered to the supposition of a choroiditis, which was especially favored by Arlt's dissections, the whole appearance of the malady, the sympathy of the iris, and the cloudiness of the vitreous body. The ophthalmoscope had only refuted the occurrence of subretinal effusions, but not of choroiditis, a point to which I shall again refer, especially as in my original note on glaucoma, fettered by the degeneration of the optic nerve, I passed too rapidly over the account of the internal membranes. Now when I compared the general appearance of this glaucomatous inflammation with that of other internal inflammations, for example, of the common irido-choroiditis, it seemed to me that all the characteristic symptoms tended to one point—*increase of the intra-ocular pressure.*

*The hardness of the glaucomatous globe* has been remarked from the earliest periods of ophthalmology. Since no change in the sclerotic, capable of explaining the altered resistance of the globe, can be justly admitted, it must be founded on the more complete filling of the globe with fluid. The dilatation and immobility of the pupil, are, it is known, not caused by the blindness: were this the case, the pupil must contract on the passage of light into the other and healthy eye, as in unilateral anæsthesia of the retina; the diameter of the pupil must also change in rotations of the globe, in alterations of accommodation, and in closure of the lids. Besides, not unfrequently, after the first attack of glaucomatous inflammation, more or less power of vision returns, and yet the pupil preserves its abnormal properties. Evidently we must refer the pupillary affection directly to iridoplegia—paralysis of the nerves passing to the iris. The degree of mydriasis in glaucoma compared with that in paralysis of the oculomotorius, might indeed seem too great for the admission of iridoplegia; but as I have already elsewhere stated, the maximum dilatation, in which sometimes the iris almost peripherically vanishes, does not exist from the commencement, but is developed with the progressive atrophy of tissue, and it sometimes also proceeds from other mechanical causes (see the account of dissections in the previous treatise on Sympathetic Amaurosis). The increase of the intra-ocular pressure would furnish a further reason for iridoplegia, the power of conduction in the ciliary nerves being thereby annulled. As a phenomenon analogous to iridoplegia, I found *corneal anæsthesia;* this is also explained by compression of the nerves passing to it; in a second note on glaucoma (*vide* A. f. O., Bd. i, Abth. 2, S. 305) I have already given a direct proof of this, by showing that after the aqueous humour has escaped, the sensibility of the cornea is again restored, provided the operation is performed at a sufficiently early period of the disease. With these symptoms may be classed the *flattening of the anterior chamber;* which, in my opinion, depends upon two circumstances. First, the convexity of the cornea is diminished; secondly, the iris is really more arched forwards. The flattening of the cornea, which may be proved by examinations of the reflection from it, compared with that of another and healthy eye, is in itself an invaluable argument for the increase of intra-ocular pressure. In an inflammatory affection we could scarcely explain this symptom in any other way; perhaps, also, we may be able to found on it an accurate method of measuring the amount of increased pressure, for it is subject to mathematical estimate by means of Helmholtz's ophthalmometer. If the radius of corneal curvature approach that of the sclerotic, the receding angle of the cornea will be pushed outwards, and occasion an alteration in the form of the anterior chamber; at the same time, the iris will be pressed backwards. Since, on the contrary, the iris in glaucoma appears more convex anteriorly, there must, with the demonstrable flattening of the cornea, be a compensating, or more correctly an over-compensating momentum, a far greater increase of pressure acting in the space occupied by the vitreous body than in the anterior chamber, so that the iris is actually pressed forward. Again, the *circulatory changes* in the subconjunctival veins favour the idea of an increased pressure. It is well known that, in the inflammatory stage, the whole system of anterior ciliary vessels becomes much injected; that at a later period, however, the arteries gradually diminish, whilst the great venous trunks twist and expand, anastomose with one another by loops near the corneal periphery, and at length produce those figures formerly indicated as pathognomonic of the glaucomatous process, under the name of arthritic or abdominal veins. The arteries ultimately contract even to less than their normal size, and with this is connected a progressive atrophy of the subconjunctival layer of cellular tissue, which is proved by the white sclerotic shining through it with much more than natural brightness. The veins are then seen as isolated, dark-red strings, ramifying over a background, which is porcelain-white or wax-like, or after the formation of ectasia, bluish-gray or bluish. The older authors have already mentioned, that "the white of the eye between the arthritic vessels presents a peculiar, dead, lifeless appearance." The dilatation of the veins may be reasonably referred to a mechanical obstruction of the internal circulation. If, from increase of the pressure in the space limited by the choroid and the crystalline system, the blood cannot readily escape by the posterior venous canals, especially by the vasa vorticosa, it passes anteriorly through the anterior ciliary veins, which open into the muscular ones. Then these expand, so as to form a species of collateral circulation. Various views, having, however, no immediate connexion with our subject, may be formed as to the atrophy of the anterior ciliary arteries, occurring at a later period, which in some cases is undeniable. At all events it is closely connected with the progressive atrophy of the iris. That the *ciliary neurosis* is similarly caused by compression, is in agreement with the fact that it is often immediately relieved by paracentesis.

The arterial pulsation was the first of the ophthalmoscopic signs that suggested the idea of increased pressure. It is true, that in my first note I gave a different explanation of this phenomenon—obstruction of the arteries. Indeed, it is undeniable that arterial pulsation in the retina may be caused by compression of the arteries externally to the eye, or a diminution in their calibre, provided the explanation I have given of the experimental phenomenon, and which has been accepted by Donders, is correct. But, on the contrary, the results of experiment more especially favour the view that it is owing to an increase of the intra-ocular pressure. As regards the occurrence of pulsation, it is clearly the same, whether the bulb is compressed by the finger, or by an increased collection of fluid in its interior. Again, the manner in which the patient becomes totally blind, in the acute cases, reminded me very strongly of the *deprival of sight by compression.* The contraction of the visual field during the temporary obscurations, the occurrence of coloured vision, the nature of the blindness even, present the greatest analogy with the perceptions obtained by artificially compressing the bulb until the appearance of arterial pulsation (Donders).

When I published my second notice upon glaucoma in the first volume of this journal (Abth. 2), I expressed the opinion that glaucomatous inflammations essentially depend on increased intra-ocular pressure; this, indeed, induced me to make the trials of paracentesis, there related. *The form of the papilla,* however, prevented me from coming to a general decision. The supposed convexity continually turned my attention back to a substantial lesion of the optic nerve. When I became convinced of the concavity of the papilla, an explanation was immediately sought in another direction; but it required longer observation to become fully satisfied, the cases in which the lesion of the optic nerve apparently pre-existed (see hereafter) still remaining perfectly inexplicable. A case treated by paracentesis, first showed me, that the excavation of the optic nerve only becomes developed secondarily in the so-called acute glaucoma. The patient had come to me during a violent attack of glaucomatous choroiditis. I had performed paracentesis three times in a space of eight days. Clearness of the refractive media was as perfectly obtained as could be wished, and continued also during the following weeks; at the same time there were all the signs of a glaucomatous affection, visible in the iris and pupil. The ophthalmoscope showed the papilla to be perfectly normal, and only after many months, when fresh obscurations occurred, did the optic nerve progressively degenerate, advancing with the other symptoms of increased pressure. I only attained a more general conviction as to the point in question, after the employment of iridectomy had enabled me to decide more accurately upon the condition in the earliest periods of disease. It was constantly found that the lesion of the optic nerve did not yet exist after the first inflammatory attacks, but was gradually developed at the same time as the other symptoms of increased pressure. Hence, I felt obliged to conclude that the excavation of the papilla arises in the same way as many of the sclerotic ectasiæ which appear in the later stages of the glaucomatous process. The entrance of the optic nerve is, in respect to resistance, the weakest part of the envelopes of the bulb, and it may easily be imagined that this part would also be the first to be pressed outwards when the intra-ocular pressure is increased.

Whilst occupied with the examination of these views, I received last winter a letter from Professor Heinrich Müller. Without any knowledge of my nosological investigations, he had arrived at the same conviction, through the anatomical examination of an excavated optic nerve. I should forestall H. Müller's publication, were I more closely to represent the reasons which guided him. But I briefly allude to the circumstance, because I had long desired the anatomical confirmation, and it was naturally of the highest importance in the continuance of my investigations.

Admitting that the lesion of the optic nerve is, in certain cases, caused by intra-ocular pressure, still I must at once guard against a too generic and over-hasty adoption of this law. The point I have just maintained is limited, at present, to the acutely inflammatory cases. With respect to the insidious form, in which the symptoms of pressure become distinct only at a later period, I think that I might also propose this view, as a probable, although not a certain explanation;

and, finally, in reference to the third group, in which the excavation of the optic nerve generally continues, without the addition of other glaucomatous signs, there can of course be no question about such a derivation.

VI.—Having advanced thus far in the analysis of our subject, let us pass to a short exposition of the course of the disease. I do not aim at depicting any new form, nor even at giving an exact nosological description, such having been admirably performed by many authors. I intend to limit the symptomatology of particular morbid series to what is necessary to supply a connexion with the more general principles above stated, and to render possible an agreement about glaucoma—the ophthalmoscopic results included. As already mentioned, I distinguish three groups, and would indicate them by the names of *acute or inflammatory glaucoma*, of *chronic glaucoma*, and of *amaurosis with excavation of the optic nerve*. The transitions or separations of these forms will be most naturally discussed in the course of this exposition.

### 1. *Acute or inflammatory glaucoma.*

(Syn. Glaucomatous Choroiditis, Ophthalmia Arthritica).

There is generally a precursory stage; it is absent in only from twenty-five to thirty per cent. In this premonitory stage, any existing presbyopia is increased, coloured spectra emerge from time to time, especially in the form of rainbows around the flame of a candle. There are also, especially as this stage advances, intercurrent obscurations; then everything appears gray and misty to the patient, and a functional examination during such attacks sometimes shows a slight contraction of the field of vision, but, as the rule, only great indistinctness of excentric impressions in certain directions. Towards the end of this stage, the intercurrent obscurations become more frequent, longer, and more intense; at the same time, the pupil becomes somewhat larger and sluggish, the aqueous humour even already seems slightly and uniformly clouded. Pains in the forehead and temples in the form of ciliary neuroses, which are, as is known, symptomatic of internal ophthalmiæ, sometimes occur at a very early period, sometimes only in the later epochs of the premonitory stage, contemporaneously with the obscurations; only in rare cases are they entirely absent. The premonitory stage has an indefinite duration, generally of many months, sometimes years. If the obscurations occur at intervals of many weeks, the termination of this stage is still uncertain; if the intervals between the attacks are not longer than a few days, the commencement of the second stage is to be expected; indeed this may ensue even under the former conditions. The premonitory stage is entirely absent in some cases.

The rapidly increased presbyopia is not without significance; I think that here it proceeds from an increase of the internal pressure and flattening of the cornea. The coloured spectra have similar characteristics to those occasioned by pressure on the eye; they do not depend on diffraction, or conditions of accommodation, but must be referred to a morbid innervation of the retina. This is also true of the obscurations. The temporary dilatations of the pupil proceed from commencing iridoplegia. The sensibility of the cornea is probably correspondingly diminished, but I do not venture positively to assert that it is so, for slight differences in sensibility can with difficulty be proved, and especially in the aged, in whom the corneal sensibility is generally less acute.

The special outbreak of the disease is generally sudden; sometimes it is developed by a gradual increase in the premonitory attacks. The general appearance of an internal ophthalmia is presented: violent, often unbearable pains in the eye, but especially in the forehead, temples, and side of the nose (as far as the extremity of the bone), injection of the subconjunctival vascular network, not unfrequently to the extent of chemotic swelling, with copious lachrymation, but with very little mucus; the anterior chamber diffusely hazy, the cornea generally dulled on its posterior surface, the pupil irregularly dilated, occasionally also broad posterior synechiæ, the iris of a dirty hue and pressed forwards; the power of vision sometimes entirely lost as if by a stroke, sometimes only much diminished; the field of vision, when it can be measured, either normal or somewhat concentrically contracted; at the same time, in the mass of cases, there are well-marked subjective appearances of light, photopsia, chromopsia: as the rule, these violent symptoms arise in a restless night, and generally after much previous suffering from want of sleep. These inflammatory attacks may recede, vision being partially or almost entirely restored, yet the anterior chamber usually remains somewhat flatter, the pupil a little dilated and more sluggish, the iris spotted, and the visual field often somewhat contracted. Such a temporary restoration may be spontaneous, although it is usually obtained by antiphlogosis, by opium in large doses, and by paracentesis of the anterior chamber. But in many cases the blindness continues from the very first attack, notwithstanding the retrocession of the inflammatory symptoms. The insidious nature of the disease is such, that either these inflammatory attacks are occasionally repeated, each time leaving a renewed and greater deterioration of vision; or no fresh inflammatory symptoms again appear, yet the visual field becomes continually more contracted, finally excentric, the grayish hue of the iris increases, the pupil dilates and entirely loses its mobility, the globe becomes constantly tenser, and the cornea perfectly anæsthetic. During this process the refractive media—the aqueous humour and vitreous body—may again lose their diffuse turbidity, so as perfectly to allow ophthalmoscopic examination of the back of the eye; then we generally find certain changes in the internal membranes, peculiar retinal ecchymoses in the form of round spots, and not unfrequently larger choroidal extravasations, especially in the equatorial region. I shall presently add a few remarks upon their signification. There are also constantly found, at this later period, a progressively increasing excavation of the optic nerve, and arterial pulsation, appearing either spontaneously or on the slightest compression with the finger, appearances which were entirely absent after the first or the few first attacks.

Here we have all the appearances previously mentioned as characteristic of increased pressure. The question cannot any longer be passed over, by which one of the internal membranes is the morbid process of secretion effected? The changes shown by the ophthalmoscope afford no immediate decision; even the apparently positive results must be employed with caution in coming to a conclusion. In the very frequent occurrence of retinal ecchymoses, we might readily find a support for the view once promulgated by Ph. v. Walther, who accordingly held glaucoma to be a *lesion of the retina.* The rapidly advancing blindness, the appearance of photopsiæ, and chromopsiæ, would certainly harmonise with such a conception, the more as, on the other hand, we know how little even far-advanced structural changes of the choroid interfere with the action of the retina, provided there is no retinal separation. Still, I think that the participation of the retina is quite secondary. Iridectomy has taught me that extensive retinal ecchymoses of the kind referred to do actually diminish, to some extent, the acuteness of vision, yet they do not by any means explain the peculiar blindness. Again, I have ascertained, in a number of cases, that most (perhaps all?) of the retinal ecchymoses do not occur until after iridectomy, and yet that, at the time of observation, there is very great improvement of vision. This refers to those cases in which the ocular background could be critically examined even before the operation, the haziness of the refractive media not being very great. These retinal apoplexies differ essentially in form from the extravasations occurring in apoplectic retinitis, which are distinctly striped, and follow the course of the fibres; in the former we find extremely regular, round spots, which seem to be seated exclusively on the veins, and for the most part where the larger trunks unite. Besides, in the early stages there is not the slightest granular or striped turbidity of the retina. The general appearance of the retinal lesion gives me quite the impression of vascular ruptures, caused by mechanical hyperæmia. When the intra-ocular pressure is so much increased that it completely interrupts the passage of the blood through the arteria centralis retinæ between the arterial diastoles (arterial pulsation), we may imagine the much greater effect upon the far more yielding vena centralis. This is also shown by the dilatation of the retinal veins, which always occurs in a certain stage of the disease. If paracentesis of the anterior chamber, or iridectomy, be performed, the sudden relaxation of pressure very readily accounts for the occurrence of ruptured vessels, when there is such venous congestion. It is true that an abnormal hæmorrhagic tendency may also be induced by other causes, especially in old persons with rigid arteries. Forms of glaucoma occur, which have been called apoplectic, in which the hæmorrhages of the inner membranes attain an unusual extent, and which are even prematurely accompanied by hæmorrhagic separation of the retina; but in deciding nosological questions, we must always adhere to typical forms of disease, and, judging from them, I believe that the retina plays a subordinate and secondary part in acute glaucoma.

What are the direct proofs of *choroidal inflammation* in glaucoma? We know that in the later periods ectasiæ frequently form, especially in the equatorial region of the globe; we also know, chiefly from Arlt's investigations, that in these places inflammatory processes can be positively shown by dissection; all this, however, refers to a later period of the disease, and, considered with reference to the pathogenesis, would also always admit of other explanations. Thus, some relatively weak parts might be bulged out when the intra-ocular pressure was increased, without reference to the original cause, and certain textural changes might then occur in those parts, as consequences of the ectasia. Such reasoning would be the more admissible, because the textural changes which have been observed, are for the most part restricted to thinning of the choroid, and its adhesion with the sclerotic. After a single attack of glaucomatous inflammation, the ophthalmoscope seldom shows any change, except irregular distribution of pigment, and occasionally ecchymoses in the choroid, especially in the equatorial region. Formerly I had seen the latter only in chronic cases; but since the introduction of iridectomy has rendered an ophthalmoscopic examination possible at an earlier period, it has been found with increased frequency in the acute cases, which we are now considering. The choroidal ecchymoses seem to disappear far more rapidly than those of the retina; the latter usually continue two or three weeks after iridectomy, and sometimes considerably longer (see below). I only discovered choroidal ecchymoses, provided I made the examination before the end of a week and a half after the operation; it is generally much more difficult to perceive them, because they are less marked, owing to their irregular form, and because, at the same time, we are obliged to look very much to one side or downwards. On the other hand, during the last few months I have become convinced that these choroidal ecchymoses exist before the operation, and perhaps do not occur consecutively, as do the greater part of the retinal ecchymoses. Thus, a condition has been proved which would favour the opinion that the disease proceeds from the choroid. The participation of the iris also forces us to direct our attention to the region of the uvea. In regard to this point, I must especially remark that the iris, even though to a very various degree, always becomes affected with inflammation in glaucoma. This would only be admitted by most persons in the cases in which posterior synechiæ are at the same time formed; yet in other cases, in which they do not occur, inflammation may be proved by examination of the excised iris. This was always found stiff and infiltrated. The muddiness of the aqueous humour, and the dulness of the posterior surface of the cornea, with the irregular refraction of light (mydriasis) and the yellow lens (age of the patient), are the chief causes of the glaucomatous hue of the pupil, and yet these opacities must indisputably be referred to inflammatory effusion from the iris. Besides, the degree in which the iris participates essentially influences the appearance of the affection. If far developed, the pressure seems also to materially increase in the anterior chamber, through hypersecretion of turbid aqueous humour, and then the iris is not pressed forward, &c. The chief argument in favour of choroiditis is, in my opinion, the turbidity of the vitreous body. Even if it contributes little or nothing to the so-called glaucomatous habitus (of the pupil), as we have found by experiments made after paracentesis of the anterior chamber, still its existence is shown with certainty by the ophthalmoscope, notwithstanding its diffuse nature. Again, examinations immediately after the discharge of the aqueous humour, also prove its existence; even if the iris appears perfectly clear, and the glaucomatous hue of the pupil has almost disappeared, still there constantly remains a mist, rendering the details of the ocular background indistinct. Besides, the opacity is not perfectly uniform, the inferior portion of the vitreous body being generally the more turbid, so that the upper part of the retina is relatively more accessible to examination. The opacity cannot, however, be resolved into separate parts. It is obvious, that in these cases it is most natural to refer the cloudiness to a morbid process of secretion by the choroid. At all events, this presents no difficulty when we have once overcome the physiological doubt with respect to the nourishment of the vitreous body by the choroid. The objection has some degree of plausibility, that after the glaucomatous attack but little disease can be shown with the ophthalmoscope, especially in the tissue of the choroid, whilst very striking changes are seen in other of its inflammations. This, however, only proves that there are inflammations of the choroid of a very different kind,[1] and a glance

[1] On this point, H. Müller, who has during the last few years traced with so much penetration the pathologico-histological changes in internal ophthalmiæ, made a statement that much interested me. He assured me that he often did not find distinct structural changes, even when there were extensive effusions on the inner surface of the choroid and ciliary body. This shows how cautious we should be in denying choroidal affections, when, as in the present case, the diagnosis is not immediately determined through the seat of the exudation.

at the diseases of the iris will, I think, assist us in forming an opinion. Diseases occur in this tissue also, which are characterised by great circulatory and textural changes, the aqueous humour being at the same time not much altered; whilst there are others, of which the opacity of the aqueous humour is pathognomonic. The general appearance of the so-called iritis serosa, or hydromeningitis, was very well described by the older authors; that their account now requires considerable alteration, is only owing to the anatomical ideas that formerly prevailed. Such an inflammation may continue for a very long time, without the occurrence of distinct changes in texture, adhesions, &c.; at all events, the chief symptom continues to be diffuse cloudiness and increased amount of the aqueous humour, probably with increased pressure in the anterior chamber (perhaps to this should be referred the dilatation of the pupil, which occasionally occurs). I hold a similar view of glaucomatous choroiditis—that it is a disease of secretion. Serous iritis is also nosologically allied to chronic glaucoma; we not unfrequently find transitions of the former into the latter, and we find, *mutatis mutandis*, this fact already pointed out by the older authors. The treatment of both affections is also analogous, with the difference that, in iritis serosa, iridectomy is a last resource, recovery being often obtained by other means. In short, *I consider acute glaucoma to be a choroiditis (or irido-choroiditis) with diffuse imbibition of the vitreous body (and aqueous humour), and in which increase of the intra-ocular pressure, compression of the retina, and the well-known series of secondary symptoms, are produced by the increased volume of the vitreous humour.*

### 2. *Chronic Glaucoma.*

The process of development differs in this form from the cases described under the first head, by the absence of any distinct and periodically returning internal inflammations. The attacks, which were intercurrent in the premonitory stage, continue for a longer time, and at a later period leave no intermissions, but only remissions between them; the eye acquires its glaucomatous habitus, nearly as in the previous form after the inflammatory process had ended; the pupil gradually becomes wider, the anterior chamber flatter, the iris discoloured, although not very strikingly, the globe tenser, the subconjunctival veins more dilated, the visual field contracted, and the acuteness of vision diminished—all this occurring without any attack of violent redness, swelling, or symptoms of irritation. Ciliary neurosis is rarely quite absent, yet at the same time the attacks are not very violent. Did not the condition of the refractive media and of the iris indicate a local process in the eye, the disease up to a certain stage might be confounded with an amaurosis of extra-ocular origin. Since, in addition, the ophthalmoscope shows, at a relatively early period, an excavation of the optic nerve, which is gradually developed, and soon followed by arterial pulsation; in many of these cases we might easily fall into the error of considering the lesion of the optic nerve as the primary stage. But an exact comparison of both eyes shows that the iris on the diseased side appears somewhat duller, whence we may at once conclude that there is a diffuse turbidity of the aqueous humour. This haziness also changes with extreme rapidity, in comparison with its amount, so as to disappear and reappear many times during a single day. (In some cases this is indisputably connected with the meals, movements of the body, sleep, &c.) On ophthalmoscopic examination, the background of the eye always appears somewhat indistinct, yet it is difficult to determine how far this is caused by the aqueous humour, and how far by the vitreous. The pupil is also larger, and somewhat more sluggish, not simply in regard to the entrance of light into the affected eye, but also (relatively) to the passage of light into the other healthy eye, to accommodation-changes and contractions of the recti interni. This feature essentially distinguishes it from anæsthesia retinæ incipiens, where the contraction of the pupil is unaffected under the above conditions. It is clear that the conduction in the ciliary nerves is here directly diminished through increase of the intra-ocular pressure. Upon very careful palpation of the globe (the customary precautions being taken to prevent errors from displacement), increased resistance is generally evident; and upon touching the cornea with a roll of paper, diminished sensibility. I should not have repeated all these remarks, had not these very cases at one time induced errors through the subtilty of the symptoms. By means of the ophthalmoscope, I found, though not constantly, choroidal ecchymoses in the equatorial region. I cannot decide whether retinal ecchymoses are present before operative interference; they often form to a surprising extent afterwards. If the disease has run its course, it very much resembles the cases described under the first head, except that all the symptoms depending on increase of the intra-ocular pressure are usually less prominent. At the first glance, it appears probable, that there is only a difference of degree between this and the former category of cases, because the first form is very often developed in the one eye, and the second in the other. This is the essential feature of the fact long since noted, according to which there was developed in one eye an exquisite glaucoma (with the symptoms of arthritic ophthalmia or glaucomatous choroiditis), but in the other eye, a blindness, which only in its later course could be distinguished from a simple amaurosis dependent on extra-ocular causes. Again, the essential identity of both diseases is shown by the same changes of the inner membranes (especially of an ecchymotic nature), and by the same termination. In conclusion, it must be mentioned, that the second form not unfrequently passes into the first; it then represents to some extent a more violent, and no longer intermitting, but only remitting premonitory stage. The previous statement of the secondary occurrence of excavation of the optic nerve is of course also true, but with a limitation, because at the time of the more acute outbreak, the affection of the optic nerve has been already induced by the pre-existent (chronic) disease.

Besides, I willingly admit that we are still very ignorant as to this form of chronic glaucoma. I think, indeed, that the excavation of the optic nerve in these cases is explained also by increased pressure; I am, however, unable to demonstrate it, because the harmony which existed in the first form between the lesion of the optic nerve and the other symptoms of pressure is not here always apparent.

### 3. *Amaurosis with excavation of the optic nerve.*

In these cases, which have been often called glaucoma, (but only since the introduction of the ophthalmoscope) the glaucomatous habitus is altogether absent in the external parts of the eye, whilst exactly the same form of lesion as in glaucoma occurs in the optic nerve. This is the only organic change that can be shown. Owing to the refractive media remaining perfectly clear, the optic nerve may indeed appear of a somewhat different colour than in glaucoma, but no essential distinction can at present be made. As the rule, however, arterial pulsation does not spontaneously appear; yet I cannot deny that it generally occurs more readily on the application of the finger than in healthy eyes. In this case it is impossible for us to consider the pathogenesis of the lesion of the optic nerve in the manner already described, owing to the absence of all the other symptoms indicative of increased pressure. To be clearly understood, it seems to me absolutely necessary to exclude these cases from the group of glaucomatous diseases, and to pursue their study under this or some other name. In the functional disturbances they have also the greatest similarity to chronic glaucoma; but their development is more uniform (generally extremely slow), and the intercurrent obscurations are less marked. The chromopsiæ also are not so prominent. The essential character is a gradual limitation of the field of vision, generally spreading from one side; sometimes it is exactly concentrical, and the central vision of these cases is often found to be, in a relative sense, extremely good, so that individuals can read the smallest print, and yet no longer guide themselves with safety—an extreme discordance never found in chronic glaucoma. Besides the identity in the appearance of the optic nerve, and the similarity in the functional symptoms, the incorrect classing of this group of diseases with the glaucomatous was furthered by the circumstance, that sometimes a typical glaucoma is developed in the one eye, and in the other an amaurosis of this description, with excavation of the optic nerve. But independently of the fact that these instances are extremely rare, when cases of chronic glaucoma are definitely excluded, and hence should perhaps be referred to an accidental complication; my former remarks upon sympathetic amaurosis of the second eye (see the previous treatise) might here deserve consideration, provided, on further study, the excavation of the optic nerve should maintain a kind of pathognomonic indication of sympathetic amaurosis. There might then be found in glaucoma a relation of the disease in the second eye analogous to that we have already discovered in irido-choroiditis.

I cannot at present confirm the observation that amauroses of this kind ultimately assume the appearance already depicted of glaucoma. I urge this, because it contradicts the opinion of some of my colleagues, and my own earlier suspicions. We should be especially liable to be led into error by the second category of cases, in which the change of the optic nerve is sometimes the most striking symptom, whilst in the earlier periods the other signs require a very careful investigation, and only at a later time become prominent, a metamorphosis apparently taking place. The exceptional occurrence of discordant affections in the two eyes *à priori* also favoured the view mentioned. In amaurosis with excavation of the optic nerve, I have seen no other transformations than those of atrophy of the optic nerve and retina; and if the future should decide otherwise—if a disease of the internal membranes, similar to that of glaucoma, should be actually added to the simple affection of the optic nerve—still this would in no way justify us in designating the lesion of the optic nerve in general as a first stage of the glaucomatous affection, since the very opposite is certainly the fact in the typical and most perspicuous cases; but it would simply follow that a common internal cause (*e.g.* in the vessels), according to its kind and degree, may educe two different forms of disease. (See A. f. O., Bd. i, Abth. I.)

After I had perceived the necessity of excluding these cases from the glaucomatous group, I was long inclined to combine them with cerebral amaurosis, because, amongst the changes presented by the latter, we not unfrequently discover in the optic nerves a state approaching excavation. But more distinct differences became by degrees apparent. In those cerebral amauroses to which I refer, the optic nerve is indeed excavated, but there is no displacement of the vessels, or it is only slightly marked. Again, the vessels themselves become more delicate from the very first, and the substance of the nerve white, glistening like a tendon, and the periphery of the papilla smaller. In our excavation the veins especially are *more dilated* at first; and only at a very late period does the nerve become white, and sometimes a little glistening, the papilla, however, scarcely any smaller. For the sake of distinction, I no longer term the former state "excavation," but "retraction." It certainly denotes a species of atrophy of the optic nerve, and is generally accompanied by other symptoms, indicative of cerebral causes, which are almost constantly absent in the excavation. We must, therefore, for the present consider the excavation as an organic disease of the optic nerve. It is still very problematical whether there are contractile exudations, drawing back the surface, for no stage of swelling can be detected; but there must certainly be a twofold process by which the lesions of the optic nerve take place—first, by pressure on the surface of the papilla (glaucoma), and secondly, by traction from within the trunk of the nerve (amaurosis with excavation of the optic nerve). It remains unexplained why the latter, though subordinately, should predispose to the phenomenon of pulsation.

From my own observations, indeed, it is evident that we yet meet with much uncertainty in this subject, but I cannot too emphatically remark, *that in the present state of our knowledge, the lesion of the optic nerve alone is no longer to be considered as defining glaucoma, because in a series of cases it has a pathogenesis quite foreign to glaucoma.*

VII.—According to the results originally presented by the ophthalmoscope, the incurability of glaucoma seemed to be caused by the changes in the eye being only consecutive and arising from an extra-ocular source, either in the optic nerve, or in the vessels of supply. Although I cannot yet entirely abandon the view of the etiological participation of arterial atheroma, as explained in my first note on glaucoma—a point to which I shall hereafter return,—still the question of treatment took another direction so soon as I no longer referred the origin of the blindness to the change of the optic nerve, but to the increase of intra-ocular pressure. The inflammation even of the choroid, as we know, yields spontaneously, or is, as the rule, overcome by the usual remedies, especially by antiphlogosis; but the results of increased pressure—in particular the excavation of the optic nerve—are, from their injurious nature, most momentous. Hence my attention was directed to discovering some method of lessening the intra-ocular pressure.

After all other means, which have as their object a rapid withdrawal of the ocular fluids—in particular, antiphlogosis, diaphoretics, diuretics, purgatives, and a mercurial course carried even to salivation—had been fruitless in my hands, as in those of other practitioners, I considered that I ought specially to direct my attention to a local treatment. The first means I tried were the mydriatics, the influence of which in diminishing pressure I had long ago endeavoured to demonstrate, and to render therapeutically serviceable in various ways. But in this case there was not the slightest curative effect. Even the accompanying ciliary neuroses, which in other diseases (keratitis, iritis) generally yield with such rapidity to instillations of atropine, were not in the least influenced, probably because, owing to the increase of the intra-ocular pressure, the mydriatic was only very slightly, if at all, absorbed through the cornea.

With this were connected trials of repeated paracentesis of the anterior chamber, which gave such evident results, that, with the view of promoting further trials of them, I did not hesitate to publish them at the time (A. f. O., Bd. i, Abth. 2). Not only did the discharge of the turbid aqueous humour, and its replacement by a more transparent fluid, improve the vision, but in addition to the immediate action, and clearly distinguishable from it, a secondary curative action was induced in the disease itself. Another and a great advantage of paracentesis was, that it showed the dependence of many glaucomatous symptoms on increased pressure (thus, of the corneal anæsthesia). Finally, it was paracentesis which first enabled me to discover the ecchymotic changes in the ocular background during the earlier period of the disease, because it caused the refractive media to become clear at a relatively early time. But, unfortunately, in by far the majority of cases the curative results were only temporary. Of the many patients whom I thus treated, only two have been permanently cured: a woman, about fifty years of age, in whom both eyes successively presented the symptoms of acute glaucoma, and who now, three years later, yet enjoys perfectly good vision, in spite of an atrophied, discoloured iris, and irregularly dilated pupil: the second case, a man of forty, whose right eye first became affected with glaucoma, and was cured by paracentesis, and whose left eye was attacked half a year later, and has been cured by iridectomy. It was evident that paracentesis was insufficient; and besides, the few really successful cases were of those in which the inflammatory process of exudation, though accompanied by the whole series of symptoms of acute glaucoma, still on its first occurrence only moderately diminishes the power of vision. In other patients, after the improvement had lasted days, weeks, or even some months, a deterioration occurred, although generally not in the form of an acute inflammation, but in that of chronic glaucoma. Even where the improvement in the visual acuteness seemed to last more than three months, still, even within this period, a change for the worse might be foreseen, owing to the contraction of the field of vision. At first I thought I could oppose these relapses by a methodical repetition of the paracentesis; but the duration of the therapeutical effect became each time less, and finally null (in regard to the visual power).

Paracentesis having proved insufficient, my next inquiry was, whether a permanent change of the pressure could be obtained in place of the temporary one? I already knew the action of iridectomy in chronic iritis and various forms of irido-choroiditis. But the conditions in glaucoma are so different from those in the ordinary irido-choroiditis, that I scarcely ventured to hope for therapeutical analogies with reference to this operation. There I was entirely guided by the condition of the iris, and the operation was directed against the exclusion of the pupil as the source of injurious consequences; but it did not appear from the results in irido-choroiditis that the excision of a portion of the iris had a direct action in diminishing pressure, and I was the less reminded of such an action, because the secondary effect is often even the refilling of atrophied eyes.[1]

On the other hand, it was especially the use of iridectomy in ulcerations and infiltrations of the cornea, that directed me to its effect in diminishing pressure. To the results of this treatment adduced in my work (A. f. O., Bd. ii, Abth. 2), another was soon added, apparently of great importance. It had reference to partial staphyloma of the cornea, and to staphyloma of the sclerotic. In the former, it was generally the custom in former days to combine removal of the staphyloma with the formation of an artificial pupil (provided it was indicated by the natural pupil being unserviceable), the removal being first made, and then the artificial pupil formed.

[1] The objection has been raised in many quarters, that the very increase of tension in atrophied eyes must have turned my mind from iridectomy in glaucoma. I cannot entirely admit this. I have never thence drawn the conclusion that iridectomy includes the direct action of an increase of pressure, but I have simply considered it as acting against choroiditis, and explained the refilling of the globe as an indirect result. Just as choroiditis, according to its degree and kind, may produce overfilling of the globe or collapse, so also may the same means, which relieve choroiditis, apparently produce opposite effects. The therapeutical effect of the treatment is often diametrically opposed to the physiological, and if I now believe that iridectomy has physiologically a pressure-diminishing effect, this is not, in my opinion, opposed to my earlier experience with reference to the refilling of atrophied eyes.

Having for other reasons reversed this practice, I found that after iridectomy the protruded part often entirely receded to the level of the cornea, and that then the second operation became unnecessary. I have even seen cases in which partial staphylomata had been repeatedly operated on without success, and in which iridectomy succeeded. Thus, I have many times seen a perfect and permanent sinking back of the protruded parts after iridectomy, at first in blind eyes affected with many sclerotic staphylomata; and I have since performed the operation with success under similar conditions, when vision was still left.

The question now occurred, whether iridectomy also causes a diminution of intra-ocular pressure in the healthy eye, or whether this only takes place under certain conditions of disease. I think that I may answer this question affirmatively, although I cannot at present adduce any more exact investigations. The eyes of animals, from which I had excised large pieces of iris, generally appeared to me a little softer to the touch, and when I carefully introduced the canula of Anel's syringe into the anterior chamber of such eyes, the whole of the aqueous humour did not ascend through the action of the intra-ocular pressure, as is usually the case, but only a part. I think I have also perceived a slight permanent diminution of tension in patients, where an artificial pupil has been made for leucoma adhærens.

Supported by these facts and considerations, I considered myself perfectly justified in performing iridectomy in glaucoma; for I knew the favorable action of the operation on the condition of the choroid in regard to its circulation; and everything seemed to favour the opinion that the operation probably possessed a physiological, and certainly, in many cases, a therapeutical pressure-diminishing action. The first trials were extremely uncertain, for I had no fixed principles, either in regard to the choice of cases or the manner of making the trial. I first employed this method in June, 1856, and from that time have continued it, especially in the cases which I have already described as acute glaucoma. The immediate effects appeared from the first very favorable; but remembering how my hopes had been frustrated in paracentesis, I was extremely mistrustful, and remained so until, in time, distinct differences appeared between the present results and those formerly obtained. A continued improvement was generally apparent exactly in proportion as the observation was prolonged; the signs of glaucoma retrograded in the manner hereafter to be described, and now, having followed some cases more than a year, and a considerable number more than nine months, I think I cannot be mistaken in regarding iridectomy as a true curative treatment of the glaucomatous process. It has its natural limits, like every therapeutical method; and in some degree to define these is the object of the following communication.

VIII.—Were I to discuss the application of iridectomy to the various stages and groups of glaucoma in the same order in which they were successively presented for trial, I should have to begin with the old, and in part with cases that had completely run their course; for it is obvious that, owing to the uncertainty of success, a new method will be first tried in cases where as little as possible can be lost. I think, however, that by such an exposition I should lose sight of the indications on which I especially depend; and therefore prefer to leave entirely out of question the historical development, and to discuss the relative results in accordance with the previous nosological divisions. Accordingly I shall communicate my results in regard to iridectomy—

1. In the premonitory stage of glaucoma.
2. In the acute period of inflammatory glaucoma.
3. In the later period of inflammatory glaucoma.
4. In chronic glaucoma.
5. In amaurosis with excavation of the optic nerve.

Perhaps it might have been better to communicate *in extenso* all the reports of cases at my command, the number of which has become very large; as by their consideration, the indications would have been spontaneously presented. But I have decided otherwise, partly to avoid so large an expansion of my work, and partly because many of the cases must be considered as not concluded, there being some probability that the condition last noted will not be permanent. The addition of some observations will, however, I think, assist in illustrating my previous remarks.

### 1. *Iridectomy in the premonitory stage of Glaucoma.*

Patients affected with premonitory symptoms of glaucomatous disease in the one eye only, seldom seek medical aid; the symptoms are overlooked, or thought of little importance; as is so often the case in visual disturbances of one side. On the other hand, it very often happens, that one eye having been lost by glaucoma, the patients are frightened by the premonitory symptoms in the second eye. The question naturally arises, whether we should wait for the distinct outbreak of glaucomatous disease in the second eye, or proceed to operate even during the premonitory stage. For a long time I delayed operating, because vision is still acute during the intermissions; and for the same reason, the whole of the treatment must previously be proved quite safe. At length, having continually become bolder, from repeated successes, I operated on some cases, even in the premonitory stage, and was perfectly satisfied with the result. The obscurations did not in any case recur after iridectomy. The ciliary neuroses and chromopsiæ also disappeared; even the periodical cloudiness of the aqueous humour, which in one case regularly accompanied the obscurations to a moderate extent, never reappeared after the operation. Sometimes the anterior chamber appeared less flat than previously; I cannot at present decide as to whether there is a slight diminution of the presbyopia. I have now watched for some months after the operation, three such cases, in which the obscurations occurred with tolerable frequency; and think I may conclude that this success will probably be permanent. By the formation of a moderately broad coloboma, the acuteness of vision is no more affected than the accommodation, as is already known; and if slight differences in regard to the latter points should result, still these would be unworthy of consideration, compared with the prevention of perfect blindness. Of course, such an early application of iridectomy has its reasonable limits. If, for example, the premonitory signs are limited to painful sensations in the forehead and temples, and to iridescent vision, without any obscuration, and if these pains return at intervals of many months; if in addition the eye does not present the slightest appearance of disease, I should not advise any operative interference; because this state may continue for a period of many years, and because very few of the patients perceive, indeed, their danger. There is not the least risk in temporising under such conditions, or in the use of proper internal means; and we should not forget, that an operation, even though attended with so little danger as iridectomy, may exceptionally become the exciting cause of bad results, through the concurrence of accidents, the disobedience of patients, &c. When one eye is blind from glaucoma, and the second is threatened, I am in the habit of recommending the patient to resort to the operation as soon as the premonitory symptoms become tolerably distinct in the second eye, and especially if they are accompanied by increased obscuration. We cannot safely wait for an acute inflammatory attack; for though I shall also show (sub. 2) that iridectomy, even during the acute stage, generally induces perfect restoration, still the transport of the patient becomes more critical, the operation itself more painful, requiring greater care in its performance and in the after-treatment; there are more extensive retinal ecchymoses, owing to which vision is more slowly restored; there usually remain changes of the iris, immobility of the pupil, and paresis of accommodation; and it is much more difficult to define the limits beyond which relief may be only partial. Besides, we must not omit to state that the premonitory stage does not always pass into the acute form, but sometimes, by continual elongations of the exacerbations, into the chronic; and that then the affection either does not assume an inflammatory character, or only at a time when important secondary results prevent a perfect restoration. At all events, the premonitory stage is the most favorable period for the performance of iridectomy. Sometimes, indeed, even in this case, retinal ecchymoses appear after the operation, yet, as before stated, to a far less extent, and (even without a compressing bandage) extensive hæmorrhages into the aqueous or vitreous humours never occur.

Had iridectomy only the power of preserving a second and threatened eye, after the first had become blind from glaucoma, our science would have been deeply indebted to the operation: to a thoughtful practitioner, these cases were of an extremely depressing character, for owing to his complete powerlessness, blindness appeared an inevitable result. We must indeed deplore that this most happy application of iridectomy is limited to the least part of glaucomatous cases; because there is frequently no premonitory stage, and very often medical aid is not sought until the disease has further advanced.

Case i.[1]—Wilhelm Höffler, resident in Berlin, æt. 71 years, came to me on the 15th February, 1857, on account of almost perfect blindness of the right eye. It had existed for many months, and presented the signs of an acute glaucoma, in its latter stage. I shall return to the history of this right eye when I consider the morbid group concerned (*vide* Case 9). Even at the time when the patient was admitted into my clinic for iridectomy on the right side, the visual acuteness of the left was found on trial a little changeable, and a few weeks after the performance of iridectomy on the right side with relatively good effect, very distinct periodical obscurations occurred on the left, which excited the fear of an early outbreak of the glaucomatous process. In the last week in March, scarcely two days passed without such obscurations, to which were added ominous objective appearances, the pupil became somewhat dilated and perfectly immoveable, the cornea a little less sensitive, the aqueous humour diffusely clouded, the subconjunctival vessels injected; rainbows appeared around the flame of a candle, pretty considerable photophobia, vision diminished until large print could scarcely be recognised, and the distinctness of excentrical vision in particular lessened on every side, so that during the attacks the patient could scarcely guide himself. At the same time he had extremely violent pains in the forehead and temples, which, when they occurred at night, completely banished sleep. At first, the attacks lasted some hours; in the latter days of March, twelve hours and more; an opiate appeared to shorten them, but not to lengthen the interval, and, as usual, other means proved ineffectual. Finally, even the intervals threatened to disappear entirely, and the pupil no longer recovered complete mobility, so that I considered the time for an operation had arrived.

Shortly before the operation the state of the vision was as follows: the patient could count fingers at the distance of six feet, and read No. 16 of Jäger's specimens of print with difficulty and with errors, No. 14 not at all; with convex 6 he read No. 14 word by word, but tolerably precisely, of No. 11 the shorter words, of No. 8 nothing; there was no essential contraction of the

[1] In these histories of cases I shall pay little regard to circumstances having reference to the general condition, because, however important such may be in other respects for the comprehension of glaucoma, their consideration would materially increase the length of my essay, and not be of much service with reference to my object.

visual field, but diminished clearness of the excentrical vision in every direction; frontal pains moderate. The period of the operation corresponded with an obscuration which had imperfectly ceased; correspondent with that were the objective signs, which I need not repeat. I performed iridectomy at the inner side on the 1st of April. The frontal pains ceased immediately afterwards. On the 5th of April the patient was discharged from the hospital; no obscurations nor other premonitory symptoms recurred. Vision continually improved, the pupil regained its normal mobility, so far as was compatible with the coloboma; the cornea became normally sensitive. On the 13th of April an examination gave the following results: the patient read with the convex glasses (+ 12, + 10), proper for his presbyopia, print No. 6 at sight, No. 4 still precisely but rather slowly, No. 3 also precisely but word by word, stopping occasionally, of No. 1 he recognised only the easier words. The ophthalmoscope showed no retinal ecchymoses nor other changes of the internal coats; the refractive media were now perfectly clear, and the optic nerve normal. Vision continued to improve, so that in the month of August he could even read print No. 1, with the exception of only a few words. At that time he followed his usual occupations, paying not the slightest attention to the eye—a point to which I cannot draw too great attention, because it is well known, how otherwise, with similar antecedents, accidents are caused by the least injuries.

*Summary.*—Cure, and apparently a permanent one,[1] of a glaucoma of the left side after from four to five weeks' premonitory stage, in which the obscurations occurred at intervals of from one to two days, and consequently the outbreak of a subacute glaucoma had to be taken into consideration.[2] The cure of the glaucomatous inflammation in the right eye had no influence in respect to the second eye becoming diseased.

Iridectomy had the same result even when the premonitory stage

[1] If in the future, recurrences should take place in patients, whom I at present adduce as "apparently permanently cured," I shall consider myself bound to refer to them in later notices. To be able to do so eventually, I give the names of all the cases, which otherwise I should prefer omitting.

[2] No exact limits can be drawn between the premonitory stage and chronic glaucoma. I generally consider the former to be ended when the intervals are no longer distinct.

had lasted a very long time. As an instance, I mention a patient who was under my treatment two years ago, one eye blinded by glaucoma which had run its course, and the second in the premonitory stage. Since at that time the periodical obscurations were constantly becoming more frequent and intense, and I knew no treatment for the glaucomatous process, I prepared the patient for the worst, and sent him home to his residence elsewhere. In this very case iridectomy was performed with great success three fourths of a year ago, by my assistant-surgeon, Dr. Alfred Graefe. In the intermediate time the obscurations had become more intense, but there had always been tolerably long intervals between them.

2. *Iridectomy in the acute period of Inflammatory Glaucoma.*

I have had much more experience in this than in the premonitory stage. I have performed the operation on more than twenty eyes soon after the outbreak of the first acute inflammation. In some cases the inflammatory irritation was so great, that, *à priori*, operative interference appeared critical; the most violent ciliary neuroses, great chemosis, lachrymation, and photophobia were present; in short, the type of the most exquisite arthritic ophthalmia. At first, I used to endeavour to alleviate the symptoms by antiphlogistic treatment, opiates, &c.; but at a later period, I became convinced that, notwithstanding the violent inflammation, it was better to perform iridectomy immediately, for it is especially under these circumstances that any delay is dangerous, and that the operation itself is the most certain treatment of the inflammation. It was found that, not only did the symptoms of irritation recede after the operation without the use of other means, but that there correspondingly occurred in all cases a very rapid clearing of the refractive media, so that even six or seven days after the operation the posterior regions of the eye could be readily examined by the ophthalmoscope. This enabled me to ascertain various nosological results in regard to the process. The latter have been already mentioned in the course of my earlier communications; still I do not hesitate to briefly repeat them once more, in their natural connexion.

A. After the first inflammatory attack the optic nerve is perfectly normal, and there is no trace of excavation or of displacement of the vessels, provided there has been no previous chronic glaucoma, but that the disease has occurred in a healthy eye, or after a premonitory stage of a positively intermittent character.

B. It is the same with arterial pulsation.

C. The round spots of retinal ecchymosis are indeed constantly found, but there is no doubt that most of them are formed after the operation.

D. On a very accurate examination, especially of the equatorial region, choroidal ecchymoses are frequently observed. These, however, disappear with extreme rapidity, so that it has not yet been ascertained whether their inconstant occurrence depends on the disease, or altogether on the time of observation. Certainly, they must not be considered as entirely produced by the operation, for I have many times observed them before its performance. In general, the vision improved immediately after the operation, owing to the escape of the turbid aqueous humour, just as in paracentesis. Its degree is, however, trivial, when compared with the subsequent improvement of which some small part may also be referred to clearing of the ocular fluids; in my opinion it results from the retina resuming its functions, which had till then been impeded by the intra-ocular pressure.

The opinion that the restoration is entirely dependent on clearing of the refractive media, is easily disproved. For example, I refer to Gause's case (Case 2); before the operation there was no qualitative perception of light, and yet the ophthalmoscope showed to some extent the contour of the optic nerve. In accordance with that, the patient ought yet to have been able to recognise large objects. Five days after the operation there was a tolerably large quantity of blood in the anterior chamber, so that when examined by the ophthalmoscope, the background of the eye seemed still more hazy than before the operation; yet the patient could again count fingers at the distance of three to four feet.

There is in general no direct proportion whatever between the clearing of the refractive media and the restoration of vision; an indirect one is produced by the cloudiness being certainly connected with increased secretion of fluid, and this again with the continuance of choroiditis and increase of the intra-ocular pressure. The chief effect on the vision is attained in from two to three weeks. The congestive phenomena usually cease at a far earlier period. In these cases the cornea always regains its sensitiveness, whilst in older cases this no longer takes place, probably because textural changes in the nerves passing to the cornea have been formed, which are no longer capable of retrogression. The ciliary neuroses generally cease immediately after the operation; in a few cases only did slight paroxysms of frontal pain still occur for the first two days; as the rule there was perfect freedom from pain, or a traumatic sensation of slight pressure in the eye, perfectly different from the former pains. The state of the iris is very various, and clearly dependent on the degree of iritic participation. I have scarcely seen a perfectly mobile and normal iris, after acute inflammations had once occurred. Frequently partial mobility returned, but in most cases the pupil remained perfectly fixed, and moderately dilated, though not so much as it had been previously. Sometimes also, sufficient allowances being always made for the coloboma, the pupil became somewhat more contracted than normally. Irregular form and displacement of the pupil not unfrequently remained, even when there were no posterior synechiæ; and, as is usually the case in glaucoma, must be referred to unequal paralytic participation of the ciliary nerves. Hence it is a question, when we seek an explanation why the pupillary lesion continues, whether the cause lie in structural alterations of the iris, or, perhaps, in rapidly occurring changes of the ciliary nerves themselves. It is difficult to decide this with certainty; I am, however, more inclined towards the first opinion, for the pupillary affection is generally in an approximative relation with the permanent structural changes of the iris. In all acute cases the latter never recovers its normal appearance, but ash-gray discolorations and some indistinctness of fibrillation remain, in the form of spots, or extending over a larger space, especially towards the periphery. This is at all times a proof of the glaucomatous lesion, and is of importance for the determination of cases at a later period. The tenseness of the globe receded perfectly to its normal amount; the operated eyes seemed to the touch in some cases even a trifle softer.

Though the restoration of vision most strikingly advanced within the period of two to three weeks, still a continual improvement always occurred from this time onwards; so that the vision recovered its utmost acuteness only after about six weeks. This improvement was, in my opinion, especially connected with the retrogression of the retinal ecchymoses. Of these, the smaller ones were, indeed, of no great importance when they were excentrical; but, on the other hand, the larger ones caused indistinctness of excentrical vision in certain portions of the visual field, scotomata, &c. The region of the macula lutea was also sometimes affected; then the central vision, of course, was much impaired. In a case of that kind, the occurrence of excentrical fixation would have excited great fear for the result, had not the ophthalmoscope shown its cause to be a large central retinal ecchymosis; and experience already proved, that after retrogression of the retinal ecchymosis, the retina again becomes capable of conduction in all the affected parts. In six to eight weeks, at the latest, the last traces of retinal ecchymosis disappeared.

This was true of all cases of glaucoma, except one (Madame M—l, from Vienna), in whom the retinal lesion took a particular turn, after an artificial pupil had been made for chronic glaucoma. There repeatedly occurred fresh retinal ecchymoses, although the exterior of the eye looked as well as could be wished, and finally white patches formed around the spots of blood, as in albuminuria. In fact, albumen was also found in the urine at a later period. This case must be temporarily excluded from consideration, and is interesting, inasmuch as the retinal ecchymoses succeeding iridectomy formed the exciting cause of retinal degeneration, which was probably connected with a renal affection.

*Vision was perfectly restored in all cases in which the operation was performed before the termination of two weeks from the occurrence of inflammation.* Some of these cases seemed perfectly desperate; for every trace of the qualitative perception of light had been already extinguished. I need scarcely mention that at first I promised but little to these patients. I frequently undertook the operation (see Case 2) altogether on account of the violent ciliary neuroses, and the effect was, in both respects, very surprising. It is only within the last half-year that I have ventured to predict complete restoration, even where the power of distinguishing has been perfectly lost, it being presupposed that less than two weeks have passed since the commencement of the inflammation, and that a moderate quantitative perception of light exists.

On longer observation, my fears that the results might not be permanent proved unfounded. Very soon there appeared marked distinctions from the other remissions of the glaucomatous process.

The field of vision remained absolutely normal. Excentric vision continued distinct, after it had once attained a certain degree. Not the slightest premonitory symptom recurred. The congestion of the subconjunctival vessels entirely disappeared; the anterior chamber was no longer contracted; and nothing betrayed an abnormal condition of the eye, except the hue of the iris, and the sluggishness or immobility of the pupil. Should the fear of recurrence at a later period still be entertained, it is true that I cannot wholly allay it, on account of the limited duration of my cases; but this much is certain, that a similar intermission of the glaucomatous process never occurs spontaneously or after any other treatment. Accurate observation in the other states of inflammatory glaucoma, which have been called stationary, always yields essentially different characters, particularly on a functional examination. Many of the cases operated on were exposed to various noxious influences in their utmost extent, and many of them have now been under observation for about a year, without my having to make any restriction in what has been said. Whatever the final result may be, I think that practitioners who are acquainted with the course of acute glaucoma will feel themselves already justified by these statements in adopting the treatment. In spite of the surprising results of iridectomy soon after the occurrence of inflammation, still a careful survey of the effects will prove the correctness of what has been stated in favour of operating during the premonitory stage. I may point out once more the difference in the danger of the operation. An accident of consequence will rarely occur in the premonitory stage, even when the operation is not quite correctly performed. On the other hand, success may be frustrated in the acute period by internal hæmorrhages, very large retinal ecchymoses, &c., when all precautionary measures are not taken (see IX). These may possibly occur in scattered cases, notwithstanding the greatest caution; this, however, can only be decided by extensive statistics.

Where, then, must we draw the limit between the *recent* and *old* cases, so as to render ourselves intelligible? It is clear that this question can only lead to a perfectly arbitrary answer, for no distinctive symptom is found in the further course of the disease. In regard to the prognosis, it would be most proper to call the cases *recent* in which there are as yet no contraction of the field of vision and no excavation of the optic nerve. Unfortunately, both these signs are difficult to determine in the inflammatory stage of acute glaucoma, because the haziness of the refractive media sometimes renders it impossible to determine with accuracy the condition of the papilla, and because excessive difficulties are occasionally opposed to the limitation of the visual field, when there is no longer any qualitative perception of light. Hence we were forced in our communications to fix an arbitrary limit to the duration; and we repeat, that the cases mentioned were within a period of fourteen days from the first outbreak of inflammation. In all these cases no excavation of the optic nerve occurred at a later period; and I cannot admit any transitory affection of the optic nerve, so long as no case is known in which an excavation has clearly disappeared after iridectomy. Even in the case in which only quantitative perception of light existed (Obs. 2), it seemed to extend uniformly over the whole field of vision; and yet this could not be explained by any diffusion of the light. Consequently, it appears that both the above conditions are invariably present, when we speak of a duration of fourteen days. On the other hand, we shall hereafter see that, fortunately for the cure of glaucoma, these very conditions are often found even after far longer periods.

The observation of cases shows that iridectomy has no considerable influence over the second eye. It is not unusual for the affection to occur in the one eye soon after a successful operation on the other (*vide* Obs. 4 and 6), whilst in other cases the second eye has hitherto remained unaffected. Since the latter, however, is often the case for years, when the affection has followed its own course, it is not conclusively indicative of a favorable influence; and the former instances prove that the glaucomatous inflammation of the second eye does not sympathetically depend on the disease of the first eye.

Case 2.—Herr Gause, of Berlin, about 50 years old, had remarked, during the years 1850-55, his vision being good, a very great increase in his presbyopia, so that he was obliged to increase from + 24 as far as + 10. On the 3d of January, 1855, he was attacked by a violent inflammation of the right eye, without the occurrence of any premonitory symptoms, according to his account, after taking cold; when there ensued lacerating pains in the forehead and temples, iridescent vision, and a rapid obscuration of the sight on the right side. Some days later he was received into my clinic, the appearance of glaucomatous choroiditis being fully developed. The disease was at that time treated by paracentesis, which seemed to afford a very satisfactory result; in fact, no fresh inflammation arose, even at a later period. In March, however, a distinct deterioration of vision and gradual contraction of the visual field were already presented; atrophy of the iris and anæsthesia of the cornea progressively advanced, although the refractive media remained clear. In August, 1855, the right eye had become perfectly blind.

The left eye of the patient continued healthy till the 15th of December, 1856; the presbyopia alone had slightly augmented (to + 8). There occurred on the day mentioned iridescent vision and pains in the forehead and temples, and, on the next day, an extremely violent inflammation. I saw the patient on the 20th of December; he was exceedingly exhausted by the very severe pains of the last few days, and perfectly resigned to the loss of his sight, which had been immediately destroyed on the occurrence of inflammation, and, as he clearly perceived the uniformity of the disease on the left with that of the right side, he believed that permanent blindness was inevitable. It was simply for the unbearable pains that he again required my assistance. Examination showed great injection of the anterior ciliary vessels, slight chemosis, the anterior chamber densely and uniformly clouded and flattened, the cornea insensible and its posterior surface hazy, the pupil much dilated and smoky, the iris of a dirty hue, the globe tense, and *no qualitative perception of light whatever,* so that the patient could not perceive the motion of a hand, even with the strongest light. The quantitative perception of light was also very indifferent; the light of a lamp, which had burnt low, was not distinguished. On the other hand, that of a lamp which burned brightly was recognised in a darkened chamber at the distance of some feet, and, as it seemed, uniformly by every part of the visual field. I proposed iridectomy, but, owing to the power of distinguishing being perfectly lost, did not venture to promise any restoration of vision, but only relief of the inflammation. I previously made a careful ophthalmoscopic examination, with the object of determining the influence which the turbidity of the refractive media might have on the blindness; the background of the eye, of course, seemed extremely dull, and yet we perceived, to some extent, the contour of the optic nerve. Evidently there was in this an important disproportion with the patient's vision. Iridectomy was performed on the 22d of December, by excision at the inner side. Although when the aqueous humour had escaped, the pupil and iris seemed considerably clearer, yet, immediately after the operation, the patient could not perceive the motion of a hand. The ciliary neurosis immediately and for ever ceased, and the patient only slightly felt the pain of the wound in the eye, which, however, did not in the least interfere with sleep. On the next day the injection was already retrograding, but there was still a considerable quantity of blood in the anterior chamber; yet the quantitative perception of light had materially increased, and the light and shadow of a lamp, burning very low, could be distinguished almost at the distance of a foot. A slightly compressing bandage was applied. On the second day after the operation the blood in the anterior chamber had diminished in amount; the patient could clearly distinguish the motions of a hand, and this over the whole extent of the region of excentric vision—a point of special importance, because, the perception of light being dull before the operation, I had not yet been able to come to a satisfactory conclusion about the field of vision. Four days after the operation the patient was already able to count fingers with certainty, and one day later at the distance of three feet. A perfectly exact examination was now made for the first time since the operation, with the following results: the cornea normally sensitive, no injection whatever; the pupil very much diminished in comparison with its former state; the globe less tense; owing to the hæmorrhagic saturation of the aqueous humour having not yet disappeared, the colour of the iris and pupil could not be determined with certainty; for the same reason, the examination with the ophthalmoscope also gave, as yet, no positive result, and the contour of the optic nerve was now seen less distinctly than before the operation—a circumstance which I expressly point out, because it shows how little the previous state of vision can be optically explained. On the 28th of December the patient was discharged from the hospital, and eight days later the state was again noted. The pupil had now a healthy hue, and was of almost normal size, which it has since preserved; the outer portion of the iris presented some circumscribed, gray blotches, which were permanent; in other parts its colour and fibrillation were perfectly normal; the anterior chamber, compared with the presbyopia, not very small, and quite clear; the pupil very slightly affected by light. The ophthalmoscope did not as yet show the background so distinctly as in the healthy eye, which I referred to some of the diffuse turbidity of the vitreous humour still remaining, yet most of the details could be readily determined; the optic nerve was not in the least excavated; round spots of ecchymosis were found in various parts of the retina, and especially where two veins united. Accurate drawings were made of some of them, so that we might determine any changes with certainty. The patient had no difficulty in counting fingers at the distance of twenty feet, and read, with + 8, No. 14 of Jäger's specimens fluently between eight and ten inches; he deciphered No. 11 word by word; of No. 8 he recognised syllables here and there. Two weeks later, he read with the same glasses No. 6 with ease, No. 4 word by word, and recognised a few words of No. 2; the field of vision was quite normal, the background of the eye perfectly clear, a part of the retinal ecchymoses had already disappeared, and those still remaining were smaller. Eight weeks after the operation no trace of retinal ecchymosis could any longer be discovered; the patient read print No. 4 and No. 3 fluently, and recognised most words of No. 1; the pupil acted so slightly as to be scarcely noticeable, and remained so; the accommodation was yet extremely limited, as has been the general result in a great part of my operations. This probably depends on permanent changes in the iris and tensor choroideæ. From that time the patient followed his usual occupation. When I last saw him, eight months had elapsed since the operation, and yet there had not been a trace of suspicious symptoms similar to those of the premonitory stage; vision had even a little improved since the last examination; the field of vision was absolutely normal.

*Résumé.*—Case of acute glaucoma, without premonitory stage. Immediate and perfect loss of the power of distinction. Iridectomy after seven days. Cure (eight months ago). Proof that the effect is not explained by the clearing of the refractive media. Parallel of the course in the eye treated by iridectomy, and that by paracentesis.

Case 3.—Oertel, a confectioner of Berlin, a healthy man, of about 40, had been in good health, till the middle of December, 1856. At this time, according to his own account, there suddenly occurred, without premonitory symptoms, on the right side, a feeling of pressure in the eye, pains in the forehead and temples, photophobia, lachrymation, and some loss of sight. During the days immediately succeeding the outbreak the symptoms again remitted. From the 24th of December, however, they constantly increased. I saw the patient on the 26th:—choroiditis glaucomatosa;—just the same appearances as in the left eye of Gause (Case 2), the pupil, however, only moderately dilated; the sensibility of the cornea scarcely diminished; on the other hand, the anterior chamber extremely flat, the aqueous humour very turbid, the quantitative perception of light good, the qualitative almost lost, and only with the best possible illumination could the patient perceive the motion of a hand; ciliary neurosis very violent. Iridectomy, by excision on the inner side, on the 27th of December. Some hours after the operation there was a paroxysm of frontal pain, which did not recur; a perfectly good night. Next day, no blood in the anterior chamber, which was still somewhat clouded; the posterior surface of the cornea dull, the congestion less; the patient could perceive the motion of a hand at the distance of a foot. Three days after the operation he counted fingers. Discharged from the institution on the sixth day. Ten days after, the first accurate examination showed the following state: little or no congestion; the aqueous humour not yet quite clear; the cornea normally sensitive, the clouded appearance of its posterior surface limited to a rather small space in the centre; the tissue of the iris very much changed; large gray spots, in which the fibrillation was very indistinct; the pigmented margin of the pupil here and there entirely deficient; the pupil still continued to be rather dilated, almost to the same extent as before the operation, also perfectly fixed; the anterior chamber still very flat, the determination of the ocular background still difficult; retinal ecchymoses,[1] perfectly resembling those of Gause. The patient counted fingers at the distance of three to four feet, recognised words of print No. 16; the visual field was normal. Three weeks after the operation the refractive media were clear, the retinal ecchymoses already retrograding; the optic nerve perfectly normal; the iris and pupil still in the same state; the anterior chamber, however, less flattened; the patient read print No. 11 fluently, No. 8 accurately, and words of No. 4. Six weeks after the operation the objective condition was

[1] I do not append to these observations the cases in which choroidal ecchymoses could be clearly shown, because it is only within the last four months that I have succeeded in finding them in acute glaucoma, and because such recent cases would be yet too uncertain with regard to the results of treatment.

the same, excepting that the retinal ecchymoses had entirely disappeared. The patient read print No. 4 precisely, and some words of No. 2. Since then he has been in many ways exposed to the most various noxious influences, especially night-watching and exposure to glaring light (as a confectioner), yet no threatening symptom ever appeared in the trials, which were repeated at regular intervals of three to four weeks. The far-advanced alterations of the iris still remain exactly in the same state, and would certainly cause alarm had not everything else remained normal; vision has even continued to improve. The accommodation of the right eye has, in this case, remained extremely limited; the left eye hitherto healthy.

*Résumé.*—Acute glaucoma, without a premonitory stage.[1] Iridectomy a week and a half after the outbreak. Perfect restoration of vision (of eight months' duration); far advanced alterations of the iris.

Case 4.—Madame Maas, of Berlin, a lady of about 50, with rather inactive bowels, otherwise healthy, had remarked, in reference to the right eye, since the winter 1855-6 iridescent vision, increased presbyopia, and occasional obscurations; had, however, paid little attention to these appearances, so that they were only ascertained by a thorough examination of the case. In February, 1857, there suddenly occurred on the right side violent frontal pains, photophobia, lachrymation, and, in a few hours, entire blindness. I saw the patient three days later; on the right side there were all the symptoms of glaucomatous choroiditis, injection very great, chemosis to a moderate extent, the cornea tolerably insensible, mydriasis and flattening of the anterior chamber extremely great; on the other hand, the aqueous humour was not very turbid, there was quantitative perception of light over the whole of the visual field, and, indeed, to such an extent, that the light and shadow of a lamp, burning moderately low, were distinguished to the distance of eight inches; she could perceive the motion of a hand only when brightly illuminated, and even then with uncertainty; at the same time she had violent frontal pains. The next day I performed iridectomy by excision on the inner side; although the aqueous humour was only slightly turbid, still the effect was so

[1] The existence of the premonitory stage can never be with certainty denied when one side only is affected, for the symptoms easily escape the patient.

immediate, that after the operation she could count fingers with certainty. A slight pain, as of a wound, took the place of the torturing ciliary neurosis, and allowed a good night's rest. On the morning after the operation the chemosis had entirely disappeared, the injection of the anterior ciliary vessels had very much diminished. She counted fingers from two to three feet off; owing to the great mental excitability, a more accurate examination was avoided. The improvement continued for the two following days, as well as could be wished. Three days after the operation she was attacked by frontal pains on the left side, which became very acute towards evening; at the same time the right side continued perfectly unaffected. The next day an outbreak of glaucomatous choroiditis could be clearly perceived in the left eye. The congestive phenomena were so severe on the left side that I was almost afraid of operating; the chemosis in particular was very great, and even touching the eyelids caused violent pain. The pupil appeared less dilated in this than in the former eye, but very irregularly indentated; there were also broad posterior synechiæ on the internal and inferior sides, the aqueous humour very turbid; yet she could still count fingers at the distance of some feet. It was decided to perform iridectomy on the following day, when a large piece of the iris on the inner side was excised. This was on the fifth day after the operation on the right side. Owing to the large amount of chemosis a few short incisions were also made in the conjunctiva soon after the operation, so as to allow the escape of the serum. The pains ceased immediately; the day following only a slight amount of chemosis had recurred, which, however, soon entirely vanished. In a few days the injection retrograded, and improvement took place just in the same way that has been described when speaking of former patients. It was now very instructive to compare the two eyes, of which the first was operated on the fifth day of its being diseased, and the second two days after the attack. This comparison soon proved very strikingly to the advantage of the latter eye; in eight days its power of vision had already reached that of the right one; the patient could now read with either eye No. 14, by means of proper convex glasses, with trouble, and recognise most words of print No. 11. From that time the vision of the left eye surpassed that of the right; three weeks after she could read with the left eye print No. 3 with certainty; on the other hand, with the right, even print No. 6 only with difficulty. Retinal ecchymoses existed, but what relation their retrogression bore to the improvement I cannot determine, for the patient, residing in the city, was examined only at long intervals. A distinct difference in the vision of the two eyes remained even at a later time. The visual field was on both sides normal; the optic nerve healthy; the refractive media became clear, the cornea normally sensitive; the globe lost its tenseness; the pupil remained on the right side moderately dilated and perfectly fixed; the iris discoloured in spots, but the anterior chamber in relation to the presbyopia not flattened; on the left side the pupil regained a medium size, and was slightly affected by light, notwithstanding a broad posterior synechia; the tissue of the iris was but little changed, the accommodation indeed limited, but not nearly to the same extent as on the right side. When I saw her for the last time, six months after the operation, her power of vision had considerably augmented since the previous examination, so that she could read print No. 3, with precision when well illuminated, even with the worse eye. Not the least accident had occurred throughout that time.

*Résumé.*—Acute glaucoma, after a year's premonitory stage. Operation on the fifth day. Some days after,[1] glaucomatous choroiditis in the other eye. Operation in the latter eye two days after the attack. Cure on both sides (six months' duration); vision, however, more acute in the eye which was operated on last.[2]

Case 5.—General von Felden, resident in Berlin, æt. 70 years, arthritic, with very rigid arteries, otherwise robust, was attacked in February, 1857, by a very painful inflammation of the right eye. I was consulted five days after the affection had commenced. By

[1] From this, as well as from some other observations of mine, it might seem as if the operation hastened the outbreak in the second eye; this is possible. It seems to me, however, extremely doubtful, when I compare my statistics of cases operated on with those not operated on. In the acute inflammatory forms the disease very often successively attacked the eyes. (See, for example, Case 5.)

[2] I believe, indeed, that the earlier performance of the operation in this case is essentially concerned in the difference of vision on the two sides; but the difference in time being so little, a safe conclusion can be the less drawn from this single observation, because I excised on the left side a larger piece of iris, which, according to my later experience, is advantageous. Besides, even in the acutest cases, I have operated a few times during the second week, and seen restoration of a very satisfactory acuteness of vision.

examination we found: injection of the anterior ciliary vessels, the corneal sensibility normal, slight diffuse turbidity of the aqueous humour; the pupil vertically oval, at the upper part much dilated, otherwise but moderately so; at the same time some photophobia, and very violent ciliary neurosis, especially at night; vision so far good that the patient could recognise medium print; he also asserted that he had never seen so well with this eye as with the left one. Owing to the visual field being also normal, there seemed no danger in delay, and I recommended local bloodletting, Ung. Hydr. c. Bellad., and an opiate at night. He was decidedly better on the following day, so that the surgeon-in-ordinary carried out the treatment for some time. A week later I was again consulted; notwithstanding the bloodletting, &c., there had occurred during the last few days violent frontal pains on the right side, and finally an extremely violent inflammation of the left eye, with torturing ciliary neurosis. On seeing the patient, I at once found an essential change in the right eye; although the injection and the turbidity of the aqueous humour were trifling, the dilatation of the pupil at the upper part had decidedly increased, the sensibility of the cornea was diminished, and the vision was so much deteriorated that he could scarcely recognise large type. The general appearance was now distinctly that of acute or subacute glaucoma. On the left side I found great injection of the anterior ciliary vessels, the pupil fixed and uniformly dilated, the aqueous humour diffusely turbid; fingers could be counted with this eye, though with difficulty, at the distance of some feet. Iridectomy on both sides was agreed on for the following day. On this day a violent exacerbation in the left eye had occurred; great chemosis, photophobia, anterior chamber much flattened, the patient could no longer count fingers; some chemotic swelling had now become developed on the right side, the patient could only with difficulty count fingers at the distance of a foot and a half. The operation was performed in both eyes at the same time, and a piece of equal size was excised in each. The torturing pains immediately ceased, the rest of the symptoms retrograded as in the cases already mentioned; the pupil maintained on both sides a trace of mobility; on the left side there remained far-advanced changes of the iris, on the right side these were unimportant; the accommodation on both sides was limited. At first it seemed to me that the result would be most favorable in the right eye; with this he could in eight days read print No. 11 word by word, whilst with the left one he scarcely recognised syllables of No. 16. This difference was explained, on ophthalmoscopic examination, by there being on the left side extensive ecchymoses over the whole extent of the retina, and even in the region of the macula lutea, and scarcely any on the right side. In connexion with one of these central ecchymoses, he had still for a period of four weeks on the left side a misty spot in the centre of the visual field, through which objects looked smoky and somewhat distorted. When all this had disappeared, vision on the left side was somewhat more acute than on the right, which, however, probably depended in part on the difference which had formerly existed. When I saw him for the last time he could accurately read with the left eye print No. 3, with the right No. 5; the visual field and the appearance of the optic nerve on both sides were normal. Almost six months had passed away, the patient had suffered much mentally through the death of his wife; during the last few months he had even worked in the evening in opposition to my desire; since then he had also, in many ways, suffered from his arthritic affections, but his eyes had never presented the least symptoms of disease.

*Résumé.*—Successive outbreak of glaucomatous choroiditis in both eyes, first in the right eye, with moderate inflammation; a week and a half later in the left one, with very acute inflammation and rapid loss of vision. Contemporaneous iridectomy in both eyes; the cure delayed in the left one by extensive retinal ecchymoses, but still perfect (duration of six months).

Case 6.—Minna Dankhof, of Berlin, æt. 46 years, presented herself at my clinic on the 16th of October, 1856. She had suffered from her 13th to her 20th year from menstrual disorders and spasms at her catamenial periods. From her 20th year these irregularities had disappeared; she was, however, troubled by violent cephalalgia, which often lasted for weeks, compelling her to remain in bed, and which was altogether independent of the occurrence of the menses. The most violent attacks were accompanied also by racking pains in the arms and feet, which rendered any motion difficult. All this had continued up to the time when she presented herself, and had not been essentially modified either by seven labours or intercurrent diseases (typhus and intermittent fever). Every year she had been many times bled for these affections. In her 34th year the cephalic affections were first accompanied by morbid sensations in the eyes, a feeling of heat in them, and pains about the eyebrows. To these was soon added a morbid closure of the lids, so that she could not keep them open when exposed to the least light. On account of the latter affections, she had already, nine years ago (1847), sought assistance in the ophthalmic clinic of the Charité of this place, and had found relief (through repeated bloodletting). From the year 1848 she suffered periodically from iridescent vision and obscurations of the left eye. These gradually occurred at shorter intervals, until in the year 1854 inflammations, with very acute ciliary neuroses, appeared, which, after repeatedly recurring, induced perfect blindness of this eye. Since the year 1850 there had been also in the right eye iridescent vision and ciliary neuroses, since 1853 obscurations at intervals of many months. These premonitory symptoms very much increased in intensity during the summer months of 1856. On admission of the patient[1] there was found on the left side a glaucoma, which had run its course; the pupil was much dilated, the iris discoloured, the cornea insensible and slightly infiltrated, the globe tense, a cataracta glaucomatosa formed, no trace of sensibility to light; in addition, internal inflammation yet continuing, effusions of blood into the anterior chamber, frontal pains, and subconjunctival injection. The right eye was hyperpresbyopic, and seemed to be passing from the premonitory stage into subacute glaucoma. During the intervals, the acuteness of vision was still so good that, with + 6, she could recognise words of No. 2. But the obscurations were repeated very rapidly, and after fourteen days' observation it was found that now some sluggishness of the pupil, slight diffuse cloudiness of the aqueous humour, and disturbance of the visual acuteness continued, even during the intervals. Since it appeared, as if the deteriorations of the right eye were connected with the violent attacks of inflammation in the left eye, iridectomy was first performed on the left side, on the 7th of November, 1856, of course entirely with the view of removing the inflammation, and without any hope of vision. In regard to the first point, the result was very favorable: the ciliary neuroses entirely ceased, congestions and effusions of blood did not again occur, and the globe lost its tenseness; on the other hand, the cornea remained insensible, the cataract proceeded, and, as was expected, vision remained entirely abolished. Notwithstanding the disappearance of the inflammation on the left side, the symptoms on the right side rapidly became more threatening, the

[1] This occurred during my absence, and the journal was kept for the first three weeks by my assistant-surgeon, Dr. Alfred Graefe.

obscurations were accompanied by congestive phenomena; and even in the remissions the patient could only read print No. 14 word by word, No. 8 not at all. She suffered much from the violent ciliary neurosis on the right side, which now ceased exactly in the middle line. On the 16th of November iridectomy was performed on the right side; the ciliary neurosis immediately ceased, and has not again returned, although the patient has since suffered, just as before, from her other head-affections. Vision continued to improve, so that on the 29th of November she already read print No. 4 precisely, and on the 10th of December print No. 1. Obscurations have not again occurred; only twice during the winter months she has observed, on arising in the morning, a slight yellow appearance before the right eye, which, after a few minutes, has disappeared, and did not impede the perception of objects. The retinal ecchymoses were very inconsiderable in this case; the optic nerve perfectly normal, notwithstanding the long premonitory stage; and the pupil also recovered its free action, which is unusual. I have seen her for eight months at regular intervals of fourteen days; she has sewn by artificial light, and in general employed her eye rather carelessly, yet the vision has remained intact. Although the other affections were, of course, not removed, the patient relates that since the relief of the ciliary neurosis her head has been infinitely lighter, and not only the forehead, but the whole cranium has been free from the gouty pains; these now commence at the occiput. This year she has also had no occasion to be bled, which would otherwise have been indispensable.[1]

*Résumé.*—Glaucomatous blindness of the left eye, the inflammation still continuing. The latter cured by iridectomy; negative effect on the vision, negative effect also on the disease in the right eye; in this one a six years' premonitory stage, the attacks of which have for some weeks no longer entirely remitted, and through gradual augmentation have been developed into glaucomatous choroi-

[1] I take this opportunity of pointing out the favorable influence which the curing of ciliary neurosis generally exerts on very extensive hyperæsthesia. The new nervous pathology has certainly made a great advance in showing how often local irritations of particular nervous filaments successively educe morbid appearances in constantly multiplying directions. Ciliary neurosis is an instructive instance. I have not unfrequently found that very extensive pains, spreading over the whole extent of the cranium, of the occiput, and even further, diminished or ceased entirely when the ciliary neurosis had been relieved.

ditis. Iridectomy on the right side. Restoration of vision. Duration of the cure (eight months), notwithstanding the continuance of other affections, which were probably originally connected with the disease of the eye.

Case 7.—Frau von Böttcher, from Curland, about 60 years old, first presented herself at my clinic in the spring of 1856. On the right side there was blindness through chronic glaucoma. I employed no treatment, because vision was entirely lost, and all symptoms of inflammation had disappeared. On the left side there was cataracta provecta; the vision in this eye perfectly corresponded with the degree of opacity of the lens, and the appearance of the eye gave no reason for suspecting an amblyopic complication. I recommended the patient to be operated on for cataract at some future time, for it was not yet sufficiently mature. When she again presented herself according to my direction, in the autumn of 1856, I found, on examination, the cortical substance, which was formerly transparent, perfectly turbid, the pupil acting well; the eye did not present any suspicious objective symptoms. She could perceive the motion of a hand in any direction. The time for the operation seemed to me to have arrived; owing, however, to some accidental derangement of the health, it was postponed for a few weeks. During this period I was suddenly called to the patient, on account of very violent frontal pains on the left side. I was unable to see her till the following day, when I found, to my horror, the distinct signs of glaucomatous choroiditis in the cataractous eye. She had the most violent ciliary neurosis, so that she moaned incessantly; the eyelids were sensitive to the touch; there were lachrymation, photophobia, subconjunctival injection, commencing chemosis; the pupil was dilated; the iris somewhat discoloured. I prescribed leeches in front of and behind the left ear, Ung. Hydr. c. Bell., mixed with opium, to be applied to the forehead, and a full opiate in the evening. The next day the patient was rather worse; during the night she had passed only a few hours in a half-dozing condition, without being at all refreshed; there was less chemosis indeed, but the mydriasis was greater, the aqueous humour diffusely clouded, the anterior chamber flattened, and the perception of light less, so that she could no longer perceive the motions of a hand, even when well illuminated; she could, however, distinguish the light and shadow of a low-burning lamp. I ordered leeches in front of the ear, a blister to the neck, the ointment to be continued, and in the evening acetate of morphia. On the fourth day of the disease she was somewhat more free from pain; the objective symptoms were much the same. Prescription as before. Soon, however, the symptoms again became more severe. Chemosis returned, the flattening of the anterior chamber and the discoloration of the iris increased. Finally, on the eighth day of the disease, the mydriasis having considerably augmented, and the perception of light being also so much diminished that the patient could only recognise with uncertainty the light and shadow of a lamp burning very low, I proposed iridectomy as an ultimate resource, and on the ninth day it was performed. The patient's nervous system was much exhausted through the constant pain and loss of sleep; the performance of the operation also was difficult, owing to the sensitiveness of the lids, the rather considerable chemosis, the great flattening of the anterior chamber, and the peripheral retraction of the iris; besides, my intention was to remove a large piece of the iris. The excised piece was extremely stiff (infiltrated). After the operation, there was an immediate remission of the inflammatory symptoms, and the patient slept for the first time. So soon as two days after, an improvement could be perceived in the perception of light. The pupil contracted so as to be only moderately dilated, but remained fixed; the iris was very discoloured in spots. The retrograde process of the morbid symptoms then ensued, just as in the cases previously described; the perception of light gradually increased, so that four weeks after the operation she could, when her back was turned to the window, again perceive the motions of a hand, at the distance of one to two feet. It appeared, however, if we may judge from the relative clearness of the excentrical impressions, as if the external half of the retina were a little less sensitive than the inner half; yet I shall venture no decided inference, for when there is only slight difference the cataract may so dissipate the light as easily to induce error. At all events, the patient's acuteness of central vision must now be considered as normal, for she fixed well, and could bear comparison with other cases of cataract. Three months after iridectomy I extracted the cataract by the superior flap-incision; some corneal collapse took place during the escape of the aqueous humour. Although the cure was accompanied by prolapsus iridis, a very satisfactory power of vision was obtained; she could not only distinguish all objects, but with + 2½ could recognise

No. 8 precisely, and most words of Nos. 4 and 3. The visual field was of normal extent, the excentric impressions relatively indistinct towards the periphery of the inner half of the visual field; excentrical vision, however, within an angle of forty-five degrees, even at the inner part, of relatively normal acuteness. The optic nerve showed no trace of excavation. I have watched this case for nearly three months since the extraction, during which time vision has constantly improved.

*Résumé.*—Acute glaucoma in an eye previously affected with cataract. Iridectomy on the ninth day. The improvement could be shown by the gradual increase in the power of perceiving light, the objective symptoms being disregarded; restoration of vision by extraction of the cataract three months after iridectomy.

*Additional remark.*—It must not be supposed from this case that when cataracta glaucomatosa has already occurred, a cure could be obtained by the operation. The time, when the formation of secondary cataract takes place in the glaucomatous process, always lies beyond the limits, within which iridectomy affords relief; the cataract was here pre-existing, thus no cataracta glaucomatosa, and the case only shows that we may successfully extract a pre-existing cataract in an eye which has been glaucomatous and treated by iridectomy.

### 3. *Iridectomy in the later period of Acute Glaucoma.*

If the curative action of iridectomy is most decisive in fresh cases, still it in no way loses its importance when the disease has existed for a long period. Although my observations are more numerous for this group than for the preceding, still, owing to the heterogeneousness of the results, the question has been less nearly brought to a solution, and a far greater extension of study is required in the future. I may temporarily set down the following remarks as the result of my experience.

A. A duration for many weeks, even for many months, reckoned from the commencement of the first glaucomatous inflammation, does not absolutely exclude complete restoration; this, however, depends on the circumstances of individual cases. Sometimes the first inflammations are indeed intensely acute, but yet so far of a benignant nature, that in the remissions which afterwards occur, there are left for a long time an almost normal power and field of vision, and an unaltered papilla nervi optici, notwithstanding a little iridoplegia and discoloration of the iris. These are the cases in which the exact commencement of the disease cannot be clearly distinguished from the premonitory stage, because the first inflammatory attacks are developed by gradual augmentation of the premonitory attacks of obscuration. In these cases iridectomy can produce perfect restoration, even many months after the outbreak; and this result we may confidently expect when the field of vision and the papilla optici have been normal in the remission preceding the last attack. The acuteness of central vision may at the same time be already considerably diminished (see *e.g.* Case 8). The cures also seem to be permanent, as in the first period. In per-acute cases the conditions may be very much less favorable, even within a few weeks after the first attack; and certain terribly acute cases do sometimes occur, in which the faculty of distinguishing is immediately and for ever annihilated, and in which treatment, even within a few weeks, is already too late.

B. The prognosis is completely changed as soon as *the field of vision is contracted.* Yet a moderate concentric contraction is relatively the most favorable; this, however, occurs far more rarely than one proceeding principally from one side. The prognosis is rendered the more unfavorable by the latter, in proportion as it approaches the middle line. The *condition of the papilla* is of equal importance. In the cases where the field of vision was extremely contracted, and yet the papilla was very little excavated, it is true that no perfect restoration took place, but there was always considerable improvement, especially in the acuteness of vision, generally also in the visual field, which occasionally (see Case 9) attained a fourfold extension. Such improvements were usually permanent. If, on the other hand, there is well-marked excavation of the optic nerve, with great contraction of the field of vision—and this is unfortunately the most common case—I cannot sufficiently warn my readers from too sanguine expectations. Whether the lesion of the optic nerve, when once induced, becomes substantially further developed or not, after the cause has been removed, seems to depend on accidental circumstances, which cannot be calculated. The immediate effect of the operation seemed in most cases favorable; in a great number there was not only improvement in the acuteness of central vision, but also widening of the visual field; but only in some cases did this improvement continue, in others the power of vision again diminished.

It requires long-continued observation to decide as to the final result in such cases, but this much may now be said, that the results, when excavation of the optic nerve has once been induced, are extremely various and temporary. Successes often entirely vanish again. Still some cases remain of a very satisfactory nature, and it must be allowed that iridectomy, even under such circumstances, is more beneficial than any other means, though often also it may only succeed in delaying the blindness. If the field of vision is already very excentric, we should no longer count on any considerable improvement, a decision which is more true in regard to the later stage of acute glaucoma than with reference to the chronic form (see Case 13). Rapidly progressive forms were even yet occasionally arrested, so as to induce a stationary condition. I suspect, however, that it is never more than temporary. In no case where the quantitative perception of light was abolished, did any trace of a power of distinguishing reappear.

C. Tenseness of the globe, iridoplegia, anæsthesia of the cornea, and flattening of the anterior chamber, are, *cæteris paribus*, favorable, because they prove that the diminished power of vision is yet to some extent to be referred to increased pressure, on which iridectomy has always a favorable action. The same thing is almost true of the haziness of the aqueous humour and vitreous body. Even if it is to be considered as a subordinate factor in regard to the blindness, still it is a proof that the process of secretion is yet active, and as such it is a favorable sign.

D. If, when the lesion is of old date, the improvement obtained by iridectomy is not permanent, still the diminution of vision at a later period is not accompanied by the symptoms of a fresh glaucomatous choroiditis, and hence we ought not to speak of it as a relapse of the original lesion. We have rather, then, the general appearance of a progressive amaurosis, with contraction of the visual field. The substance of the optic nerve becomes whiter and less transparent, the arteria centralis smaller, even the excavation of the optic nerve seems in some cases to increase.[1] Since

[1] Of an actual increase in the excavation after the performance of iridectomy, I only possess two examples. Perhaps this result may be thought an objection to the theory, which has been formed as to the origin of the excavation of the optic nerve; it may be said, that if the excavation of the optic nerve is actually produced by the intra-ocular pressure, normalising of the latter must also occasionally produce a restoration of the form of the nerve, and at

changes in the internal membranes and opacities of the refractive media, and such symptoms as attest increased pressure, are not superadded, the continued development of the lesion of the optic nerve must be considered as the cause of the blindness. I have met with but one instance in which the ulterior deterioration again took place under symptoms of increased internal pressure. This was in the case of Madame Sack, from Vienna, a lady of about forty years of age, whose eyes had been attacked by glaucoma some months previously. On both sides the optic nerve appeared much excavated; on the left side only, there existed an excentric field of vision; on the right side the field of vision was a little contracted, yet there still was central fixation and moderate power of vision. The symptoms of increased pressure were well marked, and proved very obstinate, for on the left side a coloboma, formed by iridectomy, was obliged to be enlarged still further by a second operation, on account of the imperfect immediate result. At first the same effect as in the other cases appeared to be induced, but after six weeks the subconjunctival veins appeared more prominent, the globe became more tense, the cornea less sensitive, the pupil larger, the retinal veins broader and serpentine, the excavation more marked, the power of vision weaker, the field of vision narrower, and thus again the case presented the symptoms of chronic glaucoma. This is the only case I have met with where subsequent deterioration depended on an actual recrudescence of the glaucomatous process, and have reason to believe that a still more extensive excision of the iris might have had better success.

E. In all cases of glaucomatous blindness, even where this disease

all events must prevent an increase of the excavation. Of course it would be still more decisive as to the correctness of my views, if after iridectomy even the excavation of the optic nerve disappeared together with the other symptoms of pressure. Unfortunately, I have hitherto been unable to convince myself of this in any case; on the other hand, that the optic papilla ought to recover from the form which it has once obtained cannot be necessarily deduced, either from physical or from anatomical considerations. Neither can the increased excavation of the optic nerve, which sometimes occurs after diminution of the pressure, any more demonstrate the falsity of the theory than a case of partial staphyloma, which becomes worse in spite of iridectomy, can disprove the participation of intra-ocular pressure in the pathogenesis of this disease. It may very well be imagined, that when the substance and resistance of the optic nerve are once changed in a certain manner, pressure of the ocular fluids, even to a normal amount, is relatively too great.

has run its course, iridectomy has still the advantage of relieving any existing inflammatory symptoms and ciliary neuroses. He who knows the agony which the patients sometimes suffer for a long period of years through these blind eyes, will greet even this action of iridectomy with a hearty welcome; it renders it superfluous to treat such patients by frequent bloodletting and narcotics, which formerly were often unavoidable, even when they were contra-indicated by the general condition, by the age, &c. Finally, it is known that during the ulterior course of the glaucomatous process, peculiar softenings and ulcerations of the cornea are occasionally caused through its anæsthesia. Iridectomy may also act favorably in this respect, partly owing to the restored conduction of the corneal nerves, and partly because the diminution of intra-ocular pressure seems generally advantageous in corneal infiltrations.

Case 8.—A workman, named Kurz, of Berlin, æt. 61, presented himself, in the middle of September, 1856, for the first time, at my clinic.[1] Since the winter months of 1855-6 he had had, from time to time, blue spectra before his eyes, he had seen rainbows around the candle, and when he fixed an object whilst in this state, or exposed the eye to the light, the coloured spectra revolved, like a wheel, in the field of vision, and the sight became so dim that he could no longer recognise even large print. After a night of good sleep vision was always perfectly acute again. These attacks were gradually repeated at shorter intervals, and were of constant occurrence when the eye was exposed to any exertion, or a night was passed without sleep. In August, 1856, inflammation first occurred in the left eye, as a consequence of which vision diminished with considerable rapidity. On the right side, according to the account of the patient, the acuteness of vision had also diminished during the intervals between the obscurations; still an examination showed that this statement had altogether reference to an increase in the presbyopia. On admission, there was found on the left side an already well-marked, acute glaucoma, and tolerably decided symptoms of pressure; on the other hand, at that time, only slight turbidity of the refractive media, the papilla not yet excavated, the power of vision much diminished and a little varying, because the exacerbations and remissions were still well marked. On an average, the

[1] As this occurred during my absence, the journal was kept for the first six weeks by my assistant, Dr. Alfred Graefe.

patient could count fingers at the distance of eight feet, and with + 6 recognise words of No. 16. Vision distinctly diminished during the derivative treatment, which was employed for the next two months; the obscurations on the right side became also more intense, and each time induced some dilatation of the pupil and cloudiness of the aqueous humour. When I saw the patient, in the beginning of November, there were on the left side great mydriasis, discoloration of the iris, and considerable diffuse cloudiness of the refractive media, so that it was with some difficulty that I satisfied myself of the normal form of the optic papilla. The patient counted fingers at the distance of six feet, and, provided with + 6, recognised with difficulty words of print No. 20. The field of vision was perfectly normal. After the performance of iridectomy, on the 6th of November, the pupil on the left side contracted to a medium size; remained, however, perfectly fixed; the iris was very much altered, the refractive media cleared in the usual manner, and the vision continually improved, so that the patient could already count fingers at the distance of fifteen feet, on the 12th of November, and recognise with + 6 words of No. 13, and large letters of No. 10. The further recovery was much delayed by an attack of granular conjunctivitis, which was prevalent at that time in Berlin. In February, 1857, the patient, provided with + 6, could read No. 8 precisely, and No. 5 with errors; in March, No. 6 precisely, and words of No. 3. I may remark, that soon after the operation on the left eye acute glaucoma broke out in the threatened right eye, and that in consequence iridectomy was performed within a few days. The cure of this eye ensued, so far as a normal acuteness of vision, just as in the cases previously related (See Part II).

The comparison of the two eyes proved decisively in favour of the right one, for it regained greater acuteness of vision, some action of the pupil, and a tolerably extensive accommodation. In the eight months following the operation, during which I examined the patient at regular intervals, there occurred neither premonitory nor any other morbid symptoms, although the patient exposed himself to various noxious influences (especially night-watching).

*Résumé.*—Acute glaucoma, which had broken out after a premonitory stage of half a year, and existed for two months and a half; the optic nerve and field of vision normal; the power of distinguishing, for two months already, very much diminished; restoration by iridectomy of a satisfactory, although not perfectly normal acuteness of vision (duration, eight months). Outbreak of acute glaucoma in the second eye a few weeks after the operation on the first one; perfect cure by iridectomy, performed shortly after the outbreak (eight months' duration).

Case 9.—Wilhelm Hoeffler, of Berlin, æt. 71, whose right eye has been already mentioned (*sub* I, Case 1), came to my clinic on the 15th of February, 1857. For a year and a half he had remarked coloured rings about the flame of a light, and since December, 1856, weak vision of the right eye; it is possible that this existed at an earlier period, for it was by violent pains in the right side of the forehead and temple that he was first compelled to test this eye. With the pains, which never passed beyond the middle line, there occurred at the same time photophobia and lachrymation; at first there was some improvement during the remissions, which at that time occurred periodically, but never perfect restoration of vision; in short, it had been continually diminishing during the months of January and February. The examination showed the general appearances of an acute glaucoma in its later stage—tolerable dilatation of the subconjunctival vessels, corneal sensibility here and there almost lost, aqueous humour diffusely turbid, iris discoloured, pupil dilated, anterior chamber flattened, bulb tense—owing to the haziness of the refractive media, the background of the eye could not be examined—violent ciliary neuroses, vision almost extinguished, central fixation abolished; the patient fixed a hand with uncertainty, the visual axis passing to the inner side, so that he could still count fingers with the inner half of the retina, with good illumination, at the distance of one foot, although occasionally he was wrong. An accurate functional examination, which was very troublesome, owing to the slight power of distinction, showed that the inner half of the visual field was altogether deficient; that the (central) point of fixation lay just on the edge of the portion which still possessed the power of vision, but that it only corresponded to a very dull quantitative perception; that the region of vision, stretching from here outwards had, measured at the distance of one foot, a breadth of thirteen inches, and a height which, reckoned from within to without, increased from two and a half inches to eighteen. But within this field of vision there was only a little space which yet allowed a tolerable qualitative perception of light, and this space corresponded, as may be deduced from the first-mentioned trials of vision, to an excentric portion of the retina, which was situated pretty much on the inner side. Iridectomy was performed on the 17th of February; the ciliary neuroses were immediately relieved, so that the patient slept well, a result which could not be obtained by opiates during the previous days. The habitus of the eye gradually experienced a favorable change, the symptoms of irritation entirely ceased, the corne recovered its normal sensibility, the pupil became somewhat smaller, yet without action, the iris remained moderately discoloured, the refractive media cleared so rapidly that even six days after the operation the background of the eye could be examined. This showed very abundant retinal ecchymoses, and the optic nerve slightly excavated. On the 25th of February the state of vision was accurately examined; the patient already counted with certainty fingers at the distance of six feet, and indeed he sometimes employed central and sometimes excentral fixation, testing to some extent the advantages of the two. Hence it appeared that a striking change had already occurred in the visual field. I found by mensuration that the point of fixation, corresponding to the centre of the retina, lay already within the field of vision, and indeed about an inch more externally than the margin; the breadth was (always measured at the distance of a foot) eighteen inches; the height, in a vertical line, passing through the point of fixation, twelve inches, at the most external limit twenty inches. Fourteen days later the patient counted fingers at the distance of eighteen feet, and always fixed with the normal line of vision; the field of vision passed inwards beyond the point of fixation about an inch and a half, and the form, which was now again copied, had essentially changed since the previous examination; in place of its former similarity to a trapezium running externally in a divergent direction, it had now almost the form of a square. The breadth amounted to twenty-six inches (previously thirteen inches); the height, along a vertical line drawn through the point of fixation, twenty-four inches (previously two and a half), which increase remained nearly unchanged as far as the external limit (previously eighteen inches); in short, the field of vision was four times as large as originally. In the beginning of April the retinal ecchymoses had disappeared; the patient counted fingers at the distance of twenty-five feet or more; read with + 6 No. 11 precisely, some words of No. 7, and even of No. 5; the field of vision was as in the last examination, except that it was again somewhat broader.

During the months immediately following, everything remained much in the same condition, and not the least symptom of glaucoma recurred. On an examination made in July, I found the range for large objects pretty much as in April, but the recognition of print more difficult; provided with + 6, he could no longer recognise words of No. 5 (without distinct change of accommodation), and even very few words of No. 8. The excavation of the optic nerve had not in the least increased. In the month of August no further deterioration had occurred in the acuteness of vision; the visual field had remained at exactly the same degree of improvement, yet it is uncertain whether a further diminution of vision will not ultimately occur. In the mean time the left eye was operated on before the premonitory stage had concluded, and with perfectly satisfactory and permanent success. (See Case 1.)

*Résumé.*—Acute glaucoma, which had existed at least two months, a premonitory stage of a year and a half having preceded it. Slight excavation of the optic nerve, very great contraction of the visual field; the point of fixation was, in fact, on the margin of the field of vision; there was, however, excentrical fixation; there only yet remained a slight power of distinguishing. After iridectomy, clearing of the refractive media, retrogression of the symptoms of pressure, more than fourfold extension of the field of vision, and restoration of central fixation. Four months later slight diminution of the acuteness of central vision, without deterioration in respect to the visual field; hence the final result cannot yet be definitely stated.

### 4. *Iridectomy in Chronic Glaucoma.*

Although it was to cases of this group that I first applied iridectomy, I am still unable to make any decided statement as to the manner in which they ultimately end. Finding among my observations some instances where considerable improvement followed the operation, which remained at the same degree for a period of three months, and then again deteriorated (see Case 10), it is obvious that the utmost precaution is required in admitting a permanently curative effect. I can only state this much, as the result of the trials hitherto made—that iridectomy exerts a temporarily favorable influence, even in chronic glaucoma, and that its degree and duration depend on individual circumstances. Since this therapeutic action of the operation is at all events superior to the curative effect of any other method of treatment, it is our duty to continue and vary our observations, and we hope to be assisted in the attempt by many of our colleagues.

In general, the prognosis seems to depend on the same factors in the present case as in the later stages of acute glaucoma. Contraction of the visual field and excavation of the optic nerve render the prognosis worse, but do not unconditionally destroy the hope of a favorable influence, or of the arrest of the affection, which had till then progressed; it even appears, from my cases, that great contraction of the visual field is of less importance in chronic than in acute glaucoma, so that considerable improvement is sometimes found, even when the field of vision is very excentrical and slit-shaped (see *e.g.* Case 13). There is generally less hope of a complete cure from the circumstance that excavation of the optic nerve is developed in chronic glaucoma at a relatively early period. Hence a very early diagnosis of the affection is of essential importance. This is not so easy as in acute glaucoma, where it is announced by the first inflammatory attack with iridoplegia, whilst in the present case the external symptoms are often limited for a long time to a very slight turbidity of the aqueous humour, inactivity of the pupil, and a little flattening of the anterior chamber; and yet even in this period the lesion of the optic nerve occurs. The more the symptoms of increased pressure are distinct at the time of the operation, the more may, *cæteris paribus*, be expected from iridectomy. We need not be alarmed at the duration of the affection, for I have occasionally seen considerable improvement after a lapse of many years, improvement which has lasted to the present moment. The aspect of the eye also lost its glaucomatous appearance, the refractive media always became again transparent, the globe returned to its normal hardness, any existing ciliary neurosis ceased, retinal ecchymoses were generally presented, although to a less extent than in acute glaucoma; the structural changes of the iris were, on the average, less than in the acute form; the pupil became more contracted, and often recovered moderate mobility, effects which principally depended on the minor participation of the iris. Excavation of the optic nerve, when once well marked, did not again disappear.

Case 10.—Frau Hoffmann, of Berlin, æt. 57 years, presented herself at my clinic on the 4th of November, 1856. For a long series of years she had suffered from pains in the head, especially in the forehead, from "rheumatic twitchings in the limbs," and want of sleep. For six years she had remarked coloured vision and periodical obscurations of the left eye; for four years the vision of this eye had gradually diminished, without any inflammatory symptoms having ever occurred. Fear for the right eye, which now also suffered from periodical obscurations, had brought her to me. At the time of her first visit, there were on the left side all the symptoms of chronic glaucoma; the subconjunctival veins were dilated, the cornea rather insensible, the anterior chamber flattened, the aqueous humour slightly turbid, the pupil dilated and fixed, the iris a little discoloured, the optic nerve much excavated. She counted fingers at the distance of two feet in a seeking manner, but soon became tired; with convex glasses she recognised nothing of print No. 20 of Jäger's specimens; the visual field was much contracted, and on every side; externally the opening was only about 10°, in other directions decidedly more, yet an accurate limitation was very difficult, owing to her accounts varying. This visual power, observed for six days, proved perfectly constant. Iridectomy on the 10th of November. On the 15th of the same month she counted fingers four feet off with certainty and better fixation, she deciphered with + 6 words of No. 16, and even of No. 14. On the 24th of November she counted fingers at sixteen-feet distance, read No. 11 word by word, and recognised a few letters of No. 4. The visual field had decidedly a little extended, the opening outwards was now about 20°, but it was still very contracted, so that, measured at the distance of a foot, the transverse diameter was fourteen inches, the vertical diameter but little more; the external morbid symptoms had perfectly retrograded, and the refractive media had cleared and allowed the recognition in detail of very far-advanced excavation of the optic nerve; the anterior chamber had become distinctly deeper; the pupil showed a trace of mobility; the subconjunctival veins had perfectly retrograded; scattered retinal ecchymoses were already disappearing. The improvement of the visual power kept at the same degree for almost three months. On the 21st of February, 1857, a fresh diminution of the sight was first discovered; she could no longer recognise any of No. 4, and No. 11 only by syllables and with errors. The visual field also showed a distinct contraction, which proceeded principally along a diagonal, directed downwards and inwards from above and without. Vision diminished till the end of April; on the 26th April she could recognise fingers at eight-feet distance only, read No. 16 precisely, most words of No. 14, scattered syllables of No. 11, and nothing of No. 8. The external appearance of the eye had remained the same; even in the excavation of the optic nerve I could find no difference, except that the substance of the nerve seemed to me to have become a little whiter and less transparent, and the trunks of the retinal arteries a little smaller. I now thought that it would advance progressively to blindness; from that time, however, till August, 1857, the condition has remained exactly the same, so that the patient continues to possess, nine months after the operation, considerably better sight, and a somewhat larger field of vision, than before it was performed. In the mean time, the glaucoma which was already threatening in the right eye broke out in the acute form. Iridectomy was immediately performed with the best result, which has lasted so far (seven months).

*Résumé.*—Chronic glaucoma, of many years' standing, with advanced excavation of the optic nerve, contraction of the visual field, uncertain fixation, and extremely reduced power of vision. Soon after iridectomy, considerable improvement of vision and distinct extension of the visual field. After the improvement had lasted for three months, fresh deterioration, without glaucomatous symptoms; which, after progressing for four weeks, attained its present degree, and left, nine months after the operation, considerably improved sight in comparison with the original condition.

Case 11.—Frau Lichtenstädt, from Breslau, æt. about 50 years, first consulted me in the summer of 1855. The left eye had become perfectly blind from acute glaucoma many years ago; there had occurred also on the right side, for a long time, periodical obscurations, frontal pains and chromopsiæ, and for about a year the vision had gradually diminished, without inflammatory symptoms. Examination showed chronic glaucoma, with moderate contraction of the visual field and some diminution of the acuteness of central vision. Since I was not at that time aware of the curative action of iridectomy, other methods of treatment were followed, and the prognosis given to her relations was that the case was almost hopeless. In August, 1856, the patient came again. In the mean time the disease had considerably advanced, at the same time preserving its former (not inflammatory) character; the pupil was very much dilated, the iris being at the same time relatively but little changed in structure; the anterior chamber was flattened, the aqueous humour turbid, the cornea almost insensible, the bulb tense; there were periodical ciliary neuroses; the papilla optici was considerably excavated. Vision was now almost extinguished; it was with difficulty she could count fingers, and with + 12 decipher a few words of No. 16 of Jäger's specimens in a seeking manner. The field of vision was only a narrow slit, and, owing to the unstable fixation, could not be exactly limited. Iridectomy having been performed, there at once occurred the favorable change in the external habitus of the eye which has been so many times described; notwithstanding the long duration of the disease, the cornea recovered its sensibility, and the pupil to some extent its action. The latter also became considerably smaller than it had formerly been, the ciliary neuroses ceased, the refractive media cleared, &c. Vision much improved, so that she could count fingers with certainty at four- to six-feet distance, with + 12 read some lines of No. 14 precisely; finding objects was of course difficult, owing to the narrow visual field; but when once within the range of sight, they were now fixed more firmly than formerly. Owing to this fortunate change an accurate determination of the visual field became possible. That this had extended, was evident from her being able to find her way about, though yet only with difficulty. The field of vision for qualitative perception described an elliptical figure, the major axis (measured at the distance of a foot) being seven inches, the minor three inches; around this space there existed in a tolerably broad zone quantitative perception of light. The patient left Berlin a few weeks after the operation, and I received further information through the kindness of Foerster in Breslau. In December, 1856, the improvement in the objective symptoms had perfectly continued. With + 16 she could recognise correctly some lines of No. 13; the visual field had not become smaller, but had approximated more to a round form, the major diameter having diminished from seven to six inches, the minor, on the other hand, having increased from three to five inches. Correspondingly, she continued to have so great difficulty in finding her way, that she was still obliged to be led in the streets. She suffered during the winter months much mental affliction, and repeatedly watched at night by the bed-side of a sick daughter, unfavorable circumstances which had formerly caused immediate deterioration. Ciliary neuroses did not again occur, and even the occasional pains in the head were usually restricted to the side which had not been operated on.[1] In the spring of 1857 I again heard of her, much to the same effect.

*Résumé.*—Chronic glaucoma for many years in one eye, after glaucomatous blindness of the other eye had already ensued. Iridectomy shortly before abolition of vision (to be supposed according to the previous development), the visual field being contracted in the form of a slit, and the excavation of the optic nerve being of moderate degree. Retrograde process of the glaucomatous symptoms; slight (and immeasurable, owing to the uncertainty of fixation before iridectomy) enlargement of the visual field, moderate increase of the visual acuteness and continuance of this improvement for nine months.

Case 12.—Carl Wagner, of Berlin, æt. 58 years, presented himself on the 20th of April, 1857, at my clinic. The right eye had been perfectly blind for a year in consequence of a chronic glaucoma, which had broken out seven years ago, and which still continued to induce very troublesome ciliary neuroses. On the left side there occurred, four years ago, periodical ciliary neuroses, chromopsiæ, obscurations, and then, even in the intervals, weak vision. Especially during the last six months had the power of vision distinctly diminished, and even the patient had remarked the contraction of the visual field, passing from the inner side and rapidly progressing. There had been no inflammatory symptoms. On examination, we found on the left side the complete type of chronic glaucoma: the aqueous humour diffusely turbid, the pupil dilated and almost motionless, the iris but little discoloured, the optic nerve much excavated, arterial pulsation, however, only occurring when the finger was gently applied, the central vessels more than usually displaced, and the retinal veins very large. With + 6 the patient could recognise No. 8 tolerably well, words of No. 4, nothing whatever of No. 2; the visual field was contracted from above and outwards

[1] Dr. Foerster related, that objects in the street still constantly appeared to the patient as though they were covered with snow. I have often received a similar statement in excavation of the optic nerve, and the symptom, in my opinion, is directly to be referred to the existing lesion of the optic nerve, and to be carefully distinguished from the glaucomatous chromopsiæ, which favour the view of increased pressure.

almost a fourth. It was accurately copied in my journal. On the 27th April I performed iridectomy in both eyes, only for the ciliary neuroses, of course. On the left side the external symptoms of disease retrograded as in other cases. Since that time there have not occurred either ciliary neuroses or chromopsiæ and increased obscurations. Fourteen days after the operation the acuteness of vision was still a little less than previously, which was explained by a few retinal ecchymoses. On the 27th May the patient read with + 6 No. 8 with difficulty, yet precisely, and recognised most words of 4 and 3. Hence the visual acuteness had at least recovered its former degree, and the drawing of the visual field agreed exactly with that taken before the operation. Things continued the same till the 18th of August, when the last examination took place. On the right side there was of course no influence on vision; the ciliary neuroses were cured.

*Résumé.*—Chronic glaucoma, inclusive of the premonitory stage, which cannot be limited by the history, existing for four years, with some diminution of the visual acuteness, and considerable contraction of the visual field; the disease rapidly progressive for the last few months. After iridectomy, cessation of the periodical deteriorations, and preservation of the existing vision (since four months).

Case 13.—Frau Hauptmann Beinlich, from Pless, in her fortieth year, consulted me in March, 1857. The left eye had many years before become very weak, and gradually blind, without symptoms of inflammation. On the right side there had occurred, also many years ago, periodical obscurations and, for more than a year, increasing weakness of vision, so as now only to leave slight power of distinguishing. On examination, I found on both sides the well-marked appearances of chronic glaucoma: the globes tense, the subconjunctival veins on the left side enlarged, the corneæ on both sides very insensible, the aqueous humour slightly turbid, the pupils much dilated, on the left more than the right side, on both sides perfectly fixed, of a greenish appearance; the anterior chamber flattened, the iris in spots very discoloured and atrophied. The ophthalmoscope showed on the left side (atrophic) choroidal changes in the equatorial region; the back-ground of the eye on both sides was indistinct; on the left side even some floating opacities of the vitreous body could (against the rule) be distinguished; the optic nerve was on both sides very much excavated; on the right side, after a longer observation, intercurrent arterial pulsation could be perceived; on the left side the examination of the vessels passing into the papilla was very difficult, owing to the opacity of the vitreous body; it even seemed as though in the very fossa of the optic nerve there lay a peculiar dull substance. Functional examination showed on the left side only a trace of quantitative perception of light; on the right side fingers could yet be counted as far off as three to four feet, and letters of No. 20 recognised. The field of vision was extremely contracted, and formed a small slit; it was already very excentrical; measured at a foot, it began at two inches outwards from the point of fixation; the point of relatively most distinct vision was still more excentrical, so that the patient during the trials of vision directed the visual axis at a very distinct angle inwards. The horizontal extent of the visual field was (measured at a foot) about six inches; the vertical, two and a-half to three inches. Iridectomy was immediately performed on the right side, and a slight improvement of vision took place immediately after the operation. The following day there was a slight effusion of blood into the anterior chamber. The compressing bandage was carefully continued till reabsorption. Eight days after the operation the following results were apparent: the globe less tense, the cornea, however, yet very insensible; the aqueous humour clear, the anterior chamber less flat, the pupil less dilated, of tolerably normal hue, fixed however; the periphery of the iris generally discoloured, the ocular background distinct, the excavation of the optic nerve as before, arterial pulsation extremely seldom and after definite exciting causes. The vision had clearly improved, the patient could count fingers to the distance of ten feet, and recognise words of No. 16, and the comparative readiness with which she discovered objects made us suspect an extension of the visual field. Mensuration showed that the field of vision had not indeed extended towards the point aimed at (Visirpunkt), but that in the direction outwards it had nearly a double, and in a vertical direction almost a quadruple opening. Since the case seemed to me of dogmatic importance, the measures were taken before and after the operation (as a mutual check) at three different distances—one, four, and eight feet. At the distance of eight feet the patient could now survey more than the height of a man, whilst formerly she could scarcely include in her range the head and half the breast at the same time. Although more exact trials showed that in a great part of the visual field which had now been gained there was only an extremely dull perception, still she could find her way (Orientiring) decidedly better, as has been already pointed out. The excentric fixation had remained just the same. Iridectomy was performed on the left side a little later, not with the least idea of restoring vision, but simply on account of the other glaucomatous symptoms; a rather considerable effusion of blood into the anterior chamber having been reabsorbed, we found a little increase of the quantitative perception of light, besides clearing of the vitreous body with the exception of some floating opacities, clearing of the aqueous humour, diminution of the tenseness of the globe and of the pupillary dilatation. According to a report (medical) received three months later, the vision has remained the same.

*Résumé.*—Chronic glaucoma of more than a year's duration, with advanced excavation of the optic nerve, and a visual field in the form of a slit, excentric outwards. After iridectomy, retrogression of the glaucomatous symptoms, distinct increase in the visual acuteness, considerable extension of the visual field, but continuance of excentric fixation (present duration, three months).

### 5. *Iridectomy in Amaurosis with excavation of the optic nerve.*

Since I have assigned another cause than glaucoma as an explanation of the cases belonging to this group, it may appear strange that I have still tried iridectomy also in it. There were two reasons that induced me. In the first place, I expected to find in the comparison of the curative effects, arguments for the correctness or incorrectness of my nosological views, and besides, even the view of a positive lesion of the optic nerve would not prove the powerlessness of a certain action of iridectomy. Such a striking, direct effect, as, *e.g.* in acute glaucoma, could, of course, never be expected from a pressure-diminishing process, when the optic nerve is primarily diseased. The optic nerve is, however, constantly exposed to the pressure of the contents of the globe, and this pressure might possibly have some influence on the development of a lesion of it, through limiting the change of tissue, or in some other and unknown way; it might render the disease constantly progressive, &c. It might then, perhaps, be of use to diminish the pressure to less than its normal amount. If we suppose (to remain within the bounds of these suppositions) the substance of the optic nerve softened through any internal process, the papilla will then yield in an abnormal manner to the normal pressure, and even if the primary affection is in itself susceptible of cure, still the protruded form of the papilla, and the mechanical and trophic alterations which are connected with it, might impede the restoration of its functions.

I should certainly have left unmentioned these hypotheses, which at the time far surpassed the facts, had they not induced trials of iridectomy in primary excavation of the optic papilla, and that I wish fully to explain the motives which led to this course. I can comprise the results of my essays in the statement, that I never observed any special curative action of iridectomy in amaurosis with excavation of the optic nerve, and that I never saw an improvement in the visual acuteness or extension of the field of vision, beyond the limits of possible variations and of errors of observation. The separation of this morbid group from glaucoma is in reality favoured by the effects of the treatment,—a point of view not to be disregarded in so dark a branch of nosology.

Another question is, whether a stationary condition is sometimes induced by iridectomy in cases of progressive amaurosis with excavation, the diminution of intra-ocular pressure allowing the spontaneous or therapeutical arrest of the lesion of the optic nerve. With reference to this, I am continuing my investigations, but believe it will require some years to arrive at any conclusion, since the spontaneous changes in amaurosis with excavation of the optic nerve are so slow, that there is often scarcely any alteration in periods of three to six months. In these cases, a stationary condition is sometimes apparently induced by other methods of treatment. Though this arrest occurs, indeed, without any prognostical certainty, still it forms a distinction from the glaucomatous process, which constantly progresses, either by starts or by a slow advance. For the same reason the communication of reports of cases taken from this group, would be out of place.

IX.—I have but few words to add about the operation itself. The object is to excise a piece of the iris by the same proceeding as is customary in forming an artificial pupil by means of iridectomy. The following points must be specially considered:

1. The incisions must be situated as excentrically as possible, so that the external wound may enter the sclerotic about half a line from the cornea, and the internal one just at the junction of the two. It is possible, in this way, to remove the iris as far as its

ciliary attachment, and this seems to be necessary for success, at all events it renders it more certain. Since also the iris occupies only a small space, owing to the existing mydriasis, any deviation of the inner wound from the corneal periphery will very considerably diminish the size of the excised piece.

2. The excised piece must be as large as possible, and hence a broad lance-shaped knife must be employed, or the ordinary one be introduced tolerably far. In this the operation differs from that for the formation of an artificial pupil (*e. g.* in leucoma adhærens), where, as every one knows, excisions of moderate extent are, for optical reasons, preferable to extensive ones. The more intense the symptoms, the more marked the increase of pressure, the more extensive an excision should I advise. As to the place operated on, it is obvious that, in this case, it is unimportant. I usually make the excision at the inner side. If, with regard to personal appearance, we wish to be especially careful (which is usually unnecessary, owing to the age of the patient), we can excise at the upper part, although I really find the disfigurement produced by a coloboma placed at the inner side trifling, and in dark eyes unnoticeable. Excision above is besides inconvenient, and requires greater rotation of the bulb with the ophthalmostate; this may readily injure the eye when the inflammation is acute.

3. The aqueous humour must be very cautiously evacuated, because a too sudden relaxation of pressure (in the present affection) may cause extensive hæmorrhage into the internal membranes and cavities of the eye. In comparison with the ordinary irido-choroiditis with atrophy of the globe there is a factor—the relatively greater pressure—opposed, indeed, to such effusion of blood, even after escape of the aqueous humour. In fact, there seldom occur in glaucoma, effusions so extensive and so slowly absorbing, as in the cases mentioned. On the other hand, there is in the nature of the disease itself a great tendency to rupture of vessels; whether through direct participation of the vascular walls, or entirely through the previous venous strangulation, I leave undecided. I have repeatedly mentioned the occurrence of retinal ecchymosis, and this alone should make us cautious.

Even during the escape of the aqueous humour, I usually exert slight pressure on the globe with the finger, and soon after the operation apply a compressing bandage, which is cautiously slackened in a few hours.[1] I have not found any other after-treatment necessary. Even when the operation was performed at the time of most acute inflammation, the inflammatory symptoms spontaneously subsided; an antiphlogistic treatment may, however, be exceptionally indicated under such circumstances, to hasten the retrogression of symptoms of irritation. It is obvious that the eyes must be protected from the light for a longer period, and, in general, the ordinary precautions be more carefully observed than after the usual operation for artificial pupil.

X.—The curative effect of a local treatment on the glaucomatous process, and the duration of the cures obtained, at least in certain cases, might directly lead to the conclusion that the whole affection is necessarily a purely local one, and that the supposition of others, and of myself formerly, as to a vascular affection forming the origin, is incorrect. I admit that this supposition is much shaken by the results of iridectomy, yet such an unconditional inference as the above must for the present be avoided. It may be readily imagined that by changes in the vessels, a definite anomaly of the circulation is induced, which, *per se*, does not abolish the function of the internal parts of the eye, but only when a local factor is added to it. After the required change of the local circulation, the original cause might possibly continue, without producing the former effect. If we glance at therapeutics, we find that the cure very frequently depends on the removal of certain intermediate links which maintained the causal relation, and not in the removal of the causes.

If we bring together once more, in regard to general medical practice, all the previous statement as to the action of iridectomy, it appears—

1. That the most certain result is obtained in those cases where one eye is threatened after the other has become blind. In such cases it will be the duty of the physician to submit the patient as soon as possible to careful medical observation by an oculist, and reciprocally it will be the duty of the latter to direct the careful at-

[1] The best form of compressing bandage at present known to me, is a rather thick layer of lint laid on the closed eyelids, and held on by a frontal bandage of woollen material. The degree of tightness is regulated by a buckle placed at the side of the head, and must, under all circumstances, be agreeable to the patient.

tention of the ordinary medical attendant to those symptoms which appear to show the necessity of operative treatment.

2. When the glaucomatous process has once set in, the results are in general the more favorable and permanent, the earlier the operation is performed. In the very acute cases which immediately annihilate vision, iridectomy must, if possible, be performed during the first few days of the disease. Early performance is of the utmost importance, and since the transport of the patient at this time, even when external means are at hand, is very difficult, it is desirable that every practitioner, especially in the country, and in small towns, where opththalmology is not practised as a specialty, should make himself conversant with the symptomatology of acute glaucoma on the one hand, and with the method of performing iridectomy on the other. I think that the latter is still easier than the former, and even good assistance is less requisite in iridectomy than in many surgical operations, *e. g.* tracheotomy, which every practitioner must perform under the most unfavorable conditions when the indications are urgent. Iridectomy thus differs from other ophthalmic operations, the performance of which has remained in the hands of a relatively small number of practitioners, owing to the indications being so rarely urgent. As science advances, so also must the demands made of practitioners necessarily be correspondingly changed. A glaucomatous eye might formerly be considered incurable from the moment when the diagnosis was settled, and provided only that such injurious influences as were known to hasten the process were averted, it was comparatively unimportant whether this or that medical treatment were decided on somewhat earlier or later. A physician had never to reproach himself for such advances of the disease. Unless we are much mistaken, matters have now changed, and an eye which has become blind from acute glaucoma will excite the suspicion of neglect, just as much as closure of the pupil after simple iritis, a badly cured fracture, &c. I am obliged expressly to note this, for—

3. It has appeared that iridectomy is not, perhaps, a fitting treatment for all stages, but that its effects at a later period, at all events in particular cases, are uncertain, or do not ensue. It is painful to see how many of the incurably blind make distant journeys with the idea of their disease being still curable, although the time for assistance has long passed. To spare our medical brethren and ourselves much fruitless regret, we may urge that all glaucomatous

cases which have long been perfectly blind, should, if possible, receive advice at home, and that only moderate hopes should be given to the long diseased, who have but little sight and a narrow field of vision.

However much I have attempted, during the past year, the determination of the facts relating to the cure of glaucoma, I am quite aware of the incompleteness of the results, even in a purely empirical point of view. The number of trials cannot be too great, the effects cannot be followed for too long a period, the observation itself cannot be too exact and conscientious; the further I advance in my investigations the more I am convinced how much remains to be done, and how insufficient is the experience of one man. The theory of the treatment is as yet infinitely darker than the empirical facts. The idea of diminishing the intra-ocular pressure led me to adopt it. In this way, and in following out these views, a result seems to have been obtained, but at the same time no positive proof is afforded of the correctness of the explanation. The action of iridectomy may perhaps be highly compound. Diminution of the secreting (iris) surface certainly accounts for a lessening in the quantity of fluid, yet there is no experimental proof as to how much less aqueous humour is secreted, and whether this deficiency in its amount can explain a striking change of the intra-ocular pressure. The muscular co-operation of the iris with the tensor choroideæ, to the study of which I have been principally led by the new theory of accommodation, would in some degree explain how the excision of a piece of the iris might produce diminution of intra-ocular pressure by means of the muscles, by a relaxation of the tensor choroideæ. The continuance of accommodation in coloboma does not indeed favour this view; the conditions, however, are here essentially different. Perhaps the interference with the iris acts at first entirely on the choroidal circulation, and the therapeutical diminution of pressure is only secondary. That iridectomy in glaucoma has a powerful influence on the ocular circulation is at once shown by the occurrence of ecchymoses. Were the analysis of all these points more advanced, and a more correct explanation given, perhaps the treatment itself would be still better directed and adapted to the cases; it is very conceivable that, in certain cases, excision in the ordinary way is not sufficient, but that success may be obtained by the removal of larger pieces of the iris. I have already (*sub* IX) communicated my experience, that the excised piece of iris should be larger in proportion as the case is worse.

To conclude, the whole subject of glaucoma is open to the most various investigations. After the great change produced by the first ophthalmoscopic examinations in the views about glaucoma, I considered the necessity for analysis indisputable. The difficulties which I found will indeed have become known to any unprejudiced reader of these pages. I hope that I may have assisted somewhat in solving the question, and that some one with greater powers will soon bring the difficult task to a more happy conclusion.

# ADDITIONAL CLINICAL REMARKS

ON

# GLAUCOMA, GLAUCOMATOUS DISEASES

AND THEIR

# TREATMENT BY IRIDECTOMY.

By Dr. A. v. GRAEFE.[1]

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Another year has passed since I wrote my essay on Iridectomy in Glaucoma for the third volume of the 'Archiv.' I have had many fresh cases, and I have operated on them at most different periods of the disease. So far as was possible I have kept in view all the cases on which I had previously operated, for although the immediate improvement was clear enough, there was yet the possibility of its not being permanent. To my own observations have also been added those of many of my colleagues. And now, when I have again to consider critically the question of treatment, I can at once and with pleasure declare, that I have not the least to retract of what I formerly advanced in favour of iridectomy. Some of the cases, indeed, have ultimately been more favorable than I had expected. For the sake of more ready comprehension, I shall append these remarks to the groups of diseases and reports of cases in the same order as they appeared in the previous memoir.

I.—I cannot too strongly recommend the operation in the pre-

[1] From the 'Arch. für Ophthalm.,' B. iv, Abth. 2, S. 127, Berlin, 1858.

monitory stage, when the other eye has become blind from the same affection. Wilhelm Höffler (Case 1), the example given of this group in my previous treatise, continues to visit my clinic at long intervals; the sight of the left eye, which was operated on in the premonitory stage, is perfectly good; with it he reads No. 1 of Jäger's specimens of print, though with a little difficulty, No. 2 fluently; the extent of the field of vision is normal, and the excentric vision is in every direction satisfactory. The range of accommodation is very good. Careless of his eyes, he is occupied as a man-milliner, and since the operation has not perceived the least symptom of disease. I have had occasion to operate from ten to twelve times in this stage, after glaucoma had already caused blindness in the other eye; constantly with the same good result as in Höffler. Iridectomy is obviously most successful during this period; for the ultimate result is still more perfect, than when it is performed in the inflammatory stage, soon after the disease has broken out. Mobility of the pupil and a good range of accommodation have been recovered, and no retinal ecchymoses have been formed.

The occurrence of these ecchymoses is probably dependent on the distension of the retinal veins and capillaries; and this, again, is caused by the escape of the venous blood being impeded, when the intra-ocular pressure has rapidly augmented. This hyperæmia may be clearly shown by the ophthalmoscope in the venous trunks; as, occurring in the capillaries, it has been especially referred to in the microscopical reports of Bader ('Ophthalmic Hospital Reports,' No. 2, pp. 74—87). The so-called hæmorrhages *ex vacuo* may be readily imagined to occur, when the pressure is suddenly diminished by the performance of iridectomy, whilst the vessels are in such a condition.

Now though experience proves that such ecchymoses often retrograde, and that vision is perfectly restored, yet, on the other hand, I have met with cases of indistinct excentric or peripheral vision when they were very extensive. This, indeed, makes no essential difference in the recovery, and yet they always indicate permanent structural changes in the affected portions of the internal layers of the retina.

In all the cases on which I operated during the *first stage of acute glaucoma*, the improvement has remained fully at the extent described, although most of these patients have pursued their previous employments. A review of my list of cases showed most distinctly, that the ultimate acuteness of vision very much depended on the period at which the operation was performed. The most decisive cases were those where the same individual had both eyes affected by similar symptoms and antecedents, and where the operation was performed on both sides, but at different periods, dating from the commencement of the attack. Thus, in two cases, where one eye was operated on the first or second day after the beginning of inflammation, and the other from the fourth to the seventh day, there was a notable difference in the two eyes a year after the operation. The one, on which the operation had been earliest performed, read No. 1, and the excentric vision was normal; the other, operated on at a later period, read from No. 3 to No. 5; and the circle of tolerably distinct excentrical vision was diminished from a third to one half in diameter. The cases in my previous essay, in which both eyes were operated upon (Maass, Case 4, and Felden, Case 5), cannot be adduced as proofs; for although they favour this view, yet there was an original difference in the power of the two eyes, forbidding the drawing of any conclusion. The accommodation generally remained defective, especially when there were great and permanent changes in the iris.

I can now support my former statement, that typical glaucoma of one eye has no sympathetic influence on the other, at least—not in a practical sense—by many additional cases, where, after perfect recovery of one eye from the glaucomatous process, the other and previously healthy one has yet become diseased, and required the use of iridectomy, and by other cases, where the disease was cured in one eye, and yet the other, which had been previously suffering from chronic glaucoma, was attacked by acute glaucomatous inflammation. Of the latter class was the case of Frau v. Böttcher (Case 7), which I mentioned in my previous essay. This patient had lost the sight of one eye from chronic glaucoma, and had a cataract in the other; the latter eye was attacked by acute glaucoma, and cured by iridectomy; vision was again restored by afterwards extracting the cataract. Nine months later, long after her return home, the blind eye was attacked by acute glaucomatous inflammation. Owing to the distance at which she resided, iridectomy was long delayed, and, according to accounts received from the surgeon in attendance, the eye which had been operated on, and which had recovered its power of vision, appeared to be sympathetically affected. Further observation, however, showed, that this only referred to the external parts (lachrymation—conjunctival irritation); and an examination after the termination of the inflammation showed no change whatever of the power of vision.

The cases on which I operated during the *more advanced stage of acute glaucoma* ultimately terminated very variously—a fact which has been pointed out in my former essay. I have, however, never seen perfect blindness ensue, provided the operation was performed before the visual field had become notably contracted. Even in the case of Madame Sack, of Vienna, which I then quoted as a recurrence, vision seems to have arrived at a stationary condition. (According to a medical report lately received, she recognises fingers at fifteen feet distance, with + 15 can read print No. 16, and the field of vision, measured at the distance of a foot, has a vertical diameter a foot long and a transverse of eleven inches.) Whenever the field of vision is much contracted, a cautious prognosis must be given as to the permanency of the cure; and, indeed, according to the other symptoms, it must be considered more or less unfavorable. It is always much worse when the visual field is so contracted as to resemble a slit, and especially if the point of fixation is already close to the margin. Notwithstanding that temporary improvements and intermissions of considerable duration often occur, I have found that in the mass of such cases vision gradually deteriorates again; that the termination is sometimes perfect blindness, and often loss of central vision; in the latter case, the sight is, of course, very indifferent, owing to the fixation being excentric. As an example, I will again quote the case of W. Höffler. In this case, the left eye was operated on during the premonitory stage, and its vision has remained perfectly good. The right eye was operated on at a more advanced period, the field of vision having already contracted so as to resemble a slit. Now, after the lapse of a year and a quarter, he sees with this eye, at all events, infinitely better than before the operation; he counts fingers correctly from eight to ten feet distance (previous to the operation, only at a foot distance, and inaccurately); the point of fixation has, however, again become excentric, and the field of vision has contracted towards it; hence he can only make out words of the largest print. The field of vision has diminished about one fourth, and hence is only three times as large as before the operation. The eye has remained in this state for from four to six months; so that I rather doubt its ever becoming quite blind. Even when the visual field is already much contracted, if the point of fixation be near its centre, the prognosis is relatively favorable. I have now watched for a year and a half the course of some cases of this kind, and they have not in the least deteriorated. The second example of this group, Case 8, given in the previous treatise, in which the visual field and optic nerve were still normal, continues as much improved as ever.

To determine the probability of improvement, not only the state of vision and of the optic nerve, but also any existing symptoms of pressure or opacities of the refractive media, must be specially considered. In proportion as the deterioration of vision is caused by the latter, the greater improvement may be expected; inversely, the more the loss of sight depends on changes in the optic nerve and retina, the less improvement can we expect. In the later stage of acute glaucoma the operation is still indicated, so long as there is any qualitative perception of light. I met with the first perfectly negative results of iridectomy five weeks after the commencement of glaucoma; for eight days, however, all quantitative perception of light had been lost.

From a longer observation of cases operated on during this later period, I have generally found the excavation become gradually a little flatter. The retinal veins, which were at first gorged with blood, then became smaller than normal; at the same time, they sometimes retained a more tortuous course. The papilla became whiter, and its substance more opaque, although it never acquired the tendinous white appearance of cerebral amaurosis, but rather a dull waxy appearance. Of course, these changes have no connexion with those originally caused by glaucomatous pressure; they are symptoms of progressive secondary atrophy of the optic nerve. In general, I may repeat my former statement, that ulterior deterioration of vision does not arise from recurrence of the glaucomatous process, but from progressive atrophy of the optic nerve, and that this appears inevitable, when the affection of the nerve has once attained a certain extent.

The uncertainty of the result in the later stages of glaucoma, especially as regards duration, are so directly opposed to its completeness and durability in the acute period, that the advice, *to operate immediately and without hesitation*, cannot be too urgent. I must most decidedly reject the recommendation to try first paracentesis—advice which has been urged from unfounded ideas of caution. Three years' extensive experience has taught me, that the results of paracentesis are, in the infinite majority of cases, temporary only. It is true that, when methodically employed, it removes the acute character of the disease, and palliates the symptoms; it does not, however, prevent gradual deterioration of vision. Within from three to four months, this was almost invariably found to be the case, on a careful examination of the field of vision. When with these results we compare those of iridectomy, there can be no reasonable cause for hesitation. By such trials of paracentesis, the time is lost for radical treatment; for the degree of recovery essentially depends on the length of time the eye has been already affected, and not simply on the condition of the symptoms. Besides, we may reasonably fear that the repeated disturbances of the ocular circulation—and every change of pressure must be considered as such—may render the case less amenable to a treatment, the value of which has been actually proved. My clinic presents a considerable number of cases where one eye has been treated by paracentesis in former years, the other by iridectomy. In other cases, where the treatment had commenced with paracentesis, iridectomy was ultimately performed on the same eye, owing to the deterioration of vision, and to our having become acquainted with its beneficial action. Only a glance at the fate of these different eyes is needed, *to induce the abandonment of all other treatment in Glaucoma than that of the immediate performance of Iridectomy.*

As to this treatment in *chronic glaucoma,* I have nothing particular to add to my former remarks. It is indicated, so long as any considerable amount of vision remains, though in many cases negative results, and in others only temporary ones, will be obtained. On reviewing my notes of cases (in which the accounts as to vision have been continued to as recent a period as possible, by means of reports from the physician or patient, when I could not myself observe them), I find a series of relatively favorable cases.[1]

[1] One of my oldest observations on iridectomy in chronic glaucoma was in a Berlin saddler (Tackmann), 68 years old, on whom I operated in 1853. As at that time I was entirely ignorant of the treatment of glaucoma by iridectomy, I was guided by other indications. Subacute glaucoma had rendered the patient's left eye perfectly blind some years previously; the right was suffering under chronic glaucoma with great contraction of the field of vision, excentric fixation, and so little sight, that he had some difficulty in counting fingers. After he had been for a length of time in this condition under my care, iritis supervened; and although tolerable dilatation had been caused by the glaucomatous affection, the pupillary margin formed extensive adhesions with the capsule. Treatment by antiphlogistics, so far as the infirm condition of the patient would allow, and by mydriatics, having failed, and ciliary neurosis being very

Some of them ended in perfect blindness, with symptoms of progressive atrophy of the optic nerve; and in others, after some improvement caused by the operation, vision deteriorated to a certain point, at which it again became perfectly stationary. For example, the left eye of Madame Hoffmann (Case 10), belongs to the last group. In her, as already mentioned, there was a notable change for the worse three months after the operation, from that to the present time exactly the same state; the ophthalmoscope shows a moderately white optic papilla and contracted vessels. (The improvement in vision caused by the operation has not deteriorated in Cases 11 and 13, so far as the medical reports reach. The vision in Case 12, Carl Wagner, is constantly diminishing.) I have observed some cases of chronic glaucoma in which the vision, as improved by the operation, has remained unchanged, even though fixation has been very excentric. I have nothing fresh to add as to the points on which the prognosis more particularly depends; indeed I much fear that it will remain to a pretty considerable extent uncertain, for the point on which the decision specially depends, the condition of the optic nerve (and of the retina), cannot in all probability be accurately determined after it has once undergone organic change.

II.—To the theory, I believe I am now in a condition to make a very important addition, to the effect that in proper cases the papilla of the optic nerve may be shown to become shallower soon after the operation, or, in other words, that the excavation becomes diminished. As was mentioned in my former work, I had at that time failed in showing such a change, notwithstanding my utmost efforts. Fully to demonstrate it, we must select one particular group of cases, that where acute symptoms have supervened on

troublesome, I punctured the eye, and ultimately performed iridectomy. Besides the removal of the inflammatory symptoms, I was struck by the improvement in vision, and this could not be accounted for by the cure of the inflammation, for he saw considerably better than previously to its occurrence; he now recognised fingers at a distance of two to three feet. At the present moment, after a lapse of five years, the vision remains exactly the same; left to himself he moves about with difficulty; the field of vision, compared with that recorded in my notes, has, if anything, increased. Instead of calling it, as formerly, "chronic glaucoma operated on for secondary iritis," I should now simply say, "acute supervening on chronic glaucoma, and hence treated by iridectomy."

previous chronic glaucoma. We cannot employ very recent cases of acute glaucoma, for in them the excavation is not yet formed. It is gradually developed in the later stages of acute glaucoma, and is accompanied by displacement and atrophy of the bundles of fibres, as described by H. Müller; it is obvious, from the material changes, that such a nerve can never again return to its normal form, even when the mechanical causes of the alteration have been removed. The adhesion of the displaced retinal vessels to the sides of the cavity would oppose any such retrograde process. An excavation of the optic nerve arises, or an inconsiderable cavity becomes a large one, most rapidly, when the so-called glaucomatous choroiditis suddenly attacks an eye, which has been for some time suffering under chronic glaucoma attended by deterioration of vision and increase of pressure to a moderate extent. In such a case the papilla presents much less resistance, owing to the previous chronic disease, and hence yields more rapidly and to a greater extent to the increased pressure. If the operation is performed during this period, some days after the occurrence of an acute attack, or some weeks after the first subacute symptoms (dilatation of the pupil and diffuse opacity of the refractive media), we may most distinctly perceive the retrogression of the papilla. In this way I saw deep cavities change within a week into flat, basin-like depressions, the ends of vessels which had been much displaced at the edge of the cavity meet at an obtuse angle, and slight bends in them become perfectly straight. For the attainment of perfect certainty, the appearance of the papilla and the vessels should be carefully sketched before the operation, and this drawing should be afterwards used occasionally for the sake of comparison.

The fact that the papilla becomes flatter immediately after iridectomy seems to me of great importance, for it most decidedly proves that the excavation of the optic nerve depends on an increase of pressure. There can be no other connexion than this between the excision of a piece of iris and the form of the papilla. It is very satisfactory to find our theory so confirmed by the diminution of the excavation coinciding with that of the other symptoms of pressure; the absence of this proof in former days had always caused a feeling of uncertainty ('Comp. Arch. für Ophthal.,' Bd. iii, 2, p. 529). It is clear that we cannot at all times and in all cases expect the papilla to re-approach its normal state any more than, when the changes in the ciliary nerves from pressure have once exceeded a certain degree, we can expect recovery from the corneal anæsthesia and paralysis of the iris.

Another proof of my theory is the condition of increased refraction, which may be readily perceived in some cases after the operation. Decisive cases are, however, very rare, for it is difficult to obtain optometrical results previous to the operation, owing to the state of vision. Yet I have many times observed that a difference in this respect, which had previously existed between the glaucomatous and the healthy eye, could no longer be perceived after the performance of iridectomy. I shall not attempt any statistics, only mentioning that two cases, on which I operated during last session, saw with a convex glass (+ 6) large print many inches further off before the operation than after, although the vision had been rendered very much better by the treatment. This can only be explained by such an approximation of the point of distant vision. It is very probable that the presbyopia, which occurs even in the premonitory stage, and which often rapidly increases during the course of the affection, is caused by flattening of the cornea; and that its diminution proceeds from an increased curvature of the same part. Dr. Liebreich has found, on measuring some of my glaucomatous cases with the ophthalmometer of Helmholtz, that they favour this view. These experiments will be published so soon as a sufficient number of decisive cases has been collected.

Finally, I believe that my view has found a firm support in the recent pathologico-anatomical examinations of excavated optic nerves, and especially through the researches of H. Müller (see his essay on this subject). The formation of ectasiæ in the equatorial regions of the bulb in the later stages of the disease is so entirely analogous to excavation of the optic nerve, that any unprejudiced person must perceive that they are both caused by increase of the intra-ocular pressure. I have found from the examination of some extirpated eyes, that it is at this period that the excavation is especially liable to become increased.

Dr. Bäder ('Ophth. Hosp. Reports,' No. 2, p. 74-88) describes, in three cases, which from their symptoms must be considered as decidedly glaucomatous, a peculiar degeneration of the retina, and he seems to infer that it is this retinal degeneration that forms the origin of the disease. The essay is a very excellent one, and no objection can be made to the facts adduced; as to the pathogenesis of the disease, however, its clinical history is, in my opinion, more favorable to the view that the degeneration (atrophy or transformation of the inner layers of the retina into a gray, amorpho-granular substance) is entirely a secondary change, and, in fact, dependent on excavation of the optic nerve. Atrophy of the fibres, which are displaced in the excavation, must have a similar effect on the retina to that caused by division of the optic nerve. The great distension of the retinal capillaries (Bäder) is also, in my opinion, caused by the escape of the venous blood being impeded through the increased pressure. Thus may be explained the occurrence of retinal ecchymoses, when the pressure is diminished (see above). It seems to me improbable that the destruction of the inner retinal layers could be induced by the pressure of the distended capillaries. I think that my opinion is favoured by the fact, that the organic changes cease at the lamina cribrosa, exactly where the intra-ocular pressure can no longer act.

Admitting that increased pressure is sufficient to account for the whole of the symptoms presented by the optic nerve and retina, we meet again with the question, from whence does this pressure proceed? Notwithstanding the apparently negative results furnished by examination of the choroid and ciliary body, I adhere to my former view (l. c., p. 477-481), that they are the source of a hyper-secretion of fluid. Hence it is by no means necessary that marked organic changes should occur. We must not forget that the pigment-cells become rounded (Bäder), and that in some cases there is an increased growth of stroma-cells. In cases of iritis serosa, where the iris was undoubtedly the source of the affection, there was often nothing more found in pieces of the iris which had been excised (Junge). Finally, it deserves consideration, that acute glaucoma may occur when the retina is almost entirely destroyed. I have seen some cases where, after the continuance of chronic glaucoma for many years, the retinal vessels had become extremely contracted, the papilla whitish and excavated, perception of light long and entirely lost, and yet acute glaucoma in its typical form, and with enormous increase of intra-ocular pressure, supervened. After the inflammation had terminated, I found the trunks of the retinal veins distended in comparison with their former state, but yet far from equal to their normal condition, the arteries hardly perceptible. I have seen one case, where glaucoma occurred in an eye which had been long blind from cerebral amaurosis, and where the retina was much atrophied. Everything seems to me to militate for the view that the retina is originally passive in these inflammatory attacks, that the veins are distended owing to the escape of their blood being impeded, &c.

III.—I still hold the opinion promulgated in my former essay, that the affection of the optic nerve is by itself insufficient to characterise glaucoma. It seems to me that the following points require consideration.

1. There are some cases in which the form of the papilla is perfectly identical with that of glaucoma, and yet the symptoms and course of the disease are extremely different, so that it is necessary to separate them nosologically, and will continue to be so, unless future investigations should possibly show them to be more nearly allied. The formation of a nosological class, which I have named "amaurosis with excavation of the optic nerve," is the actual result of this necessity.

2. Should we be determined to make the diagnosis depend on the existence of excavation of the optic nerve, we should be unable to recognise the disease at the time when treatment has the most beneficial effect, it being admitted that there is no excavation in the early stage of glaucoma, but that it is only formed during the course of the disease. It may not be possible to examine the back of the eye, owing to accidental or consecutive diseases, such as iritis with opacity of the pupil, cataract, cloudiness of the vitreous body, &c.: in these cases we require some other point on which our decision may rest, and yet we have no occasion to give up the hope of diagnosing the case.

3. I consider the only characteristic to be the complex group of pressure-symptoms, of which I gave an analysis in my former essay. If our delineations of disease are to serve any practical purpose, we cannot admit excavation of the optic nerve, nor any other single symptom of pressure, paralysis of the iris, insensibility of the cornea, &c., as pathognomonic; on the contrary, these symptoms must occur sufficiently in combination. It is true that in certain cases we may fail in discovering any particular symptom, and that, in other cases, the perfect development of all the symptoms may be of more value in showing their mutual connexion than in determining the diagnosis. Thus, if the pupil is dilated, the iris atrophied, the cornea insensible, the bulb hard, and cataract formed, we conclude there is also glaucomatous excavation of the optic

nerve, although we are unable to prove it by means of the ophthalmoscope. The usual symptoms of a paralysed iris cannot occur when from old iritis the pupil is contracted, and adhesions have been formed with the capsule; yet this will not prevent us from considering the disease to be glaucomatous, if the rest of the symptoms are present.

4. Our present conception of glaucomatous disease, however, extends beyond the limits of the type of what used to be so designated. The expansion of our ideas of a disease is justifiable, in my opinion, when it springs from a careful consideration of nature, and is not opposed to practical agreement. Should the latter be feared, the name of typical glaucoma, or of glaucomatous choroiditis, may be retained for the well-known group of symptoms; all the affections which resemble that form of disease, by being accompanied by increased pressure and reaction on the optic nerve, yet which have a different origin, may be denominated, with the addition of the more special name, diseases with a glaucomatous habitus, glaucomatous tendency, glaucomatous termination, or, in short, "glaucomatous diseases." I do not hesitate, even at the danger of appearing to many indefinite, to speak of an iritis, as being "irido-choroiditis of glaucomatous character"—to add to the designation of a traumatic cataract, "with a tendency to glaucomatous blindness, &c." I do not hesitate at this, because I consider a pathogenetic method of view of greater importance, and more pregnant in results, than a diagnostic dogmatism. Transitional forms and intermediate links occur, just as in every other part of a pathology that is true to nature; this should not prevent us from clearly conceiving the type of disease, and from raising ourselves from this fixed point of view to a conception true to nature, and yet as simple as possible. I shall now proceed to explain these views more exactly, as to the relation of glaucoma to other morbid processes, and the passage of other affections into glaucoma.

IV.—If the essence of glaucomatous disease depend on an increase in the intra-ocular pressure, we may expect that not only internal but also external causes may excite it, and that we may be able experimentally to educe and to cure it. Such is really the case. The reader may imagine that I refer to experiments on animals; to these, however, it is unnecessary to have recourse. Experiments enough have been already made on man by many an operator, unconsciously and to his sorrow. These are related in the history of *cataract-operations*, especially those by discision, and in the whole subject of *traumatic cataract*. Experience has definitely settled that blindness may be induced during the process of absorption, when accompanied by excessive imbibition of the lens; there are, however, many different ways in which this may occur. Sometimes the swollen lens, by its contact with the iris and the ends of the ciliary processes, excites iritis or irido-cyclitis, with plastic or purulent exudation. The eye may be perfectly destroyed by this process, exudative membranes behind the iris may completely prevent the passage of light, effusions into the vitreous body may, by their contraction, separate the retina from the choroid—all this happens in a series of cases, where blindness is caused by the progress of an inflammatory affection, with permanent structural changes of the internal membranes. And now we meet with another termination, which has not been sufficiently noticed, though of frequent occurrence, and which we have every reason for calling traumatic glaucoma. During the swelling of the lens the globe becomes very hard, any corneal cicatrices from wounds or other causes become prominent, the cornea even insensible, the anterior chamber flatter, the iris discoloured, not, however, by inflammatory hyperæmia, but by assuming a dirty sallow appearance, and we notice a tendency to dilatation of the pupil, especially in places where there are no posterior synechiæ, so that no one conversant with the subject can fail to recognise a certain degree of paralysis of the iris. If an examination of the field of vision is not prevented by the dissipation of the light, it is found to be already laterally contracted, whilst the central vision is still, perhaps, satisfactory. If the light is dissipated to a greater extent, though not completely, by the swollen lens, we should always suspect contraction of the visual field, or at any rate indistinctness of excentric vision, when a light moved here and there before the eye is not exactly fixed, and its direction is discovered slowly or not at all. If, under these circumstances, we do not interfere, the result will usually be, when the lens is completely absorbed, that the pupil is faultless, and yet there is little or no sight. The symptoms of irritation which previously existed to a greater or less extent retrograde, and the original condition is only betrayed by a certain discoloration and paralysis of the iris, results which are often only slightly developed. It is usually supposed that this blindness is caused by the protracted choroidal irritation or choroiditis, effusions into the interior of the eye, separations of the retina, and so on. The ophthalmoscope, however, shows no trace of such affections in these cases. On the other hand, it does show excavation of the optic nerve. The process has been this: from the irritation caused by the swollen lens a state of internal congestion was caused, hyper-secretion of fluid into the vitreous body, increase of the intra-ocular pressure, which has continued for some time, and which has caused excavation by its action on the surface of the papilla of the optic nerve. If, at a certain stage of these phenomena, we employ linear extraction when the swollen lens is sufficiently softened, or iridectomy in the opposite case, we find that the threatening symptoms recede just as in the acute period of glaucoma; if, however, they have existed for some time, and attained to a moderate degree, there often remain contraction of the visual field and a certain amount of change in the optic nerve, as in the later stages of glaucoma. I have seen every stage of this process in cases of cataract, to a slight extent in those of discision, to a greater in the traumatic, and hence have deduced my views of treatment for such cases. I perform iridectomy for exactly the same reasons as in glaucoma, and cautiously avoid interfering with the swollen lens when I am not certain that I can entirely remove it, or at all events its nuclear portion. When the lens is so swollen as to educe such symptoms, it is generally in young persons so soft as to allow its escape by a linear incision. In adult or advanced life, however, the case is different; the cortex may be so much softened as to cause danger at a time when the nucleus is yet hard. The proper treatment of the former is linear incision, of the latter iridectomy. In some cases it is advisable to combine the two. The same symptoms may occur after the operation for reclination. Cases of blindness after this operation depend only to a certain extent on permanent organic changes caused by inflammation, separation of the retina, &c. In a large number of cases the eye assumes a glaucomatous habitus by exactly the same process, that we have just described. Functional examination shows contraction of the field of vision, and ultimately there is only excentrical vision; the ophthalmoscope shows the characteristic alteration in the optic nerve. Needle-operators were well acquainted with this when they said in their way, "Gout has supervened, gouty ophthalmia has been developed," &c. It is not unfrequent for blindness to ensue after reclination with extreme slowness, and this form is also very often caused by hyper-secretion of the vitreous fluid, and increase of the intra-ocular pressure being excited by the irritation of the depressed lens. The result is an amaurosis, with contraction of the field of vision, similar to that occurring in the very chronic cases of glaucoma, which are attended by few external symptoms.

The inflammations which are caused by the passage of a foreign body into the interior of the eye, of course, present very various appearances. In these cases, however, we meet with forms which induce blindness in the same way as glaucoma. The symptoms of increased pressure are characteristic, and it is by its reaction on the optic nerve, and not by organic changes in the inner membranes, that vision is destroyed. It may be readily conceived how a foreign body may induce, by its presence, hyper-secretion of fluids, and yet not cause any diffuse inflammation.

Let us now glance at the cases of blindness after iritis. The fact has been sufficiently pointed out by myself and others, that cases of iritis, which have terminated in exclusion of the pupil, are followed, sooner or later, by constantly progressive amblyopia. On this rests, to a great extent, the necessity of iridectomy in such cases. I have, however, somewhat modified my views as to the explanation of these amblyopiæ since the time when I wrote my former essay on this subject. Even at that time I believed that the amount of pressure in the posterior portion of the globe was changed through the exclusion of the pupil; I believed, however, that these changes in the pressure reacted on the choroidal circulation, excited effusions into the vitreous body, separations of the retina, &c., and that the blindness was specially caused by the latter changes. This course of the phenomena very possibly occurs in a large number of cases; but that it is not the only one, and perhaps not even the most common, I conclude from my more recent observations. Two years ago, the case of an old woman engaged my attention, where the edge of the iris adhered to the capsule, and yet the pupil was sufficiently clear to allow a minute ophthalmoscopical examination of the background. She became amblyopic whilst under my care; the visual field contracted laterally, and ultimately fixation became excentric. The globe, indeed, became decidedly hard, and the ophthalmoscope showed a moderate degree of excavation of the optic nerve; yet, owing to the refractive media remaining transparent, I could not clearly perceive how these phenomena were connected, and hence I supposed some accidental complication of the effects of an iritis, and an amaurosis with excavation of the optic nerve. Soon after that case, a man, aged forty, came under my care, who had one eye blind from irido-choroiditis and equatorial ectasiæ, and the other affected with chronic iritis. An examination of the latter showed perfect exclusion of the pupil; the iris was already pushed forwards at various places by fluid exudation, which lay behind it; there were some pigmented deposits towards the edge of the pupil, and yet the greater part of it was sufficiently free to allow the use of the ophthalmoscope. For some weeks the acuteness of vision had been rapidly diminishing, without the occurrence of any fresh inflammation, so that now he could only decipher words of No. 20; excentric vision was somewhat contracted in every direction, and the inner third of the visual field entirely wanting. The globe was very hard, and the ophthalmoscope distinctly showed an excavation of the optic nerve in process of formation; the vitreous humour was not clouded. The amblyopia clearly depended on the lesion of the optic nerve. From this case I at once perceived that it was very probable that the amblyopiæ following exclusion of the pupil are not unfrequently produced in this way, the contraction of the visual field not directly depending on destruction or separation of the retina, but on the disease of the optic nerve. Since that time I have observed a number of cases, and latterly examined some extirpated eyes, that seem to prove that such is the fact. I do not consider that the collection of serous exudation behind the iris is a direct explanation of the increased pressure, though it must assist in producing it; clinical facts render it probable that there must also always be hyper-secretion of vitreous fluid, and that this is the chief cause of the increased pressure. The resistance presented by the sclerotic must certainly play an important part in these processes; its firm resistance must favour the occurrence of increased pressure, and its ready yielding render it more difficult. This is the reason why we find these secondary affections follow iritis with pupillary exclusion far more rapidly in the old than in the young—a fact which is equally true in respect to the cases already mentioned of discision and traumatic cataract. The eyes which have been extremely tense for a time, generally become atrophied at a later period, and, since this is a permanent stage, are most often presented to our notice in this condition; this circumstance renders it difficult to prove, that the amblyopia secondary to iritis is often caused by an affection of the optic nerve. The atrophy is certainly caused in these cases by secondary organic changes, progressive atrophy of the choroid, &c. Hence the explanation of how iridectomy acts in cases of exclusion of the pupil requires change in various respects. The restored communication between the two chambers is, indeed, the immediate effect and cause of benefit; in the cases, however, to which we are now referring, secondary choroiditis is not directly allayed, but, as in glaucoma, the pressure is diminished, and the optic nerve (and retina) preserved from danger.

Our utmost attention is demanded by the transition of *sclerotico-choroiditis posterior* into a glaucomatous form of disease. Vision is generally not much affected in this disease, so long as secondary affections, such as opacity of the vitreous body, separation of the retina, cataract, &c., are absent, or so long as the choroidal changes do not extend to the region of the macula lutea. My attention has been lately, however, directed to another perfectly distinct and less frequent course. I found that lateral contraction of the field of vision and progressive deterioration of the sight occurred in old persons, who had been affected by *sclerectasia posterior* for an indefinite period. On further observation, I found that excavation of the optic nerve, and other symptoms of increased pressure, were developed in such cases. The excavation of the optic nerve is never so strikingly and clearly marked in these cases as where there is no posterior staphyloma. This may be readily explained by the state of the parts; for the sclerotic around the optic nerve is diseased, and hence its power of resistance approximating to that of the entrance of the optic nerve far more than in the normal eye, there cannot be formed by pressure a deep cavity in the papilla, but only a shallow depression, with a little displacement of the vessels at its margin. The principal difference of this depression from a normal, but rather strongly marked concavity of the papilla (Heinr. Müller) is, that it reaches to the periphery of the nerve, whilst the natural one only occupies the more central portion, near where the vessels emerge. The appearances presented by such an optic nerve are very readily noticed, provided our attention has once been called to the subject. In ordinary cases of *sclerectasia posterior*, the margin of the optic nerve is indistinct; no difference appears between the space occupied by the papilla and the adjacent sclerotic, so that often we are only able to distinguish them by supplying a continuation to the margin of the optic nerve, which still remains at the inner side, by the appearance of the vessels, or by recognising over the sclerotic the choroidal tissue in process of atrophy. In the cases just mentioned, however, the disc of the optic nerve again becomes distinct in the centre or at the side of the white figure. This is what first excites suspicion; a more careful examination shows that the papilla is superficially excavated. As already mentioned, no considerable change in the vessels can be expected, but only a little displacement; and for the same reason, the appearance of the papilla, which is characteristic of excavation of the optic nerve, exists here only to a moderate extent. The occurrence of a distinct excavation of the whole papilla in posterior staphyloma seems to me of the more pathological importance, because the normal flattening or depression of the papilla around the vessels, whenever it has previously existed, disappears more or less during the expansion of the posterior portion of the globe—a fact which I have often observed on comparing an eye accidentally affected by *sclerectasia posterior* with the other and healthy one. It is probable that this is directly caused by thinning of the adjacent choroid. During the formation of the excavation in *sclerectasia posterior*, the globe, which had been previously soft, becomes tense, the pupil generally becomes a little dilated and rather sluggish, though not perfectly motionless; the cornea also a little less sensitive. The visual field is sometimes concentrically contracted, sometimes laterally, and we occasionally see the disease end in almost total blindness. Any practitioner may succeed in soon finding for himself examples of this course. The cases in which it should be looked for are those of *sclerotico-choroiditis posterior*, in persons who are more than fifty years old, with far-advanced amblyopia, but without disease of the vitreous body, separation of the retina, cataract, or perhaps even central scotoma, which is caused by the macula lutea becoming affected. It was interesting to me to review my notes of cases taken previously to my becoming aware of this fact. I found many entries of this diagnosis: "stationary *sclerotico-choroiditis posterior*, with excessive loss of vision and lateral contraction of the visual field." The form of superficial excavation of the optic nerve had at that time escaped me. Since this course occurs almost exclusively in the old, and since there are no progressive choroidal changes connected with it, I consider it most probable that it is owing to senile changes in the sclerotic. It is clear that an increase of the intra-ocular pressure, with reaction on the optic nerve, may be induced, if the sclerotic commences to thicken and to lose its elasticity in a case of large staphyloma. What has been asserted of *sclerotico-choroiditis posterior* equally applies to the whole group of dropsies of the eye. Excavation of the optic nerve occurs also in *sclerotico-choroiditis anterior*, with *sclerectasia anterior,* in *cirsophthalmus*, &c., of a certain intensity; entire loss of vision is generally caused by it and by the secondary atrophy of the inner layers of the retina, even when the ectasiæ would otherwise be compatible with a tolerable activity of the retina. This view is favoured by the examination of extirpated eyes. When we examine the posterior section of a dropsical eye, where quantitative perception had been entirely lost, we generally find, on looking through the vitreous body, as well-marked excavation of the optic papilla as ever occurs in glaucoma. The increased pressure, and its reaction on the optic nerve, are of the utmost importance even in the earlier stages, and must be carefully considered in judging as to the condition.

Finally, we have to mention a tolerably extensive class of diseases which may assume glaucomatous symptoms, the class of *projecting corneal cicatrices.* Leucoma prominens, partial and total staphyloma, are, as is known, often connected with total amaurosis, or such a deterioration of vision as is out of proportion with the optical condition; hence, unless a very accurate examination has been made, the vision, after an operation for artificial pupil, does not improve so much as is expected; and there are found contraction of the field of vision, and even excentric fixation. This used to be attributed to the position, form, excentricity of the pupil—points which were often little or not at all concerned. Many observers (for example, Arlt) have carefully considered the question, what is the cause of weak sight or blindness in cases of prominent corneal cicatrices? Various authors, and especially the one just mentioned, have pointed out the change in pressure that occurs in the interior of the eye in these cases. In confirmation, I myself, by means of the ophthalmoscope, have arrived at the conclusion that this defective vision or blindness depends on excavation of the optic nerve caused by the pressure. I have been able to make out the excavated form of the optic nerve, both in cases left to nature, where pupils had been accidentally formed by rupture of the iris, and in those of iridectomy, so that now I have no hesitation in concluding as to its presence in projecting corneal cicatrices from the other symptoms presented by the eye, even when it is impossible to employ the ophthalmoscope. The increasing hardness of the globe, the iris pressed towards the cornea, its discoloration, the insensibility of the cornea, the congestion of the subconjunctival veins, are all most distinctly marked. Another symptom, very easy to understand, is the prominence of the corneal cicatrix, after it has already become thickened. So long as the texture filling up the cavity of an ulceration is thin and soft, it will readily yield to even normal pressure, and hence protrusion at such a time by no means justifies the conclusion that the pressure is increased. But when the new-formed tissue has become thickened, so as to afford the same or even greater resistance than the healthy cornea, we see the previous prominences approximate to the level of the adjacent parts, or even become depressed below them, provided the pressure remains at its normal amount. This is sufficiently apparent from the history of prolapsus iridis after corneal ulcers, operations for cataract, &c. When, however, the pressure is increased, the prominence does not diminish as it becomes thickened; on the contrary, the adjacent portion of the cornea, and even the sclerotic, gradually participate in the change of form. Various reasons may be assigned for the increased pressure: 1st, inflammation of the iris adherent to the cornea; this may be caused by the irritation spreading from the portion of iris which is lying in the corneal wound, or prolapsed through it, and which is invariably inflamed; it seems to be promoted by dragging of the iris, and especially by the existence of a closed pupil. It is well known that a puncture through the accidental tissue and the iris in projecting corneal cicatrices or staphylomata will often allow the escape of fluid exudation, and cure the inflammation for a time. A second and very common cause of increased pressure is a swollen, cataractous lens, irritating the iris and ends of the ciliary processes. This may excite a hyper-secretion of fluids. Every oculist knows that its removal is often the most important point in the treatment of true staphyloma; the prominence of even partial corneal cicatrices is often kept up in a similar way. Indeed, I believe that simple pressure forwards and oblique position of a perfectly transparent lens may have the same action, even though the capsule is unruptured and no cataract is formed. The following case may serve as an example:

A boy, æt. ten years, had a partial staphyloma of his left eye; the part that was especially prominent was situated towards the temple, and its diameter was about half that of the cornea; it was, however, clear that the curvature of the entire cornea had undergone much change; the pupil was displaced outwards, its inner margin to a slight extent free. I performed iridectomy at the inner side; most perfect flattening of the prominence followed, and he became able to read print of moderate size; yet so soon as fourteen days later symptoms of internal irritation appeared, and the globe again became tense and hard; the staphyloma soon attained its former size. A few weeks later the central portion of the prominence was excised, and there ensued the same transitory cure as after iridectomy. After a few weeks I decided on a freer removal of the staphylomatous projection; it was excised at its base, and now the perfectly transparent lens, lying in its capsule, presented itself, so as to close the loss of substance in the front of the eye; its external edge had probably pressed to some extent against the pseudo-cornea; at all events it was placed obliquely. I decided, though with some hesitation, on leaving the lens, partly because I thought its removal attended with danger, and partly because the other eye of my little patient being weak I considered it very important to save the vision of this eye as much as possible. A compressing bandage was applied, and cicatrization ensued without a single bad symptom; yet the improvement was of only a few weeks' duration, for then the projection again occurred, and at the same time the bulb became tense. Hence I was obliged to remove the transparent lens. The projection formed by tissue of new formation was again excised, the capsule opened, and the lens removed. The recovery was now permanent, and the vision relatively good; from the hardness of the bulb, and from the decided manner in which the surrounding cornea was becoming affected, I am certain that otherwise he would sooner or later have become blind.

Let the cause be what it may, I believe that the secretion of vitreous fluid is gradually augmented, and thus the pressure becomes greater; at all events, it is certain that choroiditis and permanent organic changes, separations of the retina, &c., are far more rarely found in the staphylomatous eyes of the blind than was formerly believed, and that the abolition of vision is generally caused by excavation of the optic nerve. Atrophy of the globe is by far the most common result of these complications. The glaucomatous appearance which such eyes in time assume has besides been long known, as well as the fact that prominence of the anterior hemisphere, together with hardness of the globe in projecting corneal cicatrices, is an almost certain indication of amaurosis. Little can be done for such cases in the way of treatment when the affection has run its course. It is, on the other hand, of infinite importance that symptoms of pressure during the formation and thickening of corneal cicatrices should be carefully watched.

We have now pointed out a number of most different conditions, which may ultimately induce glaucomatous symptoms through increase of the intra-ocular pressure. These were—traumatic cataract, iritis, irido-choroiditis, posterior staphyloma, hydrophthalmiæ, and projecting corneal cicatrices. When in speaking of these diseases we say that "they become glaucomatous," or "they threaten glaucomatous blindness," we mean, that through increased pressure, reaction on the optic papilla takes place in an analogous manner to what occurs in typical glaucoma. At the same time we mean that the only treatment from which relief can be expected is one that will diminish pressure. Without neglecting other means, such as mydriatics, paracentesis, or the removal of the swollen or displaced lens, we must still leave to iridectomy the first and most important place; in it we may often put our trust when all other means fail. It is its efficiency in diminishing pressure, and not any special relation to some particular disease, that renders the operation valuable, or determines and justifies its employment. For treatment founded on pathogenesis there even yet remains abundant space.

THE END.

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| Hogg, Charles . . . . | 12, Aldersgate Street, E.C. |
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