An Essay on the treatment of aneurism : with experiments for the closure of arteries by a new method / by Benjamin Howard.

AN ESSAY

ON THE

TREATMENT OF ANEURISM.

WITH

EXPERIMENTS FOR THE CLOSURE OF ARTERIES
BY A NEW METHOD.

BY

BENJAMIN HOWARD, A.M., M.D.,

OF NEW YORK.

LATE PROFESSOR OF CLINICAL AND OPERATIVE SURGERY, LONG ISLAND MEDICAL COLLEGE.

"Sola virtus invicta."

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PRIZE ESSAY.

ON THE TREATMENT OF ANEURISM, WITH EXPERIMENTS FOR THE CLOSURE OF ARTERIES IN THEIR CONTINUITY, BY A NEW METHOD.

THE literature of aneurism has already received so much attention, that an attempt to present an exhaustive treatise upon the subject at the present date would be superfluous.

The principal object of this essay is to lay before the profession a complete account of some new experiments with ligatures in the continuity of arteries.

These experiments were commenced simply to establish the confidence of the author in the reputed action of metallic ligatures. The unexpected results they yielded, led to the trial of various modified forms of ligature, one of which, based upon a different principle from the others, behaved in such a superior manner as to demand the test of frequent repetition.

The subsequent repetitions gave such a uniform result, and they point so directly towards practical progress in the treatment of aneurism, as to render their publication incumbent.

In the presentation of this subject, the etiology and pathology of aneurism, the history and action of ligatures, as well as some other means for the cure of aneurism, will receive such attention as perspicuity of plan, fairness of comparison, and just conclusions may require.

PART I.

THE ETIOLOGY OF ANEURISM.

An aneurism is a tumor containing blood, and communicating with the canal of an artery. Its predisposing cause is found in a weakened condition of the arterial coats; its exciting cause, in the

distending force of the blood current. When the latter force overbalances the power of resistance in the arterial coats, the result is an aneurism. The weakened condition of the coats referred to, is due to deposit from the blood upon the internal coat of the artery, which, as it increases in thickness, undergoes degenerative changes, and increasingly involves the superjacent arterial coats in succession, from the internal to the external. The deposit is known as "atheroma" or "atheromatous deposit," and this morbid state of the arterial coats as "atheromatous degeneration."

Atheroma appears first as a patch of membrane upon the internal coat of an artery, so thin, soft, and shining as scarcely to be distinguishable from it. Gradually it acquires greater firmness and a closer adhesion to the internal coat. Other and successive deposits occur in the same manner, each repetition contributing to form an indurated mass closely adherent to the coats of the artery, which then begin to suffer waste, loss of firmness, of elasticity, of color, and of natural function. This indurated living plate is now liable to new changes; a metamorphosis of its substance either of a fatty or of a calcareous nature, or of both at the same time.

In fatty degeneration, the interior of the hardened mass is transformed into a pulpy mixture of cholesterine, oil globules, albuminous, and cretaceous molecules. After the manner of an abscess seeking discharge, this pultaceous mass breaks through the most recent layer, and is washed out into the stream. Thus weakened, the diseased coats of the artery, at the base of the cavity, are then exposed to the force of the arterial current, which distends them into a pouch or aneurism.

In calcareous degeneration, the metamorphosis proceeds likewise in the same order as in the softer atheroma, involving, perhaps, more completely the internal coat of the artery at an early period.

The chalky plate is on one side in contact with the middle coat of the artery, and on the other, projects, into the arterial current, covered only by the most recent and still soft deposit.

Retardation of the current from this mechanical obstruction frequently causes formation of clots or deposits of fibrin, which are sometimes washed forward by the current, producing partial or complete obliteration of smaller arteries, just beyond or at a greater distance from the obstruction, and constituting what is known as embolism. Coincident with this, another and more direct result may ensue. The brittle bony plate is liable to crack,

and the fragments, driven by the force of the current, lacerate and become impacted in the middle and cellular coats, both of which are too much softened to permit resistance. The lesions thus produced, admit the distending arterial current, and the increase of the consequent pouch constitutes an aneurism.

The origin of the atheromatous material is unknown, save that its direct source is blood freshly charged with oxygen. Its deposition is very frequently associated with defective general nutrition, especially that form of it attended with a general accumulation of fat. The inordinate use of alcohol, gout, rheumatism, as well as general obesity, are considered conducive to the development of the aneurismal diathesis.

The nature of the atheromatous material, in its white and buff-colored form, as seen under the microscope, appears to be chiefly granules mixed with oil globules. According to Gulliver, a chemical analysis yields cholesterine, oleine, and sometimes margarine. (*Med.-Chir. Transactions,* vol. xxvi. p. 90.)

The cretaceous or bony deposit, yielded on a chemical analysis, by Dr. Bostock, "a minute trace of albumen and gelatine, animal matter, much phosphate of lime, a little carbonate, and a trace of sulphate. (*Med.-Chir. Transactions,* vol. xix. p. 87.)

The age of atheromatous subjects, though not frequently as far advanced as the middle period of life, is exceedingly various. Young, Wilson, and Andral have reported instances of cretaceous concretion occurring in young children. Andral has observed ossific laminæ in five or six persons from 18 to 24 years of age. (*Copland's Dict. Med.,* vol. i. p. 19.)

Lisfranc, in his Thesis on Aneurism (*Lancet,* vol. ii. 1833–4), has given the following table of ages in 120 cases:—

Age.	No. of Cases.	Age.	No. of Cases.
15 years,	1	40 to 45 years,	20
15 to 20 "	3	45 to 50 "	17
20 to 25 "	5	50 to 55 "	11
25 to 30 "	12	55 to 60 "	6
30 to 35 "	24	60 to 70 "	3
35 to 40 "	15	70 to 80 "	3

The following still larger table, published by Crisp (*On Structure, Diseases, and Injuries of the Bloodvessels,* London, 1847), containing 505 cases of aneurism, shows its greatest frequency to be from 30 to 50 years of age:—

Age.	No. of Cases.	Age.	No. of Cases.
Under 10 years	1	50 to 59 years	65
10 to 19 "	5	60 to 69 "	25
20 to 29 "	71	70 to 79 "	8
30 to 39 "	198	Above 80 "	8
40 to 49 "	129		

Other statistics might be adduced, but all concur so fully that their enumeration would be superfluous.

The arteries most obnoxious to atheroma are those which have the largest calibre, and are nearest to the heart. In a work, previously referred to, Crisp has supplied us with the following tabulated report of the location of all the reported cases of spontaneous aneurism which occurred in Great Britain from 1785 to 1847:—

Branches of the pulmonary artery	2	Axillary	18
Thoracic aorta	175	Subscapular	1
Abdominal aorta and its branches	59	Brachial	1
Brachio-cephalic trunk	20	Primitive iliac	2
Carotid	25	External iliac	9
Intercranial	7	Gluteal	2
Temporal	1	Femoral	66
Ophthalmic	1	Popliteal	137
Subclavian	23	Post tibial	2
			551

This enumeration, if it teaches anything, shows that the frequency of occurrence of aneurism is in proportion to the size of the artery, and that the smaller arteries are very generally exempt from this disease.

This fact, coupled with its infrequency in old age, aids greatly in distinguishing between the calcareous degeneration of atheromatous deposit, and that ossification of arteries giving rise to senile gangrene. The latter differs from the former in two respects: 1st. It occurs in old age exclusively; and 2d. The smaller and more distant arteries are alone affected with it. Further, whereas, in the calcareous degeneration of atheroma, the first stage consists in the deposit of soft atheromatous matter within the canal, in senile ossification, it begins in the arterial coats themselves, which become hardened throughout their circumference, and feel like the shank of a pipe-stem.

Though the atheromatous deposit exhibits the preference above stated, no artery can be considered exempt from it. Where the diathesis has acquired intensity, one may justly apprehend that

every artery in the body is more or less affected with it. Whatever is the manner of its deposit, whether in patches with healthy portions of artery intervening, or continuous throughout the interior of a vessel, it is pretty certain to involve, more or less, various parts of the whole arterial system.

In the body of an old man, Manec counted more than 30 aneurisms.

Pelletan also observed 63 in the same individual. Nor is this to be wondered at, for the source of the deposit being so generally distributed, it is natural to suppose that it would be difficult in any case to find one aneurism well developed, without on sufficient examination, discovering a disposition to the formation of others in different parts of the system.

THE RESOURCES OF NATURE FOR THE ARREST AND CURE OF ANEURISM.

As the treatment of each classified form of aneurism is essentially the same, let the term hereafter be used by us to signify that most typical form known as common or encysted aneurism.

In our rapid glance at the etiology of aneurism, we have seen the successive steps by which a fatal termination is reached; how, after degenerative changes, that part of the attenuated and weakened pouch which is most exposed to the shock of the arterial current finally ruptures, permitting a hemorrhage scarcely less fatal than it is sudden.

Though utterly ignorant of physiological principles, mechanical principles alone would indicate the propriety of restoring the original balance between the force of the arterial current and the power of resistance in the sac, in order to avert this accident.

They would also suggest that this should be attempted not alone by reinforcing the outside of the sac, but firstly and chiefly, by retarding the force of the current, and thus removing the first and constantly exciting cause; or, better still, they would suggest the superior advantage of using both these means conjointly.

Experience has fully indorsed the application of this theory in the treatment of aneurism, furnishing another instance of the delicate interweaving of mechanical with physiological principles. For, firstly, obedience to mechanical principles alone prompts us to obtain for the patient a state of comparative rest, which is also

a condition of prime necessity for the furtherance, secondly, of that physiological process by which alone a permanent cure through occlusion can be effected.

The resources of nature for the cure of aneurism comprise:

1st. The material used in its consolidation.

2d. The process by which the material is organized.

3d. The means by which the process is started.

Let these three leading points be for the present our mile-stones for guidance, and afterwards our corner-stones for foundations, and thus may we better arrive at truth, and build truthfully.

THE MATERIAL USED BY NATURE IN THE SOLIDIFICATION OF ANEURISM, AND THE PERMANENT CLOSURE OF ARTERIES.

As a rule, an artery is not closed by adhesion, or union, alone. Occupation of the canal, whether aneurismal or normal, by a solid substitute for the former current, is essential to permanent occlusion. Usually anything less than this would, sooner or later, yield to the force of the arterial current, according to the nearness of the heart, and size of the artery. The material with which nature permanently blocks up or closes an aneurism or artery is fibrin, and this is derived exclusively from the blood within the pouch or canal to be closed. As a constituent of normal blood, fibrin is perfectly fluid, but, under certain conditions, exhibits a striking quality of coagulation, not only when withdrawn from the body, but also while yet in its natural channels. The coagulation of fibrin of blood in the living arteries may be induced:—

By cessation, diminution, or obstruction of its natural motion.—A fine thread was passed through the artery of a dog by Mr. Simon, and in a few hours a coagulum was formed upon it, partially obstructing the vessel.

By inflammation of the arterial coats.—This causes plastic lymph to be poured out upon the lining coat of the artery, and thus forms an obstruction to the blood. The inflammation increases the proportion of the fibrin in the blood, and the plastic lymph, offering a rougher and a different surface from that of the proper lining coat, is another inducement and cause for its deposit.

Fibrin is separated from the blood also:—

By electricity; by contact with certain chemical astringents; by contact with dead, and especially dead animal substance.—This is

pre-eminently the case with pus, as proven by Hunter and by Mr. H. Lee.

The coagulation of blood is essentially a vital process. It is, indeed, the first and simplest step of which we know, by which plasma may become organized into living structure. The simplest clot, even when formed by blood withdrawn from the body, exhibits incipient organization. When, however, fibrin is coagulated and deposited slowly, and upon living tissues, the rate and degree of its organization are correspondingly increased; its fibrillation being most regular, and its organization most rapid and complete, when deposited most slowly, and upon tissues most highly organized.

The relative amount of fibrin in the blood is variable, according to the health, age, sex, and diet.

Its plasticity is augmented as the proportionate quantity is increased. From about three parts in a thousand, it may be increased by diet, regimen, and bleeding, to about five parts, without inducing disease.

Its increase is greatest in local inflammations, at which time its relative amount becomes two or three times greater than in normal health.

THE PROCESS BY WHICH AN ANEURISM OR AN ARTERY IS PERMANENTLY CLOSED.

Permanent cure of an aneurism is impossible, except by occupation of the sac, or the artery supplying it, by fibrin, which is solid, and has vital organization continuous with the walls of the original canal. This condition obtained, the cure may be said to be complete. A consideration of the natural process by which this condition is reached, will prepare us to discuss the means to be employed in order in the best way to imitate it, so that it may be continued to completion with the least vital cost and risk. The process by which *nature* establishes this condition will be fully considered in this chapter, as preparatory to a discussion of the *artificial* means employed to induce nature to start and complete this process.

An analysis of the various modes of spontaneous cure shows that they are all reducible to one and the same principle of action, viz., a slackening or obstruction of the arterial current, and that the first step in the process of occlusion thus induced, is the coagu-

lation of the fibrin of the blood at the point of greatest interruption of the current.

Running in the same direction is the fact respecting fibrin, that, of the conditions most favorable to its coagulation, the first in order, as stated in the last section, is—"cessation, diminution, or obstruction of the natural motion of the blood."

Assuming then that by some means, natural or artificial, such disturbance of the arterial current has been caused, we are, in either case, equally brought to the one first step of consequent coagulation.

The clots thus produced, differ in consistence and in color, according as they have been formed quickly, or slowly, from blood at rest, or in motion.

If, by a ligature or other means, the current be completely arrested in an artery, the stagnant blood, from the point of closure to the first proximal branch, will coagulate in from one to eighteen hours, beginning from below upwards, the upper end of the clot being the last to form.

A clot thus formed is always in its entire substance a soft clot, and is more or less red or black. If, on the contrary, a current of arterial blood be not completely arrested, but only disturbed, and its progress merely interrupted, the result is greatly modified. In illustration of this, we cannot find anything more to the point than that which is observed to occur spontaneously in the interior of aneurismal tumors.

In an aneurism of any kind the arterial current, on entering the sac, is more or less spread out and distributed over its inner surface. The volume of the current is broken, its direction changed, and its course is more circuitous. The current is both diminished in its force, and obstructed in its progress.

The consequence is, that, on cutting into the sac of an aneurism, either for the operation of Antylus or post-mortem, whether treatment has or has not been used, we usually find blood, not only liquid, but also in different degrees of coagulation. The firmest coagula are at the periphery, at the greatest distance from the current, the degree of consistence being less and less as the centre of the sac is approached, near which it may be syrupy in its nature.

In a sacciform aneurism, especially where the pouch is very large and dependent, although there may be some hard fibrous clots attached to the wall of the sac, there is much more likely to be a mass of soft clot occupying that part of the pouch which, from its

shape and distance from the current, favors almost complete stagnation.

In fusiform aneurism, the interior of the sac presents a difference, marked and characteristic. When the shape of the sac is symmetrical, it is not unusual to find soft clot entirely absent. Cases are cited in which the interior wall of the sac is lined with a coagulum of white hard fibrin, apparently an integral part of the sac. Upon this, other and successive coagula are deposited, until the entire tumor is solidified in such a manner that a section of it reveals a regularity of concentric layers closely resembling the appearance of an onion.

Sometimes this process is arrested so as, with the cure, to obtain also continuance of the current by a channel remaining through the centre of the tumor, corresponding to the original arterial canal. Cases of this kind are cited by Hodgson, by Donald Munroe, and, more recently, one with entire solidification by Mr. Luke, in the *British Med. Journ.*, Jan. 1870, in which no surgical method, but only Valsalva's treatment was resorted to.

There are fusiform dilatations of the aorta, not aneurisms, but called aneurismal, which are not unfrequently met with. In these, however, no such arrangement of coagula is found. We thus see that the process of spontaneous cure is by the formation, within the sac, of clots, either soft or hard, alone, or both together; that when the stagnation is most complete in the sac, the soft clot chiefly is found; that where the current through the sac is continuous, and evenly distributed throughout, its force only being diminished, the hard fibrous clot is not unfrequently found alone, to the entire exclusion of soft clot; that, on the other hand, when, through a dilated artery, the current is continuous and complete throughout, having great force, no clots of either kind are formed.

ON THE NATURE OF HARD AND SOFT CLOTS.

A clot may be temporary, or it may be permanent. If soft, it *must* be temporary; if hard, it may be permanent. The softness of a clot is determined by the quickness of its formation; the hardness of a clot is usually according to the slowness of its formation. It is upon the quality of the clot in the aneurismal pouch and mouth of the artery that all permanent cure depends. Notwithstanding the important bearings of this subject, we do not see that this was at all thoroughly understood until a comparatively

recent date. In a communication to the Surgical Society of Ireland, the first extensive researches upon this subject were published by O'Brien Bellingham, who, guided by this fact, became the chief agent of the revival and establishment of the treatment of aneurism by indirect compression.

The theory of Bellingham was subsequently still further developed and promulgated by Broca, Hodgson, and others, until the views upon this subject have now become pretty generally uniform.

ON THE NATURE OF SOFT OR PASSIVE CLOT.

The composition of the clot varies according to the rate at which it is formed. If formed very rapidly, its constituents are identical with those of the flowing blood, containing fibrin in the proportion of about seven parts to a thousand.

The process of its formation consists in the coagulation of its fibrin, which, if the stagnation be complete, as its fibrillation proceeds, incloses within its meshes all the other constituents of the blood.

Its rate of formation varies with the degree of rest of the blood from which it is formed. It occurs in aneurismal tumors in from about two to twenty-four hours. Once completely formed, a soft clot, as a mass, has reached the limit of its vital progress; its present bulk cannot be vitalized; it is not susceptible of organization, whether occupying an artery, an aneurism, or any other part of the body. It must, however, sooner or later undergo a change, the disintegration and separation of its elements.

Its fibrin is susceptible of organization into a structure homologous to the healthy tissues adjacent; all the other elements must be separated, or otherwise disposed of.

A soft clot completely occupying an aneurism may dispose of itself in two ways. If it is completely shut off from communication with the arterial current, it may act as a foreign body. When softening and disintegration occur, the mass having neither power of organization, nor means of egress, sets up irritation, inflammation supervenes, followed by suppuration of the sac and extrusion of its contents. It was such cases as these perhaps which guided Antyllus to his operation for removing the clots which he supposed to be the essence of the disease. If the separated serum be small in quantity, it may be absorbed, and the remaining fibrin become

organized. In an aneurism having communication directly or indirectly with the arterial current, the separated serum may join the general current, leaving the fibrin behind, attached either to the aneurismal wall, or to a layer of fibrin previously deposited within it. Into this last deposit, from the vitalized surface on which it rests, are projected bloodvessels which slowly form throughout the mass, until its organization and continuity of structure with the adjoining tissue are complete. When an artery has been closed on the cardiac side, but the sac continues to be supplied by a reflex distal current, successive "soft," or, as Broca called them, "passive clots," may be slowly transformed in color or texture, becoming increasingly white and firm, until the entire sac, perhaps, is completely consolidated with concentric layers of fibrin. When passive clots, however, are exposed to a direct current, they are liable to mechanical disintegration, and parts thereof to be carried by it to points beyond, forming an embolism.

When we consider the inherent dangers found in a passive clot, the uncertainty and slowness of the process by which alone it can promote a cure, its formation is certainly as much to be feared as it is to be desired.

In *Holmes' System of Surgery*, vol. iii. p. 359, it is stated: "The filling of the whole sac, or a great part of it, with loose clots, is often not so much an aid as a hindrance to the cure."

HARD OR ACTIVE CLOT—ITS NATURE AND PROCESS OF FORMATION.

The hard or active clot consists of fibrin alone. It is formed slowly, and from blood not at rest, but in motion which is continued at a diminished rate. Its whiteness and hardness are greater according to the slowness of its formation.

Its deposition is induced by mechanical obstruction, not only because it diminishes the force of the current, but because friction has a peculiar power to effect the separation of fibrin from the blood, as is manifest in the common process of whipping, after it is freshly drawn.

When once an obstruction has caused the commencement of deposition upon it, the rate of the process increases with the size of the obstruction. This is due not only to the increase of the friction, but because the arterial current is very prone to deposit its fibrin upon any surface presented to it, other than the natural lining of its own proper vessels. In this connection it may be

observed that the warts and excrescences so often found upon the valves of the heart, occur chiefly in subjects who have suffered sufficient inflammation of that organ to spoil the polish of the serous surface, or provoke plastic or obstructive exudation. It is upon this principle that inflammation sometimes causes the consolidation of an artery, or of an aneurism, producing a permanent cure.

The most favorable condition by far, for the production of active clot, and the one most easily established by art, is that of simply diminished motion of the arterial current. The process of its formation is described by Hodgson as "a gradual and successive deposition of the fibrinous part of the blood."

For its continuous deposition in its purest form, it is desirable that there be an unbroken current of fresh arterial blood, its rate of motion being at the minimum of its sufficient continuance.

In a clot thus formed, the changes which occur are changes of development only. The clot is, from the first, ready to become vascular by the development within itself of bloodvessels continuous with those projected from the tissue adjoining, whether that tissue be the lining coat of an artery, of an aneurismal sac, or of a subjacent layer of organized fibrin previously deposited. The fibrin deposited in this manner is likely to become organized much more quickly than that which has been precipitated from a passive clot; because, in the latter case, in the process of the separation of the serum from the clot, the fibrin is precipitated in bulk. This renders its permeation by bloodvessels from a single point of vital attachment, slow in its completion; meanwhile, its presence may provoke such inflammation as to cause an abscess and discharge of the contents.

On the contrary, if the fibrin be deposited with the gradualness, thinness, and evenness of the active clot, it may be vitalized almost as fast as it forms. Each successive layer is thus rendered secure against disintegration, and thus, however extensive the pouch to be filled, the whole mass is completely organized, and the cure is permanent.

THE MEANS WHICH ARE USED BY NATURE TO INDUCE A SPONTANEOUS CURE.

The fairest opportunity for discovering this would be in cases in which cure has occurred not only without surgical operation, but without aid from our art of any kind. Such examples it were

very difficult to procure, because those who are thus diseased, and know it, are bound to try treatment of some kind, while those who are thus diseased, and know it not, are equally ignorant of such recovery as may occur. We are inclined to think that the cases of spontaneous cure unobserved, are more frequent than those which are reported, or known even to the subjects of it, for in the larger number of cases an aneurism is not discovered until it has passed beyond the period at which such cure, if at all, is most likely to occur.

As preliminary to the fuller discussion of the points above presented, we will briefly give such instances and theories of spontaneous cure as the latest authorities accept.

Proceeding in the order of their importance, we observe that spontaneous cure is induced by—

1st. *Diminished action of the heart.*—This may occur from syncope or from rigid enforcement of rest. An aneurism $7\frac{1}{2}$ inches wide, and 4 inches long was treated by Mr. Stanley in October, 1847, by constant rest in bed with dieting for six months. From that date the patient was cured of the trouble, and died of another disease $4\frac{1}{2}$ years afterwards.

An aneurism of the femoral artery was treated in the same way by Mr. Luke, only that in addition, and as a secondary procedure, he applied a plaster over the tumor firmly, but lightly enough not to create inconvenience, except for the first half hour. At the end of five days, and for two months afterwards at the last examination made, pulsation was entirely absent. (*London Med. Gazette*, May, 1845.) "A great number of such cases might be cited from various authors who have treated this subject." (*Holmes' Syst. Surg.*, vol. iii. p. 364.) Other cases are also reported by Bellingham in his work on Aneurism. In such cases not only the sac but also the artery at the neck of the aneurism is occluded by fibrinous clot, and it is stated that such cases are followed by gangrene much more rarely than those in which the ligature has been used.

A great many cases of success are reported after the treatment of Valsalva, more or less modified as to frequency and amount of blood withdrawn.

The use of digitalis, iodide of potassium, etc., has been followed by recoveries to a slight extent.

Hodgson has described an aneurism of the aorta cured in this manner, a canal being maintained through the centre of the otherwise solid tumor.

2d. *Pressure by the aneurism upon the artery supplying it.*—Although this hypothesis was advanced by Everard Home, and accepted by Hodgson, and in theory is perfectly sound, such pressure being granted, its occurrence in the manner suggested is probably extremely rare.

3d. *By arteritis on the cardiac side of the aneurism.*—Crisp thinks that this renders the artery impermeable by forming a plug of plastic lymph within the artery.

4th. *By the pressure of blood effused by rupture of the sac, and confined under tense aponeurosis.*—In illustration of this, Crisp gives a case of rupture of an inguinal aneurism under the integuments, followed by cessation of pulsation on the fourth day.

5th. *Obliteration of the artery beyond the aneurism by clots from the sac.*—This is approved by Hart, but authentic examples of it are wanting.

6th. *Inflammation of the sac.*—This may occur in connection with the near approach of rupture, and be excited by the force of the current acting from within; or, it may be caused by force acting from without, applied either from accident or by intent, in which case the inflammation may begin in the tissues about the aneurism and reach the sac by extension. However commencing or caused, a moderate inflammation of the sac duly continued and restrained, is followed by coagulation and complete solidification of the interior of the aneurism very much as is produced by slackening or suspension of the circulation in it. This result is doubtless more or less due to the secretion of plastic lymph by the inflamed walls of the sac, and its accumulation upon their interior surface. A case presented by Hodgson, as an instance of cure from a different cause, may be here quoted as a still better illustration of cure resulting from inflammation. (*Hodgson on the Diseases of Arteries*, vol. i. p. 139.) The aneurism, which was in the groin, had so enlarged as from tension to produce gangrene, which was followed by sloughing and discharge of the aneurismal contents without hemorrhage, and with final recovery. The recovery is attributed to the gangrene, as in many other cases we find cure attributed to suppuration, both of which we consider as unfortunate accidents which have nothing whatever to do with the cure, and which, should they happen before the cure of the aneurism is complete, are full of nothing but harm and danger.

An analysis of all these modes of spontaneous cure shows in each and all, one, and only one principle in common, and that is—

Coagulation within the aneurism from slackening, or obstruction of the arterial current.

This might at first sight appear incorrect, as failing to cover such cases of cure as are induced by modified inflammation of the sac. We all admit that in such inflammation one of the first effects is, an exudation of plastic lymph. Is it not clear that such exudation furnishes an obstruction to the current, and, if need be, the first cause of fibrinous deposit from the blood, which by the same law will continue at a rate proportioned to the increase of the deposit?

THE TREATMENT OF ANEURISM BEFORE THE TIME OF HUNTER.

The point to which I desire to call especial attention in this connection is, that from the earliest date onward to the time of Hunter, the principle which regulates the formation of clots was unrecognized, and that all the methods of treatment during that period were in direct violation of it.

As a consequence of this, we shall see that the very extended experience with the various methods, including ligation and compression, served justly to condemn them to abandonment, and with only occasional exceptions to substitute the treatment by amputation.

The invention of the ligature is usually attributed to Ambrose Paré. We find, however, that long before his time it was recommended by Ætius, by Paulus of Ægina, and by other Greek and Arabian physicians.

It was referred to by Guillemeau in 1649 (Guillemeau, edition 1649, p. 699), and especially commended for arteries of a large size.

The material used for ancient ligatures was first, flax and hemp, and afterwards silk. Galen speaks of the use of thread of lint or wool in surgery. (*Kuhn's Galen*, vol. xviii., B, p. 752.) Paulus Ægineta of threads of wool. (*Dr. Adams' Translation*, vol. ii. p. 260.) Fabricius Hildanus recommends for deligation a hempen thread—*filo cannabino*. (*Opera*, Frankfort-on-the-Main, 1646, p. 852.)

The method of applying the ligature was such as most completely to strangle the vessel, and at a point as near as possible to the aneurism.

Antyllus completely isolated the aneurism by a ligature on each side of it, and, believing the clots found therein to be the essence of the disease, he cut open the sac and removed them.

Anel, in his later operation, tied the artery above and as near as

possible to the tumor, and applied pressure over the sac, "with suitable dressing and bandage."

Anel thus used every means to shut off in the completest manner all direct and collateral supply, and leave the blood within the sac absolutely at rest.

Treatment by compression is also traceable to a remote date. It was referred to by Avicenna, was employed by Galen, was described by Chauliac, and in 1664 was used for aneurism of the radial artery by Tulpius, the pressure being made with a plate of lead and a bandage. (*Obs. Médicale*, 1664, liv. iv., chap. xxii.)

In 1765 it was used by Genga and Guattani, and afterwards by others in different countries, its most prominent advocate in Germany being Bruckner.

In his description of the method of compression, Guy de Chauliac says: "This cure is doubly made—one of the ways by compression with an astringent plaster, the other by ligature, to produce obstruction." (*Joubert, Traité* 2, Doct. 2, chap. iv.)

The completeness of the obstruction was evidently deemed of such importance that the compression was really used only as an adjuvant to the ligature.

Guattani states his object in compression thus: "Simul cohibendo sanguinis cursum in arteria ad effectum locum tendente;" evidently desiring to prevent entirely any further flow of blood into the aneurism. He adds: "Ac denique linteorum beneficio ipsummet gradatim comprimendo tumorem aneurismaticum fieri posse ut non solum illius augmentum prohiberetur set tractu temporis paulatim serum sua sponte converso resolutio tandem aliquando contingeret." (*De Exterius Aneurismatibus*, Collect-de-Lauth, p. 129.)

It is plain also that, to insure more completely the arrest of the arterial current, he used not only the indirect but also the direct method of compression combined. "Nell aneurisma vero recente, facilemente se guarisce col solo mezzo della comprezzione purche questa sia regolata da perda mano ed in modo cheresti quasa libera l'inferior apertura dell' arteria e nel tempo stesso sia sostenuto e compresso il sano aneurismatico." (*Flajani*, p. 74.)

We cannot fail to see from the above, that whether by compression or ligature, the best immediate result the ancients could obtain by the most skilful application of their methods, was the formation within the aneurism of a soft, passive, and temporary clot, to be followed by inevitable disintegration, and uncertain results.

The failure of both compression and ligation.—The results of compression must have been from the first very discouraging, for from the time of Avicenna to that of Galen, we find no mention of the operation. Its subsequent fate still more strongly attests its failure, for after a still further opportunity of over a hundred years, for the exhibition of its merits, it was generally laid aside in favor of either the dangerous operation of Antyllus or of amputation.

The ligature survived with a reputation scarcely better than that of compression.

The highest development in the use of the ligature, during the previous centuries, was the method of Anel. Though this operation was hailed at first with greatest enthusiasm, during the seventy-five years which intervened between its introduction and the time of Hunter it appears to have been performed but six times, including the celebrated case of Desault; and in two of these cases the result was fatal.

In 1780, Wilmer of Coventry said of it, that there had not occurred in England one authenticated case of success.

In 1781, Alanson considered the success of ligation so small in popliteal aneurism as to judge amputation indispensable.

In 1785, of ligation for femoral and popliteal aneurism, Percival Pott says: "I have tried it myself more than once or twice—I have seen it tried by others, but the event has always been fatal."

PART II.

OBJECTIONS TO THE ORDINARY SILK, TIGHT LIGATURE.

The use of the silk thread for ligatures was adopted by Hunter, and established by Jones.

Referring to this as material for ligatures, in *Holmes' System of Surgery*, it is stated: "No other form is any longer in use." As a rule this is correct, and therefore we will consider

THE OBJECTIONS TO SILK AS A MATERIAL FOR LIGATURES.

The law of non-tolerance of foreign bodies by living tissues is most stringently enforced by nature against those which have a rough surface, readily absorb fluids, or are subject to chemical

changes. All these qualities are eminently those of the silk ligature. The roughness of its surface provokes from the first irritation of the tissues in contact with it. This, with the tightness of its application, unites to promote suppuration. As the chief part of the ligature is at the bottom of the wound, it absorbs thence irritating fluids. These swell the ligature throughout its entire length. The ligature as a seton reacts. It establishes a suppurating track from the surface to the bottom of the wound, where a pool is formed of putrid, decomposing pus, soaking constantly the wounded and ulcerating artery. The immediate tendency of this is to promote too rapid ulceration of the artery, and causing secondary hemorrhage. It promotes septæmia. It inevitably prevents union of the wound by first intention.

William Porter, of Dublin, says respecting this kind of ligature, "It is evident that until its removal the wound cannot be made to unite by first intention," "their pressure acting as so many setons keeps up irritation, and often a profuse discharge." (*Observations on the Surgical Pathol. and Treat. of Aneurism*, 1840, p. 29.)

John Hunter said: "If any extraneous body, such as a ligature, should have been left in the wound, suppuration *will* take place." (*Hunter's Works*, edited by Palmer, vol. iii. p. 258.)

In *Rees' Encyclopedia*, vol. xvii. art. Hemorrhage, it is stated: "Ligatures act as foreign bodies in wounds, exciting irritation, preventing adhesion, and producing suppuration."

William Lawrence says: "Ligatures being foreign bodies, must irritate, must cause inflammation and suppuration." Are these evils inseparable from the use of ligatures, or is there any plan by which we can avoid them? (*Medico-Chirurg. Transacts.*, vol. vi. p. 162.)

Similar statements are made by Roux and others, and are concurred in by the profession almost unanimously. All of whom, without exception, would desire healing of the wound by first intention as involving advantages of the very highest importance.

Are there no exceptions to this law by which silk ligatures are extruded from the surface? Mr. Liston writes on this point: "The practice of cutting off both ends of the ligature was at one time very much the fashion. It was thought that the nerve-noose or knot might by possibility remain imbedded in the living tissues surrounded by a cellular cyst and occasion no annoyance. All these hopes have been disappointed." (*Liston's Practical Surgery*, 4th edition, p. 24.)

Professor Chelius says: "Numerous experiments prove that reopening of the wound, suppuration, fistulous passages, and the like, may be produced by the knots remaining." (*Chelius' System of Surgery*, by South, vol. i. p. 306.)

Cutting of the ligatures short was tried by Delpech, Walther, Hennen, Haire, and by Mr. Lawrence; but this practice by the latter has been abandoned.

Porta deems the absorption of short silk ligatures as possible. (*British and Foreign Medical Review*, vol. xxii. p. 22.) It is more than likely, however, that Professor Porta got this impression from his experiments on the lower animals, in which the tolerance of foreign bodies is greater than in man.

What shall be said of cases in which silk ligatures have been used in the cavity of the abdomen, the ends cut off short and the loops dropped back into the cavity, the surface wound of the abdomen healing by first intention?

Silk ligatures have been so used by my friend, Professor Peaslee, of New York, and in some instances the patient has recovered, and nothing was heard from the ligatures from the time of their introduction.

In one case when he had tied a portion of pedicle with a silk ligature, he observed on post-mortem that the pedicle where it had been constricted had so much shrunken (perhaps from ulceration) that the ligature lay encircling it, but so loosely as to be in contact with it only at some points. There appeared to be no pus to speak of, but the pedicle and ligature, etc., were imbedded in one mass of lymph.

Permanent residence of a silk ligature in the living tissue is therefore perhaps possible. Should it excite from the first adhesive inflammation only, and so become imbedded in a mass of fibrin, or should some little pus it once contained have become absorbed by adjacent tissues, so as to leave the ligature dry, hardened, and innocuous, adhesive inflammation then occurring might perhaps cause it to be inclosed and preserved within a mass of fibrin. If such an event does occur, the rarity of the exception helps only still further to establish the conclusion that the material of the silk ligature tends directly to promote inflammation, suppuration, ulceration, secondary hemorrhage, septæmia, and to prevent the healing of the wound by first intention.

DANGERS FROM THE TIGHTNESS WITH WHICH THE LIGATURE IS APPLIED.

Until a comparatively recent date, there has always been a wholesome fear of doing direct danger to the artery in the application of the ligature. This led Hunter for some time to use broad tapes side by side, although he did afterwards use the single round ligature. Benjamin Bell, Manoir, Abernethy, A. Cooper, and Sedillot, fearing the single round ligature might sever the artery too soon, employed two ligatures a little distance apart, and divided the vessel between them to get the advantage of its retraction. Scarpa, and others of his time, sought to protect the artery by interposing a piece of diachylon plaster between the vessel and the loop of the ligatures, of which he used two, applying one near each end of the cylinder of plaster. Later on, the surgeons of Pavia used but one ligature, but in the same manner as Scarpa. This practice was generally adopted in France. Amongst others equally celebrated, it was practised by Boyer, Larrey, and Roux until 1805. At that time Dr. Jones, of England, published a book in which he seemed to have demonstrated, by a series of ingenious experiments, that there was a positive advantage in wounding the vessel by a small round ligature, like that used by Hunter, provided it was tied so tightly as to divide the internal and middle coats, leaving the outer or cellular coat alone, within the loop of the ligature. The explanation he gave of this was that the two inner elastic coats, when thus severed, retracted. The cut edges turned inwards upon themselves. That from these cut edges, now in apposition, was poured out plastic lymph, which united them together by first intention. That on the extrusion of the ligature by ulceration from between the two retracted and closed ends, even though the clots within were insecure, the escape of blood was sufficiently provided against simply by the sealing and adhesion of the internal coats. This theory at once commended itself, promptly supplanted all others, and is to-day, according to Holmes, the only method in use.

It must not be forgotten, however, that this theory was obtained from experiments upon *healthy* arteries, and was intended for application to arteries in a similar condition.

In the previous section on the etiology of aneurism we have stated that the source of the atheroma being the blood itself, though but one aneurism present itself in a patient, it is probable

that there is scarcely a single artery in the body perfectly free from the atheromatous deposit. That as many as sixty-three aneurisms have been discovered after death in the same individual.

That the disease, moreover, commences upon the internal coat, involving next the middle coat, both of which might be thoroughly metamorphosed without the external coat as yet showing clear evidence of disease.

That the first effect of this disease is to destroy the contractility of the coats of the artery.

That the metamorphosis becomes so complete that the ability to secrete plastic lymph gradually ceases.

In comparing the difference between the conditions instituted by a tight ligature in an artery which is healthy and in one which is diseased; the best arguments used by Jones for its *adoption* in the former case, seem to be the strongest that could be desired for its *rejection* in the latter.

When performing ligation for aneurism, we are justified in assuming that, however far we go from the tumor, we are probably dealing with an artery more or less atheromatous, and that consequently, in the ordinary tightening of the ligature, we are risking dangers which are greater than the advantages to be expected.

The ligature severs two-thirds of the thickness of the artery, which is entirely destitute of reparative power; the outer third or cellular coat alone being inclosed in the loop of the ligature to withstand the force of the current.

The force with which the ligature is applied, strangulates the vasa vasorum, and thus compels the part included in the loop, and a little beyond it, to die. Through this thin remaining coat thus killed, the ligature rapidly ulcerates.

Roux, Hodgson, Brodie, Thompson, Erichsen, Velpeau, Pecot, Nélaton, Guthrie, Gross, and others all agree that the portion of the artery thus strangulated is killed, and must slough away.

The first Dr. Monro, of Edinburgh, writes: "Threads tying arteries only come away afterwards by the tied parts mortifying or suppurating away, and the sooner such corruption is brought on, *which will be exactly in proportion to the tightness of the ligatures*, the separation of the threads will be the more speedy." (*Edinburgh Med. Essays*, vol. vi. p. 331.)

Petit states: "Tout ce qui s'est compris dans la ligature tombe en mortification." (*Traité des Maladies Chir.*, tom. iii. p. 195.)

Nélaton says: "The ligature strikes with mortification the part of the vessel which is submitted to the constriction." (*Elemens de Pathol. Chirurgicale*, tom. iii. p. 133.)

Brodie states: "The ligature divides the middle and inner coats, but only compresses the outer coat. It makes a slough of a little piece of the latter, and when the ligature comes away at the end of ten days or a fortnight, you find the slough in it. (*Lects. illustrative of various Subjects in Pathology and Surgery*, p. 306.)

Thompson says: "The part of the artery included in the ligature being deprived of its vitality, separates from the living parts." (*Lects. on Inflammation*, p. 253.)

Miller writes: "The noose and its contained slough are to all intents and purposes foreign matters; as such, their presence will be resented by the surrounding living textures, and as such they will be extruded by suppuration." While by this process of laceration, suppuration, ulceration, sloughing, the fate of the ligature is inevitable, let us look at the feebleness of the provision against

Secondary hemorrhage from the separation of the ligature.—There being no retraction, and no adhesion of the inner coats, the thin outer coat being thus strangulated and so soon ulcerated through, there are but two ways remaining by which secondary hemorrhage may be prevented. The inflammation excited during the process may have led to the throwing out of a mass of fibrin sufficient to inclose within itself all the injured portions of the vessel. Through this the ligature and slough may be extruded to the surface slowly, its rear track being closed up as it proceeds by a separate plug of fibrin. A very fine illustration of this will be observed in one of the drawings accompanying this paper, recently sketched by me from a specimen after experiment.

The other hope for immunity from it, is in the integrity of the clots at the divided ends of the artery.

So much has been said in a previous section on the formation of clots, that it is unnecessary to repeat any details on this point, but only to say that here we find another objection to the tightness of the ligature in the fact that in consequence of it

Soft, passive, or temporary clots only, occupy the artery at the seat of ligation.—When, therefore, the ligature breaks away, the clots are in danger of being washed out, or displaced by the force of the blood current, and allow a profuse hemorrhage to ensue.

In the *Dictionnaire Encyclopédique des Sciences Médicales*, vol. vi. p. 628, it is stated "hemorrhage following the non-obliteration of the

artery just when the ligature has divided the coats is a most grave accident." "This causes death in nearly all cases of ligation of the brachio-cephalic trunk and of the subclavian within the scaleni."

"In 74 cases of ligature of the subclavian without the scaleni, it occurred 15 times. In 14 of these death followed, being in 10 of them the direct consequence of it." (*Edinburgh Med. and Surg. Journ.*, vol. xxvii. p. 7.)

These observations have been confirmed by those of numerous other authorities, amongst whom are Blaker (*Med. Times*, 1856, vol. i. p. 62); Bransby Cooper (*Guy's Hosp. Rep.*, 1841, vol. vi. p. 348); Gregg (*Dublin Quart.*, 1858, vol. xxv. p. 210); Hancock (*Lancet*, 1849, vol. ii. p. 7); Hutin (*Archives Générales de Médecine*, 1842, vol. xv. p. 101); Le Gros Clark (*Lancet*, 1859, vol. i. p. 158); Liston (*Edinburgh Med. and Surg. Journ.*, vol. xxvii. p. 7); Mackenzie (*Gaz. Méd.*, 1852, p. 594); Mayo (*London Med.-Chir. Transactions*, vol. xii. p. 12); Paget (*Med. Times and Gazette*, 1860, vol. ii. p. 265).

THE TIGHTNESS OF THE LIGATURE A CAUSE OF GANGRENE.

The blood is the life; but this, as well as other of the elements of life, may be abstracted or withheld to an extreme degree without producing permanent harm, provided only that the change be gradual. If the change be sudden, as, for example, of the body to opposite temperatures, or, as in profuse and rapid bloodletting, death may occur—the absolute temperature, or amount of blood abstracted, being in no way inconsistent with life under other circumstances.

The sudden strangulation of an artery by the ligature deprives all the parts of the limb, beyond, of its main and accustomed supply, making the change both instant and complete. This is a combination which could scarcely be surpassed, if the express design were by the least mutilation to produce death. Accordingly, we observe, save in exceptional cases, that from the moment of applying the ligature, a gradual decline of temperature begins beyond it, with all the signs of diminishing vitality culminating at the part most distant from it.

As might be supposed, the lower extremities are more susceptible than the upper to this change; signs of gangrene frequently appearing as a black spot on one of the toes in from three to six days. Its rate of progress, too, is more rapid in proportion as its commencement is early, and its fatality increases at the same ratio;

while, on the contrary, according as its first appearance is delayed, its prognosis is favorable.

The occurrence of gangrene is not an uncommon event after ligature. In an analysis of 600 cases of ligation, collected by Porta, in the upper extremities this event followed in 5 per cent., and in the lower extremities in 14 per cent. of the whole number.

In 204 ligations of the femoral, collected by Norris, it occurred in the proportion of 11 per cent.

After the operation by the method of Anel it occurs more quickly and frequently than after the Hunterian method.

A case is reported by Roux in which it followed the Hunterian operation, but did not make its appearance till fifteen or twenty days afterwards.

When by the strangulating ligature the current through the main artery of a limb is suddenly arrested, the collateral vessels, which may be very few and small, are subjected so suddenly to the newly-directed force of the current as to suffer rather a passive distension, with more or less atony of their coats. Whereas, were the change gradual, the collateral vessels would undergo a healthy and gradual development under the combined influence of the moderately increased force behind, and the new demand of the parts beyond. Another result of the suddenness and completeness of the strangulation is, that in consequence of the collateral vessels being unprepared so suddenly to share an additional portion of the main current, the weakened artery at the site of the ligature is submitted to a strain which will tend both to rupture its single remaining ulcerating coat, to disturb the soft clot formed there, and so provoke hemorrhage.

TIGHTNESS OF THE LIGATURE AS A CAUSE OF RELAPSE.

According to the process so fully described, and the principles laid down in a previous section, the completeness of the arrest of the circulation effected by the tight ligature conduces to the occupation of the aneurism by a clot, which is passive, and hence temporary. This is always the result of Anel's operation. If, however, the principle of Hunter be carefully carried out, and the distance of the ligature from the tumor be such as to allow of a moderate supply of blood to the sac by means of collateral vessels intervening between it and the ligature, the clot may be more of an active and permanent nature. Such, however, is the prevailing

desire, even now, to stop quickly the pulsation in the tumor, that, as a rule, the temporary clot constitutes the bulk of the contents of the sac after every apparently successful ligation. When the small amount of fibrin which the temporary clot can yield has been deposited, and the separated serum has joined the circulating current, a reflex tide reaches the sac by means of distal and collateral communications, and thus pulsation reappears. This may occur very soon after the operation, or at various later periods. It has been observed by Brodie and Briggs after six months; by Bellingham after seven months; by Monteith and Lenoir after nine months; by Liston after ten months; by Key and Hosack after a year; by Roux after two years; by Gunning and Porta after four years; by Hawkins after seven years; and by A. Cooper after fifteen years.

A relapse signifies something more than an *insuccess*, as after such an event the aneurism is apt to enlarge at a rate much more rapid than before the ligation.

TIGHTNESS OF THE LIGATURE A CAUSE OF SUPPURATION OF THE SAC.

This also occurs with more frequency according as the ligature approaches the tumor, and is a very grave accident.

It is owing in the first instance to the same cause as that above given of relapse, with this additional condition, that the disintegrated clot is imprisoned within the sac. The isolated contents act as a foreign body, and demand release. Inflammation and suppuration are set up. The tumor bursts, the contents are discharged, and an open abscess is established. The debris remaining is exposed to the action of atmospheric air, and the decomposing putrefying mass becomes a focus whence general toxæmia and pyæmia may arise, which, together with the purulent drain upon the system, become a double source of danger to the patient.

Respecting its frequency, we find that, according to some statistics compiled by Morris and revised by Broca, in 156 ligations of the popliteal artery it supervened 13 times; in 20 of the femoral, 3 times; in 97 of the iliac, 10 times; in 33 of the carotid, 6 times; and in 56 of the subclavian, 6 times.

The date of its occurrence is various, and of its progress slow. The time of its commencement is reported, in 58 cases, by Broca as follows:—

In 10 cases it commenced from the 5th to the 10th day.						
17	"	"	"	10th	"	15th "
4	"	"	"	15th	"	20th "
1	"	"	"	20th	"	25th "
13	"	"	"	25th	"	30th "
4	"	"	"	30th	"	35th "
4	"	"	"	35th	"	60th "
2	"	"	"	8 months to 12 months.		
2	"	"	"	after a year.		
1	"	"	"	after 14 months.		
58						

Secondary or recurrent hemorrhage from suppuration of the sac, not unfrequently follows. It is usually due to the displacement of a distal plug, reopening communication with the artery beyond. Broca, in a report of 75 cases of inflammation of the sac after ligature, states that hemorrhage occurred in 19 of them.

Unlike the secondary hemorrhage at the site of the ligature, it occurs at various intervals. Peace tied the iliac artery in August, 1842, and in November, 1843, fourteen months after, hemorrhage occurred from this cause, which, though arrested, again broke forth and produced death.

CEREBRAL ACCIDENTS FROM COMPLETE CLOSURE OF ARTERIES BY THE TIGHT LIGATURE.

The principal accident to the brain from this cause is analogous to the gangrene which occurs in the extremities. It supervenes upon the ligation either of the internal or common carotid about equally. In 54 cases of ligation which terminated fatally, reported by Dr. Morris, 12 are referred to this class under the designation of convulsions, apoplexy, etc. Whether the process be one of softening, atrophy, or other change in the cerebral mass, it is one which evidently is sufficient to precipitate death in a manner distinct and manifest.

THE MORTALITY AFTER LIGATURE.

Notwithstanding the achievements of Hunter and others since his day, the boasted triumphs of the ligature are calculated rather to excite new enterprise than to promote complacency and content.

The following statistics are the combined compilations of Morris and Smith, together amounting to 579 cases of ligature of various

arteries, leaving out, however, ligations of the aorta and innominata, so as to avoid swelling the fatality by operations deemed by some unjustifiable. These tables are condensed from the *Am. Journ. of the Med. Sciences,* N. S. vols. x. xiii. xiv. xviii. and lx.

Artery ligated.	No. of cases.	No. of deaths.	Percentage deaths.
Subclavian	69	33	47.8
Carotid	149	54	36.2
Femoral	204	50	24.5
External iliac	118	33	27.9
Internal iliac	7	3	42.8
Common iliac	32	25	78.1
Total	579	198	33.1

We know how serious and dangerous an operation amputation of the thigh is considered to be, and yet, on looking at the most complete statistics compiled of this operation, and comparing them with the above table, we find that the operation which presents the lowest mortality on the list, viz., ligation of the femoral, exhibits a degree of fatality almost equal to that from amputation of the thigh, the former being at the rate of 24.5 per cent., and the latter 27.27 per cent.

Porta in his work (p. 404) gives a synopsis of 600 cases, of which 68 were ligations of the brachial usually so successful. Out of this number we find that 167, or 27 per cent., died. The average mortality from all cases was but a fraction less than that from amputation of the thigh.

In further evidence of this startling fact, we would refer to a comparatively recent list of cases of ligation of the femoral, published by Mr. Hutchinson, of London. (*Med. Times and Gazette,* vol. ii. 1856, p. 515; vol. i. 1860, pp. 12, 35, 62, 89, 117.)

The operations in these cases were all performed in the metropolitan hospitals of London, by the best representatives of modern surgical skill. Out of fifty consecutive cases thence compiled, sixteen died. This gives us as the result of our highest skill in the ligation of the femoral artery (one which is amongst the most favorable for the operation), a mortality even greater than from amputation of the thigh. And notwithstanding all that may be said for compression or any other method, we know, that this is the treatment upon which more than any other, general and ultimate reliance is placed at the present moment.

THE DISTINGUISHING PRINCIPLE INAUGURATED BY HUNTER.

Hunter not only introduced a method, he announced a principle, before unknown. He did not apply his ligature at a distance from the aneurism, chiefly for the advantage of a healthier site, but because in contrast to the uniform practice of complete arrest; he desired only, as he said, "to take off the force of the circulation" from the aneurism, and thereby endeavor to induce coagulation within the sac.

The first time Hunter applied this principle was in 1785, when he trusted for the continuance of a diminished current within the sac, to collateral vessels intervening between it and the ligature.

The *rules* of Hunter concerning a proximate and a healthy site were plain, and have been appreciated. The *principle* was taught obscurely, and has been much neglected.

Notwithstanding its long-continued obscurity, however, this principle has revived, and from it, as from a parent root, have sprung all the substantial improvements of modern times for the treatment of aneurism.

THE FIRST COMPLETE EXPOSITION OF THE PRINCIPLE OF COAGULATION BY DIMINISHED CURRENT, AND ITS EMBODIMENT IN THE LATER METHODS OF INDIRECT COMPRESSION.

Although Hunter recognized this principle, its complete exposition was reserved for O'Brien Bellingham, of Ireland, who, in 1843, published the results of diligent investigation and careful experiments by which he demonstrated the process of formation, and the difference between what he called "soft clots" and what he called "hard clots," showing that the "soft clots" are produced by complete stagnation, and are essentially temporary. That the "hard clots" are formed by gradual deposit from the arterial current, the "force" of which is diminished.

We know that Hunter treated a case of aneurism by proximal indirect compression; that Sir F. Blizard employed it (*Bellingham on Aneurism*, p. 28), and Freer advocated it (*Freer on Aneurism*, p. 94). It is said to have been employed successfully by Pelletan, Dubois, Dupuytren, Boyer, and Albers; but from the great frequency of its failure, it had fallen almost into disuse. The pain, too, was excessive; for, unless we except Hunter, the direct object

sought by all, was complete obliteration of the arterial canal by the force employed.

The use of indirect compression seemed again about to be abandoned, when an accidental recovery by this treatment occurred October 3, 1842, in a patient of Dr. Hutton, who would not submit to the ligature. About the same time another similar success occurring in a case of Mr. Cusack, attracted the attention of Dr. Bellingham, who met with a still greater success.

Dr. Bellingham then prosecuted the study and practice of the question in the manner and with the results just stated. In his book on the subject, he fully developed the theory of the formation of clots, and placed the entire question in a clear and scientific manner before the profession. The results of the experiments he published were fortified by a report of twenty-five cases treated in different parts of the kingdom by moderate indirect compression, being all which had been so treated up to that date. The report showed a cure in every case but one, the failure in that case being due to impatience of the treatment by the patient.

Upon this sound basis the treatment by moderate indirect compression was rapidly revived and extended throughout Ireland, England, America, France, and other countries.

The statistics of this operation cannot be said to have shown as satisfactory results in the hands of English, as in those of the Irish surgeons.

In 46 cases reported by Mr. Hutchinson, treated for popliteal aneurism, 24 were successful. Of the remaining 22, in whom the femoral was ligated, two only died of gangrene; while of ten cases where compression had not preceded the ligation, three died from this cause.

In the *Medical Times*, of London (vol. i., 1860), of 39 cases reported, a cure followed this treatment in 25 of them.

From a comparison of the results in England and in Ireland, we may presume that they depend greatly upon a difference of skill, proportionate to the familiarity with the use of the method.

In seventy-five successful cases reported, the average time in which cure was accomplished was nineteen days.

The most frequent cause of failure is the intolerance of the soft parts, or the impatience of the patient of the necessary pressure.

"*Usually when a limb is examined after the successful use of compression, the artery above the tumor shows no trace of its action. The tumor is generally quite firm, being filled with laminated coagulum;*

but sometimes a channel is seen, through which circulation has gone on in it. All this will be seen to be identical with the spontaneous cure. Enlarged anastomosing arteries are generally discovered, and this enlargement is usually and rightly regarded as one of the earliest and best symptoms of commencing cure." (*Holmes' Syst. of Surgery,* vol. iii. p. 419.)

In the absence of sufficient statistics for reliable generalization, it is very apparent that the treatment by instrumental-indirect compression; by digital compression; and by flexion; are universally preferred to any other method where they are applicable as a substitute for the ligature.

We have shown that the principle at the basis of indirect compression as first announced by Hunter, and expounded and demonstrated by Bellingham, is rational; is scientific; is efficient; is very safe.

That the principle is the same as prevails in cases of spontaneous cure.

That the appearance of the sac in successful cases is the same as after spontaneous cure.

PART III.

EXPERIMENTS

BY THE AUTHOR WITH METALLIC LIGATURES.[1]

About the beginning of August, 1867, a patient came to me to be treated for an axillary aneurism, and as indirect compression was impracticable, I was reduced to contemplate ligation of the subclavian.

As I had reason to apprehend considerable disease of that artery, however, I felt reluctant to employ the silk ligature in the ordinary way.

[1] I am under very great obligations to my friends Mr. N S. Downs, Mr. W. C. Wheeler, and Dr. Beardsley, of Birmingham, Conn; as also to my friends Mr. H. S. Terbell and Dr. Emerson, of New York, for the kind and arduous assistance they have rendered me in the prosecution of these experiments. To insure accuracy, the drawings for the engravings were done by the author from actual measurement of the specimens while fresh.

Encouraged by the operations reported by Stone, Redfern Davies, Smith, and others, I thought it advisable in this case to substitute silver for the silk ligature, and to use but moderate force in applying it; enough to close the canal without damaging the vessel. I expected in that way to obtain a permanent residence of the ligature.

Having had no personal experience, however, in the use of metallic ligatures in the continuity of arteries, I at once obtained some large, full-grown sheep, and placed them in the best conditions with good pasture and shelter; intending first of all, to justify myself in the proposed operation, by a full confirmation of the views generally entertained respecting the innocuous nature and permanent encystment of silver ligatures.

Experiment I.

I applied a silver wire ligature to the common carotid artery within the sheath, fastened it by twisting tightly, and cut the ends off short. Healing occurred by first intention. Fifty-six days afterwards, on making an examination I found the cicatrix still firm, and the parts in the vicinity apparently perfectly sound. An incision was made along the line of the cicatrix, and as the parts were dissected away, the capillary circulation was observed to be so slight that very little bleeding occurred. On coming down to the point of ligation, I was astonished to find what appeared like an aneurism, lacking only the pulsation. Thinking it might be a dissecting aneurism in a state of partial cure, I applied a ligature above and below, and removed it entire.

On making a longitudinal section of the tumor, it was found to be full of inspissated pus, so consistent as almost to retain the shape of the sac after removal from it.

Fig. I. presents its correct size and appearance. The artery at both ends is seen to be perfectly solid. The pyogenic membrane, *c*, is very much puckered and plicated, showing its contents had greatly diminished in bulk.

At *e e* are small points into which a horsehair could be inserted for about the twentieth of an inch, showing the original track of the arterial canal, and between these points upon the floor of the abscess, as shown by the dotted lines, lay the ligature, exhibited more clearly at *d*, inclosing what appeared to be the two internal coats of the artery which had sloughed off in one piece about twelve lines in length.

Had this operation been performed upon my patient, judging

from the excellent progress of the case, and the apparent soundness of the parts, in the absence both of post-mortem and of vivisection, I should certainly have concluded that the silver ligature, as I expected it would, had behaved itself innocuously, and had become quietly encysted where it was placed.

Apprehending the result here shown might have been due partly to mechanical irritation from the short projecting twist of the free ends, and that the smallness of the wire had in part caused the ligature to cut through the coats of the artery, I instituted two experiments in which these causes might certainly find no place.

Experiment II.

A rather large leaden ligature was applied to the common carotid of a sheep; the ends of the ligature, instead of being tied, were passed through a perforated shot; when the ends had been drawn upon enough to simply close the artery, but with some firmness, the shot was clamped with forceps, and the ends of the ligature were cut off closely, the shot supplying a perfectly smooth substitute for a knot or twist. The wound healed by first intention, and the result seemed all that could be desired.

Twenty-seven days after the operation I cut down through the cicatrix as in the previous experiment, when instantly a pellet of thick pus started from the incision as if propelled from behind, and on extending it, the ligature with its shot immediately followed.

The capillary circulation was much more free than in the former case, a good deal of hemorrhage occurring during the dissection. In the same manner as in the previous case, a ligature was placed above and below, and the specimen represented in Fig. II. was removed, the appearance of the interior of the artery being shown in Fig. III. In Fig. II. it will be seen what a large amount of inflammatory action and deposit of fibrin had occurred. When the specimen was removed, the perforation at *b* did not exist. On the contrary, its site was marked by a prominence almost as hard as cartilage. This was pared off, and thus the closed orifice of the sinus was revealed through which the ligature had ulcerated its way towards the surface. The ligature with its included slough is seen at *c*.

Fig. III. exhibits a longitudinal section of the artery. A proximal and distal plug are seen, *b b*, but there is an intervening space including the former site of the ligature, *a*, where the arterial canal is occupied by pus from *c* to *c*, whence the ligature ulcerated its

way, as shown by the direction of the rod. The lower end of the distal plug at *b*, which was bathed in pus, is seen to be fimbriated by disintegration.

Experiment III.

A thin band of lead, about a line in width, was prepared by nicely rounding its edges and giving it a fine polish. Its length was such that when doubled upon itself it sufficiently exceeded the diameter of the artery as to allow the two ends to be clamped together without any mechanical injury to its coats. This ligature was applied in the manner described, to the common carotid of a sheep on the 17th of October, 1867.

In its application I was careful to secure apposition of the internal coats of the artery and no more, and in the clamping of the ligature, as in every other way to avoid any mechanical injury to the vessel. The progress of the case was in every way favorable, and the wound healed by first intention.

Thirty-seven days afterwards the cicatrix and surrounding parts still seemed perfectly sound, but indurated. On cutting down, however, immediately beneath the cicatrix was found the ligature. By reference to Fig. IV. it will be seen that the artery is completely solidified for about an inch where the ligature was placed, *a*, and that through the centre of the large mass of fibrin, which extends from the artery to the integuments, a sinus is still permeable from the place where the ligature was extracted to within four lines of the point where it was first applied.

The ligature is seen at *d*, as found at *e*, embracing a sloughed portion of the artery.

So far, let it be observed, the healing in these cases has been by first intention, the progress of the case faultless, and the parts, judging from the surface, have appeared so sound as to justify the impression that the ligatures used had established occlusion without creating any irritation, and had become permanently encysted where they were placed.

Very special pains have been taken in these cases to exclude any possible source of mechanical irritation either from projecting ends, sharp angles, or rough surfaces; also, to avoid damage to the coats of the artery. In both cases, however, we find similar results in and about the artery. Irritation, as shown by the large mass of fibrin thrown out, and inflammation and suppuration, with ulceration,

for the extrusion of the ligature to a safe distance towards the surface.

The results in both these cases served but to increase my disappointment, which had been first caused by the action of the silver ligature, all of which was precisely contrary to what the experiments of Levert had led me to expect. Contrasted with the experiments of Levert, I could but recognize in these, however, one very important difference. Levert's experiments, as Malgaigne indeed said, when speaking of metallic ligatures in 1853, "had never yet been tried except upon *dogs*," and some of Levert's experiments had been performed upon the small femoral artery of these animals at that.

Experiment IV.

THE FIRST CONSTRICTING SILVER WIRE LIGATURE.

September 20th, 1867, I applied to the common carotid of a sheep a silver wire ligature, from the same coil as that used in the first experiment. I commenced to tie the wire as in the ordinary silk ligature for making the first part of the sailor's knot, and pulled upon the ends until the canal of the artery was diminished about two-thirds of its diameter, and then stopped. Instead of completing the knot, I then crossed the ends firmly over each other, and, finding this promised to be amply strong enough, cut them off very closely, and carefully turned them down beside each other, so that there was no projection of either of them. In that way I left the ligature, deeming it of great advantage that the knot should be as small as might be consistent with the required strength. Assuring myself of the continuance of pulsation in the artery beyond the ligature, the wound was closed.

The progress of the wound was excellent, healing promptly by first intention. I examined the patient on the 27th of October, and had some difficulty in finding the cicatrix. I made an incision as nearly as I could judge, however, in the line of it, and, on dissecting down, found it so difficult to determine the site of the ligation that, after tying the artery above and below as usual, I removed all the intervening parts *en masse*, and prosecuted the examination afterwards without disturbance from bleeding. On dissecting out the artery it presented a short slightly bulbous expansion, about a third larger than the rest of the artery. It looked like a solid mass of fibrin, and no ligature could be seen or felt in it.

There was no sign whatever of any recent disturbance in the

vicinity, but, feeling sure the bulb marked the site where the ligature had been applied, a longitudinal incision was made in it, when in the centre was found the ligature, inclosed in the solid mass which had so completely enwrapped it.

In Fig. X., at *a*, the ligature is seen, a rod being passed through it *in situ*, to show the size of the loop. This, as may be seen, separates the lips of the incision, and so increases the apparent size of the bulb. The plug, both distal and proximal, is much more extensive than in either of the previous specimens; its structure too is more hard and white, and its attachment to the coats of the artery is more intimate.

The result in this case was so different from the others; it combined in itself so completely, all one could desire, to the complete exclusion of all one could wish to avoid, that I feared it might be but a pleasing accident.

I resolved, therefore, to repeat the same experiment several times in succession, to see if the same results would be repeated in the majority of cases, deeming that, at the least, necessary to establish for this procedure any claim to serious consideration.

Experiment V.

The common carotid of another sheep was operated upon precisely in the same way as the last, except that the ligature was applied outside the sheath. The wound healed by first intention; twenty-three days after the operation the parts were removed, and the dissection exhibited results the same as the last, there being simply more fibrin thrown out in connection with the bulb which inclosed the ligature, as seen at *a*, Fig. XI. Although the bulb is just as solid, the plug is not so extensive as in the last specimen; *d*, is the pneumogastric nerve.

It will have been observed that so far, the entire bulbous portion inclosing the ligature has appeared to be a homogeneous mass of fibrin, neither the plug, arterial coats, nor the superimposed fibrin, presenting any distinct appearance or separate outline. To enable me better to observe the process by which this result was accomplished, I determined in the two following cases to remove the specimen, and kill the animal at an earlier period after the operation than before.

Experiment VI.

In the same manner as before, a silver ligature was applied to

the common carotid of a sheep outside the sheath. As usual, the wound healed by first intention.

Fig. XII. shows the appearance on the tenth day afterwards. The integrity of the ligature and the solidity of the bulb are just the same as in the specimen removed after a longer interval. The result therefore failed to yield any further information on the subject, but added, however, an additional fact to the evidence obtained.

The question on which I especially desired further information, was respecting the action of the ligature upon the coats of the artery. That it had not provoked any inflammation of them seemed plain enough, at least no evidence of it had so far appeared. Still, it seemed strange that such an amount of constriction around the artery, with the counter-pressure of the diminished current or accumulating clot within the artery, could combine for any considerable period without inducing either inflammatory ulceration or dry ulceration by absorption. The following experiment, though performed on the same date, and the specimen removed within a few hours of the last, exhibits a different condition, and will be found to throw a good deal of light on the point in question:—

Experiment VII.

The common carotid of a sheep was tied on the same day and in the same manner as in the other last experiments. The wound healed by first intention, and on the tenth day after the operation, the specimen, as shown of natural size in Fig. XIII., was removed. The ligature *a* is seen to retain its original site. At the base of the incision made to expose the ligature, the clot is less white than in the previous specimens, however, and on closer examination it is not difficult to discover the outline of the plug inclosed by the ligature distinct from the coats of the artery, its color being different, and stained slightly of a bluish-red hue.

I withdrew the rod introduced into the loop of the ligature at *a*, Fig. 13, and carefully made an incision, and hooked back the flaps so as to show the view, which is presented twice its natural size in Fig. XIV. At *b b* is seen the thick layer of fibrin which constitutes the chief bulk of the bulbous enlargement, divided by the vertical incision, and turned back. The distal plug is firm, but its color is a brown dusky red throughout. The lining coat of the artery in contact with it is also stained with the same color.

The proximal portion of the clot *d* is much lighter, increasingly so towards its termination, where it is white and quite hard.

On removing a section at *c*, the clot is seen to be inclosed as by a thick capsule whiter than its interior. The clot or plug beneath the ligature is seen to have been mutilated by the rod of whalebone which, in Fig. XIII. at *a*, was introduced through the loop of the ligature to show the degree of constriction employed.

On examining the exact site of the ligature with a lens, the outer coat of the artery, and this alone, as far as my friend Dr. Emerson and myself could judge, was found to have disappeared by absorption beneath the ligature; a sulcus being thereby formed in which the ligature rested. The abrupt margins of this groove, which are a little retracted, are drawn in a style somewhat exaggerated in order to show them more clearly at *a*, *b*, *b*.

The inner coat of the artery was so firmly attached to the proximal portion of the plug, that for some distance from the ligature it was almost impossible to separate them. The attachment of the distal portion of the clot was less intimate, especially towards its upper end.

Neither in the vicinity of the ligature, nor elsewhere, was a drop of pus or any undesirable sign of inflammation perceptible.

The only difference between the original condition of this portion of artery and that in Experiment VI., which might perhaps be mentioned, was a small branch given off at *m*.

To explain why in the same experiments, upon the same artery, the same period intervening, such a different stage of the process should appear, would be very difficult, and can hardly be accounted for by the difference of the small branch seen at *m*, Fig. XIV.

This experiment demonstrates clearly some important facts. We observe here that the "active, hard" quality is found in the greatest degree when there is the best supply of fresh arterial blood, and that where the clot is hardest, there also is its union with the internal coat of the artery most complete.

That the ligature, though it excited no inflammation nor suppuration, did, by its pressure, give rise to a process of slow interstitial absorption of the outer coat.

We, however, also see that beneath the ligature, and for a considerable distance on both sides of it, the artery is perfectly occluded by a hard "active" clot, firmly attached to the internal coat of the artery, and that the outside of the artery is at the same time reinforced by a deposit of fibrin, which seals and secures the ligature and the artery thereabout by completely enveloping it.

Therefore, though absorption had continued until all the coats

of the artery had become divided, hemorrhage could not have occurred from it, because the process of cure has proceeded so much more rapidly than the process of absorption.

Had the animal remained a little longer undisturbed, we may fairly infer that the organization of the entire plug would have been completed, and a homogeneous appearance with the surrounding fibrin would soon have been effected.

The process of repair is seen to have been so much in advance of the slower process of absorption, which occurred in the external coat, as to completely exclude any apprehension of hemorrhage.

The following experiment was undertaken with a double view of exhibiting, firstly, the appearance of the arterial canal after its proper function had for some time ceased; and secondly, to trace the comparative effects of slightly different degrees of tightness in the tying of ligatures.

Experiment VIII.

To the common carotid of a sheep I applied, outside its sheath, three separate silver wire ligatures at different points, and with different degrees of tightness.

The first I applied about twelve lines above the subclavian, and so tightly that one end of the wire thread broke off close to the loop in the tying. The second was applied about thirteen lines above the first, with considerable firmness, but with care to avoid repetition of the accident incident to the first. The third was applied about five lines above the second, with the intention of securing apposition, but of avoiding any lesion of the arterial coats. The wound closed by first intention.

Figs. V. and VI. exhibit the appearance of the specimen, removed twenty-two days after the operation. Fig. V., at *a* and *b*, just beneath the skin were projecting nodules of fibrin, the removal of which, as may be observed, exposed the ends of sinuses, through which rods of whalebone are seen projecting in this profile view of the specimen.

Fig. VI. presents a view of the interior of the artery, as exposed by a longitudinal incision. The exterior of the specimen is marked by two large rounded masses of fibrin, corresponding to the original site of the ligatures.

It is noticeable that the mass corresponding to the site of the first and tightest ligature, is much larger than that which marks

the site of both the others, which were placed near together, but tied less tightly.

The calibre of the unused portion of the arterial canal, between the ligatures, is seen to be much diminished; for a small distance midway it is partly occupied by a small reddish clot which, as we approach the ligatures on either hand, becomes a firm plug of fibrin, homogeneous with the entire mass. The artery above and below the ligatures is seen to be securely occupied with hard permanent clots *d d*. The rest of this specimen is, however, of but trifling importance compared with that which exhibits the history of the respective ligatures.

At *e* the canal of the artery is seen to be enlarged. This enlargement was found to constitute an abscess containing purulent matter. The ragged black opening in the bottom of the abscess is the mouth of the sinus, through the end of which the point of the lower rod projects in Fig. V., *b*, the ulcerous track having been formed by the ligature which had passed through, and could not be found either in the course of the sinus or in the tissues adjoining.

At *g*, where the second ligature was applied, but with less force than the first, is seen the mouth of another sinus, in which, on its way towards the surface, is the second ligature, which evidently has but recently left its place. A rod, *g*, passed into this sinus is seen projecting through the other end of it at *a*, Fig. V.

At *k* is seen the third ligature, still inclosing a clot, but evidently about ready to be extruded. The portion of clot just below its grasp is fimbriated and disintegrating, and close beside and beneath the ligature is seen the mouth of another sinus prepared for the passage of this ligature also. This sinus joins in the centre of the fibrinous mass the sinus of the second ligature, both uniting for the extrusion of both ligatures at the same point at *a*, V. The course of the upper sinus is indicated by the direction of the upper rod, Fig. V., *k*.

The above experiment, VIII, exhibits a relation remarkably exact between the rate of the ulceration and extrusion, and the degree of tightness with which the ligatures were tied.

The degree of tightness, in an equally exact degree, seems to have regulated the amount of inflammatory action, and fibrinous deposit thrown out in the adjoining parts.

The first ligature, which was tied very tightly, has become completely extruded and lost; the second ligature, which was tied

with but a little less force, has become quite detached, and is seen just within a suppurating sinus ulcerating its way towards the surface. The third ligature, which was tied with firmness, with a care not to divide either of the coats of the artery, yet sufficiently to strangulate the vasa vasorum, is found almost ready to be detached, and lying at the mouth of a sinus, already prepared for its transit towards the surface.

Seeing that the wire for the ligatures in this experiment was from the same coil as in the previous experiments; that the loops were formed and fastened just in the same manner; that the sole difference was in the studied difference of tightness with which the ligatures were applied; the difference in the result cannot well be attributed to any other cause. If, however, it be advanced that this difference in the results may have happened from accident, how shall we explain the exactness with which the degree of the inflammation and ulceration, different as they are in each instance, corresponds to the different degrees of tightness with which the ligatures were respectively applied?

The two following experiments were performed to discover the action of other constricting ligatures, applied in the same manner, but formed of different materials from the preceding:—

Experiment IX.

To the right carotid of a sheep I applied a silk ligature outside its sheath, diminishing the calibre of the artery one-half, and tying it in the ordinary manner, taking the precaution to stitch the free end outside to the integument. Fig. VII. represents the specimen as removed twenty-three day afterwards. A considerable deposit of fibrin is observed about the artery. A longitudinal section of the vessel at the original site of the ligature *a*, shows it to be occupied with a firm clot, which is sufficiently stained to be definable.

Of the ligature there is no sign at the point where it was applied. There is no trace of a sinus having existed for the transit of the ligature, except it be at the outer part of the fibrinous mass *b*, into which a rod is shown inserted about four lines; this has the appearance of being the remains of one. That the ligature did not become encysted at any part, however, there is the best of evidence in its being found outside where its free end had been stitched to the integument.

Experiment X.

A lead wire ligature was applied to the right common carotid of a sheep so as to diminish the diameter of its canal about two-thirds, and was fastened in the same way as the previous silver ligatures. On examining the parts thirty-six days afterwards, I found the wound healed soundly enough, but at about the middle of the cicatrix, beneath the integument, was a small soft tumor. On making the first incision for the removal of the specimen, there exuded a drachm of very thick pus, and in this I found the lead ligature. A profile and section of the specimen as removed is represented in Figures VIII. and IX.

In Figure VIII. the amount of fibrin thrown out in the neighborhood all the way to the skin is seen to be very large. Where the ligature was applied *a*, the artery is consolidated, and is soundly plugged for a good distance above, and for a short distance below.

There is no appearance, so far, of any ulceration or of a sinus having formed.

Fig. IX. is a view presented by a longitudinal incision of the entire specimen down to the artery, in search of the track of the ligature's transit.

A cyst with thick plicated walls is seen at *a*. It was thence came the pus and the ligature on the first incision.

Traversing the diameter of the fibrinous mass obliquely from this cyst to the original site of the ligature, is observed a hard plug of fibrin *c*, which evidently has been slowly deposited in such a way as to close up the rear of the ligature as it ulcerated its way towards the point where it became encysted beneath the integument, thus precluding the possibility of hemorrhage.

In the last two experiments we see that ligatures, the material of which rendered ulceration through the artery and their extrusion inevitable, did not give rise to any hemorrhage, although the silk ligature was so loosely applied as to diminish the diameter of the artery only one-half, and in the case of the lead ligature only about two-thirds. This shows that even with ligatures of this quality, where no lesion of the coats had been inflicted in their application, the process of consolidation and deposit within and around the artery, proceeded so much more rapidly than the ulceration caused by the ligature as to render secondary hemorrhage impossible.

Although in none of the specimens where the loose silver ligature had been used do we see any reason for suspecting future displacement, their continued permanence a point of considerable importance, could be established only by experience. Accordingly, in 1867, I performed the three following experiments, and allowed the animals to remain undisturbed, one until late in 1868, the other two until early in 1869. This I was the more prompted to do, because when the previous experiments were exhibited at the New York Pathological Society, some of the members, who seemed to coincide on other points, appeared to entertain some doubt as to the ultimate disposition of the silver constricting ligature if allowed to remain for a much longer period than that in the cases presented.

Experiment XI.

November 23, 1867. To the right common carotid of a sheep I applied a silver wire ligature outside the sheath, diminishing the diameter of the artery about two-thirds, and tying with a half knot as previously described. The wound healed by first intention.

From the time of tying the artery there was no manifest disturbance of the health of the animal up to October 10th, 1868, when the specimen represented at Fig. XV. was dissected out, and the animal afterwards killed. *a* shows the relative size of the artery at this date, compared with its fellow of the opposite side *d*, and of the pneumogastric nerve *c*. The present size of the artery which was tied is seen to be a little less than that of the pneumogastric nerve of the opposite side, except at one point, where there is a bulb-shaped expansion. On cutting into this, the silver ligature was exposed as seen at *a*, with a rod passed through it *in situ*, to show the size of its loop. The lips of the incision being separated thus by the rod, the bulb is made to appear larger than it really is.

The artery at the bulb, and for some distance above and below, is solid and hard. The ligature is precisely where it was placed. There is no sign whatever of any previous inflammation. The abnormal condition consists simply in the occlusion by fibrin, and the atrophy of the vessel from disuse.

Experiment XII.

A silver ligature was applied in the same manner to the carotid of another sheep, November 25th, 1867. The progress of this case was the same as in the former one.

January 25, 1869. The parts were removed, and presented the appearance exhibited in Fig. XVI.

The size of the artery *a* is seen to be but little larger than that of the pneumogastric nerve in Fig. XV.

On either side the former vicinity of the ligature, the artery is perfectly occupied with a very hard plug. That on the distal side is unusually long, extending to *b*, the first collateral branch, approaching which it becomes tapering. On seeking for the bulb, which in the previous cases marked externally the location of the ligature, I was very much surprised to find, in its stead, an interspace of about six or seven lines, *c*, occupied by loose fibro-cellular tissue, having a rather flocculent appearance, and seeming to have a fringe-like continuity of structure with the two ends of the artery, which were gradually flattened out and fimbriated. There was no sign whatever of past inflammation, either there or in the vicinity, yet, with the most careful search, the ligature could nowhere be found.

The only explanation of which this exceptional case seems to be susceptible, is that the fibrinous bulb, having no further use, underwent fatty degeneration and absorption, and so released the ligature which gravitated to some other part, where it could not readily be found.

Of the following experiments, the first was performed as a repetition of the two last, and the second upon the same animal to discover the effects upon an artery, of a silver wire ligature in simple contact with the absence of all avoidable constriction or pressure.

Experiment XIII.

A silver ligature was applied to the common carotid of a sheep precisely as in the two previous experiments, November 23d, 1867. By an extension of the same incision, a ligature of the same wire was applied about ten lines above. It was applied with great care, so as to have the loop without kink and of a regular circular form. The ends were drawn upon sufficiently only to prevent the loop slipping down from its position. This may have caused a constriction to some degree, though it must have been but very slight. The ends were fastened in the same manner as in the previous ligatures, being cut off very closely, and turned down parallel with and upon the loop. The progress of the wound was all that could be desired.

January 5, 1869. After thirteen and a half months, the artery

was laid bare for a considerable length. As the examination proceeded, no sign of any past inflammation or diseased action in the vicinity could be detected. The artery was tied above and below, and the intermediate part, as removed, is exhibited at Fig. XVII. The first ligature which was applied is seen at *a*. So slight is the change it produced in the outward appearance of the artery that I was unable to detect its whereabouts, and narrowly escaped leaving the ligature behind *in situ* by dividing the artery for removal, above it. It is seen at *a* just where it was first placed, imbedded in the interior of the solid block of fibrin which occupies the artery up to *b*.

Where the second ligature was applied, so as simply to encircle the artery at *c*, there is seen a scarcely perceptible ridge, beneath which a rather dark line is visible through an *overlaying* coat of fibrin. On pressing this with the fingers, a resisting hard ring is felt, which by a touch of the knife is proved to be the ligature in question.

Through an incision into the artery, a little above this ligature, a curved piece of wire, *d*, is passed so as to traverse the canal encircled by the ligature, and reappear through the lower incision. By this means the canal is found to be unobstructed within the loop of the ligature. On careful examination with a lens, the internal coat of the artery within the loop is found to have sustained no change. The middle coat is a little softened. Between the middle and outer coats rests the ligature, somewhat blackened and seeming to have stained the parts in contact with it.

Covering the ligature externally is the outer coat, and a thin layer of fibrin over that for some distance, completely but thinly enwrapping it.

The combined results of these last experiments, it must be admitted, are all that could be desired as far as they go. They sufficiently prove that the results obtained in the similar previous experiments may be relied on as permanent.

The negative evidence, too, furnished by the last ligature, concerning obstruction as a cause of deposit from the arterial current, is of equal importance with the positive contrast exhibited by the tighter ligature below.

RECOGNITION OF THE VALUE OF THE FOREGOING EXPERIMENTS.

Up to the present, I have delayed publishing anything upon this subject. In order to secure for the experiments, however, the fullest inspection and criticism, I have at different times presented each specimen, soon after its preparation, to the New York Pathological Society. In the course of the presentations of them, no accident or failure from any cause has been suppressed or withheld. One of the sheep unfortunately strayed, and was killed and partly devoured by dogs.

With this exception, every experiment whatsoever which has been commenced has been submitted to the Pathological Society for its examination. The first presentation I made, gave rise to a discussion occupying most of the evening, which was participated in by Professors F. Hamilton, Markoe, Sands, Post, Peaslee, Dr. Bozeman, and others.

They have also been privately examined by Prof. S. Smith, Prof. F. Hamilton, Dr. Sims, Dr. Knapp, Dr. Neftel, and many others.

On the occasion of the presentation of the last set of specimens at the Pathological Society, it was unanimously resolved that, in view of their practical importance, a committee be appointed to make a special report upon them, though, for reasons unknown to me, I believe it never assembled.

An abstract of some extemporaneous remarks I made upon them in the Society, was soon after quoted in the principal journals both here, in France, and in Germany, but before committing anything in detail to the profession, I have preferred to wait until any unconscious tendency on my own part to overestimate the importance of these experiments may have subsided.

A SUMMARY OF THE FACTS DEMONSTRATED IN THESE EXPERIMENTS.

A reference to Figs. I., II., III., IV., V., and VI. shows that of whatever material the ligatures were made, whether of silver, lead, or silk, if they were applied with the ordinary tightness, or with the firmness necessary to merely close the arterial canal, they in every case provoked inflammation, extrusion, inflammatory deposit, and suppuration.

In every instance, by active ulceration, the tight ligature severed

the coats of the artery, and formed a sinus through which it was expelled from the surface, or removed to a point subjacent to the superficial cicatrix; or else it became the centre of an abscess. The wound in every case of metallic ligature healed, nevertheless, by first intention, and up to the time of final dissection, there was no visible cause for suspecting that the ligatures had not become quietly encysted just where they were first placed. These facts show that the retention or expulsion of a ligature depends not alone upon the *material* of which the ligature is made.

The specimens represented in Figs. VII., VIII., and IX. show that ligatures which were applied so loosely as to diminish the diameter of the arterial canal but one-half or two-thirds, the material of the ligature being lead or silk, induced very complete occlusion of the artery, but that subsequently they were displaced, the silk being expelled from the surface; the lead to a point near to the surface, the inflammatory action, however, having been manifestly less intense than after the tighter ligatures, even though made of silver.

These facts show that permanence of a ligature is by no means insured by *looseness alone.*

The specimens shown in Figs. X., XI., XII., XIII., XIV., XV., XVI., and XVII. show that the ligatures, being in their material innocuous (silver), and in their application so loose as to diminish the canal but about one-half or two-thirds its diameter, and thus allow the arterial current to continue through it, induced occlusion, and by the formation of a better organized clot, than did the ordinary tight ligature.

The loose silver wire ligatures thus applied produced no undue inflammation, no suppuration, no active ulceration.

The coats of the artery, in contact with this ligature, did in most cases undergo a subsequent interstitial absorption, according to the degree of the constriction used, until resistance of the coats ceased.

That before such absorption took place, the arterial canal was securely closed by a well-organized clot within, while simultaneously without, the ligature and the artery for some little distance above and below it, were safely enwrapped by layers of fibrin. These, with the internal plug and the arterial coats, subsequently formed a small solid bulb-shaped and apparently homogeneous mass, in the centre of which the ligature was imbedded.

That after various periods, extending to over thirteen months,

they were found just where they were originally placed, exhibiting no sign of irritation, with the bulb inclosing them increasingly firm, healthy, and organized.

That in one case, however, examined at the latest date, the bulb appeared to have undergone fatty degeneration and absorption, and so allowed the ligature to gravitate amongst the adjacent tissues.

Fig. XVII. shows that whereas the silver ligature with constriction induced consolidation of the arterial canal at that point by deposit, the ligature applied without constriction caused no change in the canal whatever.

All the foregoing results combine to establish that a ligature of innocuous material, applied so as only to obstruct and regulate the arterial current through it, to a certain degree induces a better organized solidification of the artery, than does a complete arrest, with less danger of secondary hemorrhage; and that such a ligature, so applied, constitutes a *permanent ligature.*

THE DEGREE OF ANALOGY BETWEEN THE EXPERIMENTS SUBMITTED, AND THE USE OF THE CONSTRICTING SILVER LIGATURE FOR THE TREATMENT OF ANEURISM IN MAN.

So far, I have confined myself exclusively to facts. Before allowing myself to venture upon any deductions from them, I prefer to analyze the nature of the experiments I have presented, so as to fix their value for such inductions as may follow.

To dispute the analogy between the operation of physiological laws in man and in the lower animals, would be to ignore the greatest discoveries in medical science. While there is a close analogy, however, there are also many points of difference between them, both in the ends and the means, both between their organs and their functions.

The important question in all our experiments upon animals is, to understand precisely in each case what these points of difference are, otherwise we become at once unscientific and unsafe.

The points of analogy of chief importance in experiments with ligatures upon arteries, concern 1st. The structure of the coats; 2d. The size of the vessel; 3d. The force of the current; and 4th. The quality of the blood in the arterial canal.

A long time ago I performed various experiments with ligatures upon the arteries of dogs, but I found the analogy to be so imper-

fect in all those points which in man are the chief sources of failure after such operations, that I cast aside all my notes of them as useless for reliable conclusion or practical application.

For these reasons, in a previous part of this essay, I have objected to conclusions based upon the experiments of Levert, which were performed not only exclusively upon dogs, but in some of the cases upon the arteries of their extremities.

In all the foregoing experiments the ligatures were applied low down upon the common carotid of sheep, the animals all being selected for their full growth and large size.

The sheep is an animal notoriously intolerant of injury, and as compared with the human carotid, the arteries operated upon were very nearly the same, in 1st. The structure of the coats; 2d. The size of the vessel; 3d. The force and frequency of the current; and 4th. The quality of the blood in the arterial canal. The same operations upon these animals produced uniformly the same results. These results were precisely the same as follow the same operations in man, as far as known. For these reasons it is plainly just to assume that if the operations which in the experiments adduced were performed upon the healthy arteries of sheep with such uniform and superior results, had been performed upon the healthy arteries of man, the results in both cases would have been analogous. That, therefore, the superiority of the constricting silver ligature, if applied to the healthy human artery, is thereby morally proven.

REASONS WHY THE CONSTRICTING SILVER LIGATURE SHOULD BE SPECIALLY ADAPTED TO PROMOTE SOLIDIFICATION OF AN ANEURISMAL SAC.

The first great object to be desired in the treatment of aneurism by any method, is the continued formation within it of hard active clot until the sac is solid.

The processes by which such consolidation is effected, according to the means employed, were so fully dwelt upon in the earlier part of this essay, that a brief allusion only will be sufficient to recall them for our present purpose. It was there shown that the distinguishing principle which marked the new epoch inaugurated by Hunter, was that of *diminished,* in contra-distinction to that of *arrested* current.

That in the various attested cases of spontaneous cure, this was observed to be the common ruling principle in all of them.

That the incomprehension and neglect of this principle in the treatment by compression very nearly resulted in the abandonment of this method.

That the explanation of this principle, and the demonstrations of its action in the production of hard instead of soft clot, revived the treatment by indirect compression on a new and scientific basis.

That the observance of this principle led to the remarkable successes which afterward established this method in universal favor, and which from the time of Bellingham has continued to the present day.

That "flexion," "manipulation," and other improvements of modern times for producing permanent obliteration of the cavity of the sac, are but different methods of applying more or less the same principle.

It requires less constriction to obliterate an aneurism beyond, than to induce closure of an artery at the seat of pressure. Mr. E. Hart says (*Holmes' Sys. Surg.*, vol. iii. p. 419): "Usually when a limb is examined after the successful use of compression, the artery above the tumor shows no trace of its action. The tumor is quite firm, being filled with coagulum." This is in conformity with the principle stated above; for when a diminished current rendered insufficient to fill the natural canal of the artery, enters the cavity of an aneurismal sac, at once its direction is changed, its volume is reduced, its motion is embarrassed and diminished. These changes, the very shape of the sac compels; and so induces coagulation within itself first, while the arterial canal at the point compressed, remains for the present unaffected and free.

It is on precisely the same principle the constricting ligature is calculated to act. Instead of causing complete stagnation, and so the formation of soft clot in the aneurism, it allows a continuance of fresh arterial current into the sac, in quantity sufficient to furnish all the fibrin required, and with a slowness favorable to the deposition of it, in the form of hard active clot. The continuance of this process is in this way contemplated until the solid contents of the sac are organized throughout.

The constricting ligature may thus be a means of using indirect compression, where by the ordinary method it would be impracticable.

We know that the contents of an aneurism solidified as above

described could not disintegrate, and therefore the integral dangers which so often arise therefrom after the ordinary ligature would be thus avoided.

As the organization of the active clot progresses, there would be increasing immunity from

1st. Relapse; 2d. Suppuration of the sac; 3d. Secondary hemorrhage from the sac.

THE LOOSENESS OF THE CONSTRICTING LIGATURE TENDS TO AVERT SERIOUS DAMAGE FREQUENTLY DONE TO THE PARTS BEYOND BY THE ORDINARY LIGATURE.

In a previous part of this essay it has been shown that one of the principal causes of failure after the ordinary ligature, is *gangrene.* It will be seen that the causes of this very dangerous complication, as therein described, are by the use of the constricting ligature excluded. The change of circulation, unlike that by the other mode, is neither sudden nor complete. At the suggestion of the constricting ligature we may expect the collateral vessels gradually to develop and assume the new and increasing task assigned to them, taking it up at the same rate it is relinquished by the main artery, so as to preserve the balance and regularity of the circulation in the parts beyond.

Cerebral accidents, after ligation of the carotid, would for the same reasons be avoided by the substitution of this method.

AN ATHEROMATOUS CONDITION OF THE ARTERIES A SPECIAL REASON FOR PREFERRING THE CONSTRICTING SILVER LIGATURE.

Having already devoted one section of this essay to the etiology of aneurism, and collated therein the opinions of the principal authorities on the subject, we will now simply recapitulate the principal points which are there stated.

In the first place, we observe that in aneurismal subjects the atheromatous condition usually involves all the larger arteries, in the order of their distance from the heart.

That atheroma affects first those coats which by the ordinary ligature are severed.

That the first effect of this degeneration is to destroy the retractility of these coats.

That in this condition these coats when divided have no ability to throw out plastic lymph.

We accordingly see that an ordinary silk ligature applied to an artery in a completely atheromatous condition, contains within its loops the external coat only, which is already strangled and killed by the force used in tying.

That to arrest the force of the arterial current there is neither retraction nor plastic exudation.

That as soon as the inevitable ulceration and sloughing from without, and the force of the current from within, have resulted in division of the thin external coat, nothing remains to prevent hemorrhage but the soft or passive clot at the pouting ends of the divided vessel.

If the degeneration be calcareous, the danger is more immediate, as the artery may be cracked or crushed at once by the force applied in tying the ligature.

We have seen that however great may be the care to select a site distant from the aneurism, certainty in obtaining a healthy site for the ligature is impossible.

In view of the fact that the principal mortality after this operation is from secondary hemorrhage, it would seem ironical to ask: If in such a case the ordinary silk ligature is a *safe* ligature!

Admitting that ligation under such circumstances is attended with risks which although great, are nevertheless unavoidable, the question still remains. Is the ordinary silk ligature *expedient?* Under such circumstances, I think it is not. I believe that the constricting silver ligature under these circumstances will be found much more expedient, because

(*a.*) It inflicts no immediate lesion upon the coats of the vessel.

(*b.*) It does not strangulate the capillaries nor greatly disturb the nourishment of the coats. The ligature can be applied outside the sheath.

(*c.*) The closure of the artery is effected independently of any lesion or inflammation, by hard active clot deposited from the passing arterial current at the seat of the constriction, regardless of the condition of the coats of the vessel.

I think the constricting wire ligature will be found more expedient, because of the immunity it promises from further and subsequent dangers which ensue after the application of the ordinary silk ligature.

It is not followed by destructive inflammation, or by active

ulceration. Its action is not favorable to pyæmia. It does not hinder healing of the wound by first intention.

I think it must be admitted that, with respect to the analogy between the experiments submitted, and the application of the constricting silver wire ligature to the diseased arteries of man, the points of difference, instead of being grounds of objection, are reasons for preference so strong, as to appear incontrovertible by any evidence short of actual experience.

PREVIOUS ATTEMPTS WHICH HAVE BEEN MADE TO MODIFY THE ORDINARY PLAN OF LIGATION.

The great fatality we have shown to attend the expulsion of the ordinary ligature creates increasing anxiety until its ejection has been accomplished.

How to avoid the dangers incident to the release of the ligature bv inevitable ulceration? and how to secure permanent union of the wound by first intention? These have ever been the foremost questions in connection with the ligation of arteries.

TEMPORARY LIGATURES.

Jones of England, and afterwards Maunoir (de Genève), thinking to furnish a satisfactory answer to the above questions, tied the thread so as to divide with certainty the inner coats of the artery, and immediately removed it; thus expecting by the retraction of the divided coats and the quick formation of coagulum, to insure occlusion of the artery, and be at the same time rid of the seton-like action of the ligature in the wound.

Travers and Beclard pursued the same plan, but did not remove the ligature within from one to six, twenty-four, or fifty hours. Scarpa, avoided injuring either of the coats of the vessel, removed his compressing cylinders in from three to six days. The removal of these temporary ligatures was always exceedingly troublesome, and to facilitate it a great number of ingenious instruments were invented.

The temporary ligature was at a later day employed by Velpeau, who pressed the artery between a pin and a thread, and "a second thread fixed to the head of the pin served for its withdrawal," a proceeding so very like what is now known as acupressure, that

one could scarcely state the difference. "Velpeau avait paré a cette difficulté en transformant la suture entortillée en ligature temporaire; l'artére servée entre l'épingle d'une part et les anses de fil entre croisées de l'autre; un second fil fixé a la téte de l'épingle servait a la retirer." (*Dict. Encyc. des Sciences Méd.*, vol. ix. p. 322.)

More recently Mr. Dix, of Hull, and afterward Mr. T. Pridgin Teale, applied a temporary ligature by passing a silver wire beneath the artery, the free ends of the ligature by means of needles being carried through the soft parts at a distance from the wound where they were tied over a compress.

Although the wound was thus enabled to proceed with healing by first intention, erysipelas occurred and death resulted.

Since then, during 1868, temporary ligatures were used in New York by Drs. Peters, Buck, and Prof. Markoe.

Dr. Geo. Peters compressed the femoral artery between a hempen loop and the cross-bar of a double canula; the free ends traversing the tubes of the canula were tied over its outer extremity. The ligature was tightened so as only to stop the circulation, the weight of the canula resting upon the artery.

The patient, who was previously in a very weak state, did not thrive well. The ligature was removed in forty-seven hours. Subsequent gangrene compelled amputation, but recovery followed.

Dr. Buck applied a silver wire to the femoral artery and also to the subclavian. In each case the wire was secured by three twists, so as to close the canal, the ends of the ligature protruding from the wound.

In the latter case, on account of the difficulty and danger of attempting removal, the ligature was left until it ulcerated its way through the vessel. The patient was cured. In the former case in which the patient was also cured, a separate operation had to be performed for the removal of the ligature.

Dr. Markoe used the same treatment on the femoral artery, having also to make a subsequent operation for removal of the ligature. Patient died from gangrene. (*Essay on Acupressure*, by Dr. Geo. A. Peters, New York, 1869.)

Notwithstanding the well-known skill of the operators in the last-mentioned cases, I believe these operations have not since been repeated by them with success.

In the New York *Medical Record* for December 16, 1869, p. 473, we find a case reported by Dr. Buck, of gradual compression of the femoral artery by a hemp thread, applied by means of a double

canula and miniature tourniquet. Patient survived twenty days, and died from secondary hemorrhage at the seat of the ligature. This faithful surgeon, after the results of these efforts, stated that he contemplates a future trial of digital compression upon the naked artery.

ANIMAL LIGATURES.

To avoid occasion for extrusion of the ligatures, Travers, Physick, Cooper, Lawrence, Cawardine, and Porta, had recourse to threads made from intestine, nerves, tendons, and untanned integument, which in some cases as recommended by Jameson were applied so as not to divide any of the arterial coats, but so as only to stop the circulation. The results, however, were generally bad; they gave rise to secondary abscess, and have for a long time been abandoned.

METALLIC LIGATURES.

Dr. Levert, of Alabama, upon a suggestion of Dr. Physick, tried some experiments upon dogs, with ligatures of lead, gold, and other metals, as also of gum-elastic and grass. In all cases the ligatures were tied firmly, so as to close the artery, and the parts were examined mostly in from two to four weeks after, the longest interval being seven weeks. It is stated that the metallic ligatures were generally found where they were placed. Sir James Simpson, we believe, has repeated these experiments with like results. Dogs and cats, however, were the animals principally used.

Dr. Stone, of Louisiana, ligated the common iliac with a silver wire drawn tight enough only to stop the circulation. The patient died twenty-six days afterward of dysentery, and as there was no post mortem, the exact action of the ligature was never ascertained. (*Amer. Journ. Med. Sciences*, October, 1859, p. 570.)

Mr. Thomas Smith applied a silver ligature to the radial artery, and in three months afterward had to cut the ligature out. (*Holmes' Syst. Surg.*, vol. iii. p. 15.)

Redfern Davies tied the popliteal artery for elephantiasis Arabum with a silver ligature firmly, and it came away on the twenty-first day afterward. (*Lancet*, February 28th, 1863, p. 233.)

Mr. King, of the Hall Infirmary, applied the silver ligature in two cases. In one case the external iliac was tied, and death

resulted from suppuration; in the other, the femoral was ligated, and secondary hemorrhage occurred on the eighth day, when the vessel was secured higher up with a silk ligature. No account, however, is given of the state of the vessels. (*Lancet*, vol. ii. October 6, 1866.)

The external iliac was tied by Mr. Pollock with a silver wire, and the patient died of another disease. The ligature is said to have been satisfactory. (*Lancet*, vol. ii. September 22, 1866.)

A silver wire ligature was applied to the femoral artery by Mr. Brodhurst. "The artery having been exposed in the usual manner, a silver wire was passed round it, and the two ends twisted together; by this means, the pulsation in the tumor was entirely arrested. The silver wire was now cut off short, and the wound closed with sutures. Secondary hemorrhage followed, which three additional ligatures failed to permanently control. The day after the application of the last, which was silk, the patient died. Of the post-mortem appearance it is said 'the lower wire is the one first applied, and it will be noticed that this has almost entirely cut its way through the artery, only about an eighth of the calibre of the vessel remaining intact.'" (*Trans. Pathol. Soc. of London*, vol. xviii. p. 67.)

At the bleeding ends of arteries, silver ligatures have been firmly tied by Dr. Letteueur, and they came away about the same, he said, as if they had been silk. (*Letteueur, Gazette Hebdomadaire*, Feb. 21, 1862, p. 119.) Dr. Lente, of New York, claims a different experience.

Langenbeck used iron ligatures in the same way in two amputations, and they were extruded as if they had been organic, only a little more slowly. (*Ansa fili Metallici nova Methodus Hæmostatica*, Berlin, 1861, pp. 12–17.)

In the latest highly authoritative review of this question we find "it is incontestable that ligatures of gold, silver, platinum, or iron can rest inoffensive and encysted in the parts. Still, however small they be, they more often cause the formation of secondary abscesses, and are eliminated with the pus." (*Dict. Encyc. des Sciences Méd.*, 1867, vol. vi. p. 321.)

"Ligatures of a metallic nature have been employed with expectation that they would become encysted and quietly resident, as bullets and other metallic substances not unfrequently do when lodged in the ordinary tissues. Both forms of ligature, however, have hitherto been regarded by nature as foreign substances, and have been extruded accordingly." (*Miller's Principles of Surgery*, p. 321.)

THE CHIEF CAUSES WHICH HAVE CONTRIBUTED TO THE FAILURE OF THE TEMPORARY LIGATURE, ANIMAL LIGATURES AND METALLIC LIGATURES.

After all the efforts which have been made with these various styles of ligature, neither of them can lay claim to any general acceptance, their use, when ventured upon, being rather in the way of experiment.

As we have reviewed the objections to the ordinary silk ligature, we will now proceed to point out the chief causes of the failure of the above mentioned methods.

In the plan pursued by Jones and Manoir, great care was taken to effect with certainty the division of the internal coats, as upon the completeness of their retraction within the external coat depended primarily the arrest of the current. The force with which the ligature was applied, even though it was to be removed instantly thereafter, was sufficient to strangulate the vasa vasorum, and endanger ultimate sloughing of the external coat at that point.

Beside this, the artery so severely wounded and weakened was immediately, by the removal of the ligature, compelled unsupported to endure the full force of the current, which, in many cases, must have continued through it, notwithstanding the retraction more or less imperfect of the divided internal coats.

In the method pursued by Travers and Beclard, the process was the same, with this exception, that after from one to fifty hours, another operation was superadded for the reopening of the wound and extraction of the ligature. This, in addition to the previous injuries inflicted, must certainly have retarded or prevented all prospect of healing by adhesion, a point which was specially contemplated in the operation.

In Scarpa's plan, the extensive contusion of the artery by the ligature, together with the seriousness of the disturbance for its removal at the late period of from three to six days afterwards, was specially adapted to produce extensive sloughing of the artery, and septæmia.

The animal ligatures are all more or less liable to possess within themselves septic properties. They were usually applied so tightly as to certainly divide two-thirds of the substance of the arterial coats, and, though by Jameson used more carefully, so as to avoid actual lesion, their tightness was probably sufficient to strangulate the vasa vasorum.

Though the metallic ligatures seem at first to present a better history, there is not one instance on record, as far as I can ascertain, where such a ligature has been applied, and its permanence demonstrated in the human subject for any considerable period. The only examples of their continuance for even a short time, as far as I can find, have been in the case of dogs.

The results of the experiments by Levert, which, as Malgaigne once remarked, were on "dogs" alone, are on this account for practical inference totally unreliable.

Apart from the notorious tolerance which dogs and cats have of injury and abnormal conditions over even other animals, there is an entire want of analogy in the essential points in the case, viz., the size of the artery and the force and volume of the current.

Experience in the application of the tight metallic ligature to the ends of divided arteries, by Thom, Smith, Langenbeck, Letteueur, Simpson, and others, confirms the similarity of its action to that of the ordinary ligature.

I have quoted Dr. Stone's ligation of the iliac, and other cases of sutures which have been left behind in closed cavities, and were never afterwards seen or otherwise heard from. This as evidence however, is purely negative. Ligatures and sutures so small, may have easily escaped from the wound unnoticed; or, as with the metallic ligatures in Figs. IV., V., VI., and XI., the wound may have healed by first intention, yet ulceration and displacement of the ligature occur, with nothing on the surface to indicate it.

All the *positive* evidence we have, is that metallic ligatures have not become quietly encysted where placed, and the reasons why they have not are ample. They have always been applied either so as to *divide* the inner coats, or else to *strangle* them. It is for the following reason Mr. Nunnelly, of Leeds, recommends iron thread of a very fine kind, because, he says, it will be found "to cut well through the inner coats of a vessel, leaving the outer one entire, upon which the wire holds well." (*Lancet*, May 10th, 1862, p. 486.) Mr. Peck, who presented the specimen of Mr. Broadhurst's case to the Pathological Society of London, said on this point in explanation of the result: "The answer appears to be in the fact, that in order that the artery may not be divided, the ligature must not be drawn too tight; the force employed should only be sufficient to stop the beating of the tumor." (*Transactions of the Pathological Society of London*, vol. xviii. p. 67.) Even where a degree of looseness has ostensibly been attempted, I think the

coats have rarely escaped without immediate damage, because in tightening the ligature, the puckering within its loop insures pressure greater upon some points than upon others.

As far as any positive evidence goes, the mere closing of the canal has always been enough to set up active ulceration, as in Mr. Broadhurst's case, and as corroborated by the results of cases seen in Figs. I., II., III., IV., V., VI., and IX., in some of which the greatest care was used to avoid damage to the coats in the closing of the artery.

ABSENCE OF THE FOREGOING CAUSES OF FAILURE FROM THE METHOD OF THE AUTHOR.

In the permanent ligatures exhibited at Figs. X., XI., XII., XIII., XIV., XV., and XVII., an immediate lesion of either of the arterial coats was in no case inflicted. In no case was there strangulation of the vasa vasorum. In no case was the arterial current completely arrested. On the contrary, in all these cases, the integrity of the vasa vasorum was relied upon for aid in promoting the encystment of the ligature, and the organization of the future clot.

There was no direct lesion, no great and sudden change, no morbid action was set up, but processes purely physiological, were instituted to meet the demands of the new conditions.

SOME OTHER METHODS WHICH HAVE BEEN PROPOSED TO SUPERSEDE THE ORDINARY LIGATURE.

The difficulties attending an early extraction of the temporary ligature, and the dangers attending the expulsion of the ordinary ligature, have suggested compression of the artery by means of instruments so constructed as to enable the operator to regulate both the degree and continuance of the pressure.

Gradual constriction by such means has been tried by Dubois. The "Serrenœud simple," the "Serrenœud" of Assaline, and the "Presse Artere" of Deschamps were inventions for the same purpose. They were applied to the artery, and gradually tightened until the vessel gave way, when the instrument was removed from the wound. As Sedillot remarks, all these have been successively abandoned.

In evidence of the general dissatisfaction which is constantly felt with the ordinary ligature, we find various similar attempts being constantly repeated. Amongst others more recent may be mentioned the Spring Forceps of Mr. Nunnelly. (*British Medical Journal*, October 12, 1867.) The "Tubular Presse Artere," of Mr. Richardson (*Dublin Quarterly Journal*, November, 1869), which is very like fine forceps, but is worked by a screw. Instruments of similar construction have also been invented by Prof. N. R. Smith, of Baltimore, and by Dr. Buck, of New York.

Sir James Simpson has done more than any one else to show the evils of the ordinary ligature, and to establish a method possessing many superior advantages, especially as applied to wounds. The application of acupressure in some regions, however, must be difficult, and in all cases accurate regulation of the current by it must be impracticable.

A CASE IN WHICH THE CONSTRICTING SILVER WIRE LIGATURE WAS APPLIED TO THE FEMORAL FOR THE CURE OF POPLITEAL ANEURISM.

On the 28th of January, 1869, I was present by invitation at an operation for ligation of the femoral artery for popliteal aneurism of the right leg.

Being invited by the operator to apply the ligature, and in my own way, I used the silver wire, and gradually increased the constriction until the pulsation in the tumor was doubtful, and in the intervening portion continued unmistakably. The loop of the ligature was made as in Fig. XVIII. *a*, and an additional tie as in the ordinary knot was added. The ends were cut off closely, turned down, and the ligature left. My part of the operation there ended. The wound was partly closed with silver wire sutures and adhesive straps, the limb bandaged, moderate pressure by interposed compress being made over the aneurism.

The following notes made by me are extracted from my Case-book in which they were recorded daily until February 8th:—

Jan. 29. Pulse, 80; temperature right foot, 90; left, 89; pulsation in tumor distinct; size considerably diminished.

30*th.* Pulsation diminished, patient says he feels better than for months before.

31*st.* Pulsation of tumor not perceptible; temperature of limb normal.

Feb. 2. Wound healed throughout by first intention, except at one end where lips had not been in apposition. Cannot detect pulsation in tumor. Temperature right foot, 94; left, 90; sleep, appetite, bowels, all natural.

4*th.* Pulse, 84; temperature right foot, 94; left, 91; tumor subsiding; but this morning there is a sort of diverticulum from the tumor yielding slight pulsation. It seems to be a dilatation of an external articular artery.

5*th.* Pulse, 78; temperature right foot, 94; left, 91.

6*th.* Pulse, 80; no pulsation perceptible; tumor very much diminished, and hardness increased.

The cure seems so complete, his surgeon encourages the patient to walk about a large hall. The patient thinks it does him good, and is in high spirits.

7*th.* Pulse, 80; temperature right foot, 95; left, 94. Patient feels well, is up and dressed, and allowed by his attending surgeon to walk about the room and large hall as much as he likes, which he does without a cane or assistance.

8*th.* *The eleventh day after the operation the patient was sent away apparently cured.*

I expressed great regret on finding he had gone so soon, but neither saw nor heard anything about the patient until the fifteenth of February.

15*th.* I was called for by the attending surgeon, who informed me that he had not seen the patient for some days; but was just informed that he was bleeding.

I accompanied him to see the patient, whom I found in the attic room of a boarding-house in the lower part of the city. The patient then told me that, on leaving, he proceeded alone on the public cars about three miles, and then walked some little distance to his boarding-house. That the stairs, which were very steep and crooked, he had gone up and down several times a day, and had taken walks in the street.

That on the 13th he had become, as he said, "excited" in a crowd, in that bustling part of the city, and that on the following evening bleeding occurred from the wound, which he stopped by pressure. It slightly recurred, and he stopped it by a bandage which was then around the limb.

The bandage we at once removed, but no bleeding followed. The femoral artery just above the wound was plainly felt to be solid. The bandage was reapplied with compress, and the patient

then walked down stairs, and was taken back again to the operating-room. On arriving, there was still no bleeding, but, for security, a tourniquet was applied as near as possible to Poupart's ligament, and the patient was left for the night.

On the 16th, the attending surgeon applied an ordinary silk ligature just below Poupart's ligament, and shortly afterward he was sent to hospital.

Several weeks afterwards, on hearing of his death, I sought for an account of his case at Bellevue Hospital, where he had been carried, but found no notes had been kept, and no *post mortem* made. The synopsis of the latter part of his history is that,

When the silk ligature was applied, the constitutional condition of the patient was comparatively robust. Five or six days afterward he was dead from secondary hemorrhage.

The constricting silver ligature in this case must be admitted to have yielded a success quite extraordinary, so long as the ordinary rules in the after-treatment were even indifferently observed. This success was obtained, too, in spite of the violation of a most important rule with me in this operation. I prefer that the ligature should be applied either outside the sheath, or that the artery should be separated from the sheath as little as possible. In this case, the sheath was separated from the artery quite a distance, in consequence of changing the site first prepared for the ligature. Again, instead of the complete repose such a case demands, the patient lay all the time very uncomfortably upon a narrow, bare lounge, in constant danger of slipping off.

In contrast with all this: After the application of the silk ligature, the patient was carefully carried and placed in one of the best hospitals of the city, in the immediate vicinity. Yet, notwithstanding these comparative advantages, we see how quickly and completely the silk ligature failed.

My experience in this case has certainly increased my confidence in the "Constricting Silver Ligature," as the result, under the circumstances, surpassed my anticipations.

PRACTICAL SUGGESTIONS CONCERNING THE STEPS OF THE OPERATION FOR APPLYING THE CONSTRICTING SILVER LIGATURE.

Throughout all the steps of the operation, every precaution should be taken to avoid anything which might interfere with the healing of any part of the wound by first intention.

For the arrest of hemorrhage in the wound, cold affusion, ice, pressure, or torsion, should be substituted for ligature.

The size of the silver ligature I prefer to be medium, not so small as to have too much tendency to cut, nor so large as to make a clumsy knot.

The disturbance of the artery in its bed should be as little as is consistent with the safety of the accompanying vessels.

In my later experiments, I applied the ligature outside the sheath of the vessel, and this I would recommend, because, thus—

The nourishment of the arterial coats is less endangered.

Absorption of the external coat from pressure of the ligature is postponed or avoided.

The advantages of ordinary indirect compression are more nearly obtained without risk of pain or sloughing, while the diminution of the arterial current can be regulated with greater accuracy.

Before using the wire, it is better to test its strength, and to draw it repeatedly through woollen cloth, so as to remove any irregularity and to give it a good polish. Let the wire used be not less than fifteen or eighteen inches in length, as this contributes much to steadiness in the tying of it.

Aneurism needles are made mostly too large and clumsy, and of too great curve, requiring some force in passing them, and a good deal of depression of the handle before they can be disarmed.

In arming the needle, pass the wire but a short distance through its eye, then see that the short end lies smoothly upon the under surface, and the long end upon the upper and concave surface, and along the handle of the instrument.

If these points have been carefully attended to, on the appearance of the eye of the needle from beneath the artery, the short end of the wire can be seized with common forceps, and the aneurism needle be withdrawn with great ease.

Draw the ends of the wire until they are equidistant from the artery. Begin the formation of the loop at a good distance from the artery, making the tie as represented at Fig. XVIII. *a*, and continue traction steadily until the loop is in uniform contact with the artery. In commencing the constriction, let the nails of the index fingers touch each other, and then with the fingers slowly reduce the size of the loop, which must be carefully regulated by the pulsation of the vessel on the distal side of the ligature. Having reached the degree of constriction desired, at once cross the ends promptly and firmly over in opposite directions and

parallel with the loop. Cut them off short, and turn them down, as represented in Fig. XVIII. *b*. To do this delicately and well, it should be practised beforehand. By observing these apparently unimportant details, the kinking and irregularity otherwise so troublesome, may be wholly avoided, and a neat flat knot be obtained free from cause of irritation. As after any other treatment for aneurism, so in this method we cannot well overestimate the importance of the subsequent treatment. In all cases, rest should be absolute for about three weeks. The diet should receive the most careful attention, and nothing be neglected which can contribute to the material and the means which we have seen are used when nature unaided effects a spontaneous cure.

Especially should direct pressure be kept up over the tumor, but so as not to cause pain. This both helps to diminish the current through the sac, and favors the contraction of it upon the hard clot as it forms.

There is, perhaps, too general a tendency to rely exclusively upon the local treatment, whereas all the means mutually consistent should be skilfully combined with it.

The circumstances in which this method promises to be most valuable are: Those in which the location of the vessel renders indirect compression impracticable.

Those in which also the probable degree of degeneration of the vessel renders the use of the ordinary ligature unusually hazardous.

When, too, ligation, as the only treatment possible, has to be practised very near to the aneurism.

The error in application most liable to be fallen into is that of making the constriction too great, and so violating the distinctive principle of the operation.

It must be remembered that this treatment is but a modification of "indirect compression," intended chiefly as a substitute for it, when that treatment is impracticable on account of the inconvenient location of the artery, or the intolerance of the necessary pressure.

I should give the constricting silver ligature preference to any other treatment, for closure of the carotid or subclavian; not because it is more likely to succeed there than elsewhere, but because there are other means more apt to fail. The constricting silver ligature is, I think, essentially adapted to the cure of aneurism equally in the other arteries, while it promises success where no other treatment would be readily practicable.

SUMMARY OF RESULTS DEMONSTRATED BY THE FOREGOING EXPERIMENTS CONCERNING THE ACTION OF TIGHT LIGATURES OF SILK, LEAD, AND SILVER.

Ligatures of silk, lead, and silver, when applied tightly, so as to divide the internal coats; or, when so as to secure complete closure only of the canal of the artery without immediate lesion, become alike, and in either case, displaced from the point of ligation by destructive inflammation. The silk ligature is expelled from the surface. The lead and the silver ligature may remain for various periods in the adjacent tissues.

SUMMARY OF RESULTS DEMONSTRATED CONCERNING CONSTRICTING LEAD AND SILK LIGATURES.

Ligatures of lead and of silk, applied so as only to diminish the arterial current, cause closure of the artery at the point of application, but are subsequently extruded therefrom, and are disposed of in the same manner as if they had been tied tightly; but the extrusion of the lead ligature proceeds more slowly than that of the silk.

Tabulated comparison of the different results to the aneurismal sac, contents, and the parts beyond, from the use of the ordinary silk ligature, and the prospective results which may reasonably be anticipated from the use of the constricting silver ligature.

THE ORDINARY SILK LIGATURE.	THE CONSTRICTING SILVER LIGATURE.
From complete arrest, the blood in the sac stagnates and occupies it completely with *soft* clot.	The sac may be solidified by laminated *hard active* clot deposited directly from the continuous current.
Disintegration of soft clot inevitable.	Hard active clot cannot disintegrate.
Relapse, a frequent sequence of disintegration.	No cause for relapse.
Suppuration of sac resulting from imprisonment of disintegrating contents in open abscess.	No cause of inflammation is formed within the sac.
Secondary hemorrhage from sac following its rupture.	No occasion for suppuration, or rupture.
Gangrene of extremities from the suddenness and completeness of the arrest of the accustomed supply of arterial blood.	The change is neither sudden, nor complete. The collateral vessels are gradually developed to their additional task, and without shock or sudden revulsion the balance of the circulation is preserved.

The ordinary silk ligature.	The constricting silver ligature.
Cerebral trouble after ligation of the carotids, supposed to be analogous to gangrene in the extremities, and to arise from the same cause.	Cause avoided.
Requires great discretion as to the point of its application; that the artery be healthy; that it be not too near to the sac, nor too far from it.	Can be applied anywhere and in any condition. The ligature is applied outside the sheath, and though near the collateral vessels or the sac, the volume and force of the current can be regulated by the degree of constriction employed.

Tabulated statement contrasting the action of the ordinary silk ligature with the different behavior of the constricting silver ligature as

DEMONSTRATED IN THE PRECEDING EXPERIMENTS.

The ordinary tight silk ligature.	The constricting silver ligature.
Divides both the inner coats, which are presumably too much degenerated to retract or secrete plastic lymph, and strangulates and kills the outer coat.	Does no harm to the coats of the artery.
Excites a destructive grade of inflammation.	Induces sufficient inflammation only, to promote plastic exudation.
Sets up a process of suppuration.	No suppuration.
Causes mortification and sloughing of the artery in contact with and just below the ligature.	The vasa vasorum are not strangulated, and the vitality of the arterial coats remains undisturbed.
Absorbs fetid discharges.	Is non-absorbent.
Becomes source of septic infection and of pyæmia.	Is innocuous.
Acts as a seton in the wound, and makes complete healing by first intention impossible.	Is no obstacle whatever to complete healing by first intention.
Causes the occluding clots or plugs necessarily, to be soft or passive clots, susceptible to expulsion or disintegration.	Insures occlusion of the canal by hard active organized clot by direct deposit from passing current.
Sets up active ulceration.	Does not excite inflammation of a sufficiently high grade for this, but according to the degree of the pressure of the ligature, and of the counter-resistance of the arterial pulse and forming clot, slow interstitial absorption of the arterial coats in contact with the ligature follows.
Its application involves great disturbance of the artery from its bed, and of its usual deprivation of nourishment.	Is applied outside the sheath, with no strangulation of the capillaries supply-the arterial coats.

THE ORDINARY TIGHT SILK LIGATURE.	THE CONSTRICTING SILVER LIGATURE.
Is inevitably expelled to the surface with great danger of attendant secondary hemorrhage.	Suffers no displacement, becomes completely encysted, as does also the circumference of the artery for some distance above and below it, *permanently*.

WHAT THE AUTHOR CLAIMS TO HAVE ACCOMPLISHED BY THE FOREGOING EXPERIMENTS.

Constricting silver ligatures are shown *in situ*, which, after nearly fourteen months of quiet residence, are still seen just where they were first placed, with no evidence beyond the closure of the artery of abnormal action in the past, and with no indication of change in the future.

By the experiments I have submitted in this essay, it is established—

Firstly, that the "constricting silver ligature" is sufficient to induce permanent closure of an artery.

Secondly, that its use is free from ~~distinctive~~ inflammation.

Thirdly, that the *looseness* of the ligature as described, *is essential to its permanence.*

As far as I can ascertain, closure of arteries by this method has never before been accomplished nor suggested.

After careful search I fail to find a recorded instance of ligature in which equal permanence has been demonstrated.

EXPERIMENT I.

Results after ligation of common carotid of sheep, with silver wire fastened by twisting tightly with intent to divide the internal coats. The free ends are cut off closely, and the ligature left behind. Specimen removed 56 *days after the operation.*

a. Point where ligature was applied.

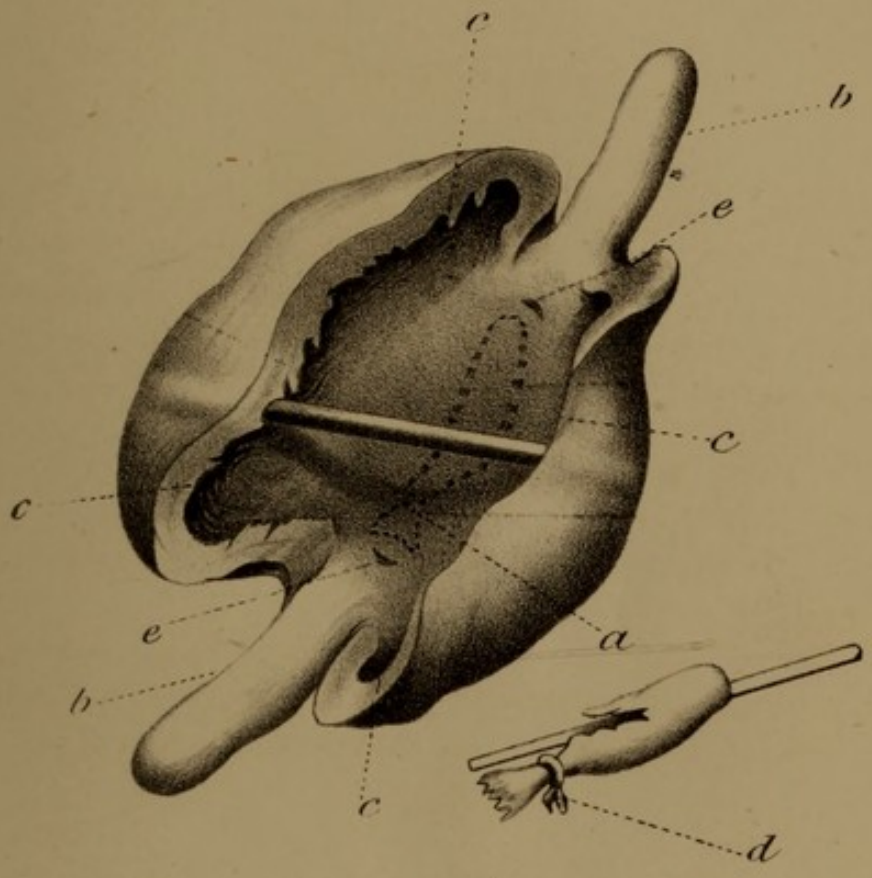
b, *b*. Artery above and below solidified.

c, *c*, *c*, *c*. Walls of abscess formed of thickened external coat of artery.

d. The ligature embracing the internal coats corresponding to the length of the abscess in the middle of which they were found wholly detached.

Fig. I.

Fig.I



EXPERIMENT II.

Appearance on 27th day after application of lead wire to common carotid of sheep, with intent only to close the canal, without damage to internal coats, and so as to avoid mechanical irritation from free ends of ligature.

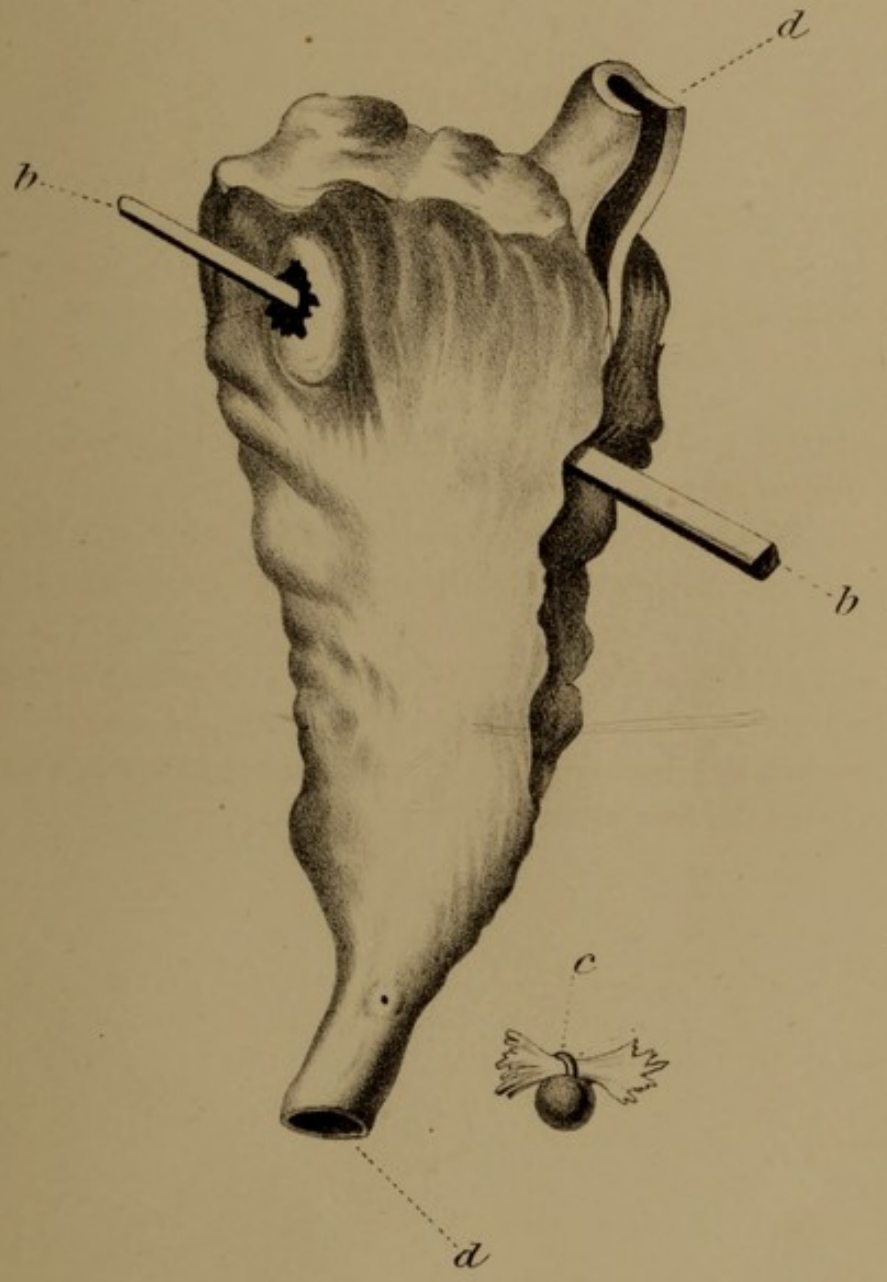
a, *a*. At upper and lower ends of section, artery is seen to be unobstructed.

b, *b*. Rod, showing course by which ligature ulcerated its way through the extensive fibrinous deposit, towards surface.

c. The ligature as found just beneath the skin, embracing a portion of the internal coats sloughed away. The perforated lead shot at *c* was clamped upon, and incloses the free ends of the ligature.

(Fig. II.)

Fig. II.



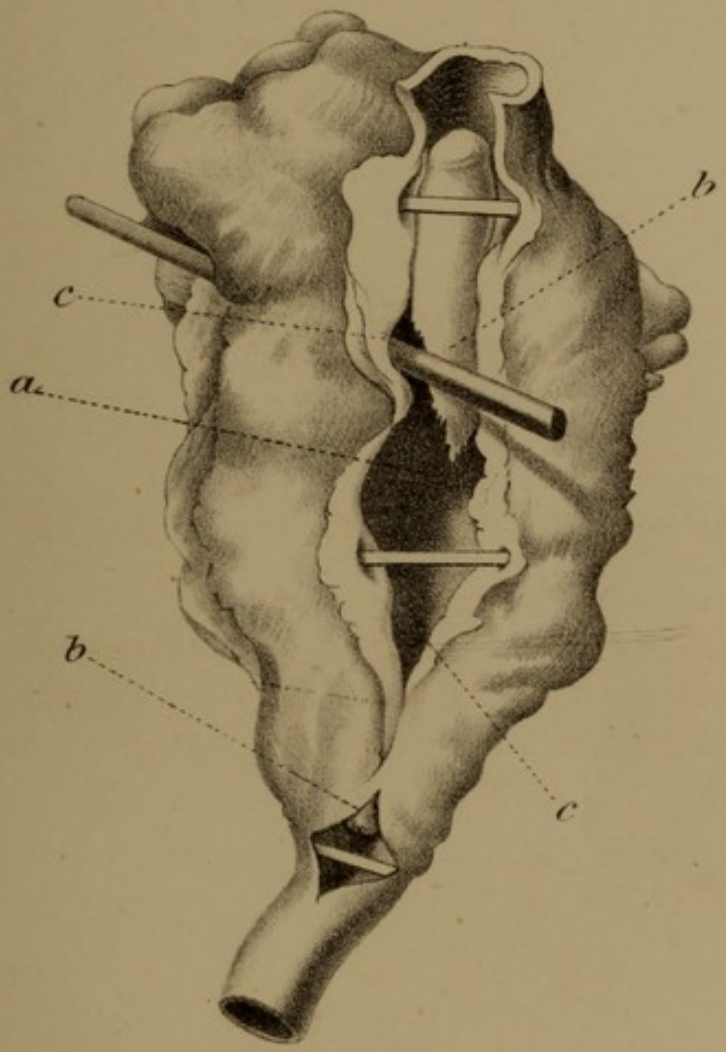
EXPERIMENT II.

Interior view of artery in Experiment II., Fig. II.

a. Point where the ligature was applied.
b, b. Permanent clots occluding artery above and below.
c. Point of departure of ligature from the intervening abscess *c c*, which it created.

(Fig. III.)

Fig. III.



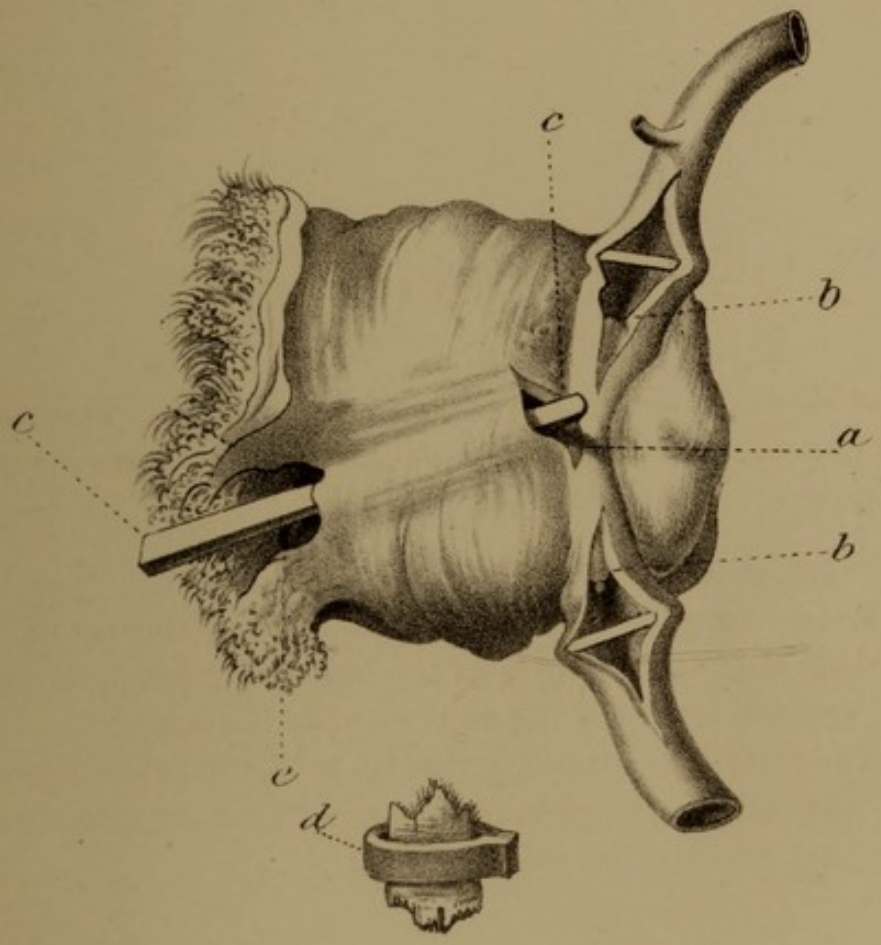
EXPERIMENT III.

The same object sought as in Experiment II., by substituting a lead band and clamping its free ends. Specimen removed 37 days after the operation.

a. Point at which ligature was applied.
b, *b.* Extent of solidification of artery above and below.
c, *c.* Rod, indicating course of the ligature through the inflammatory fibrinous deposit towards the surface.
d. The ligature embracing a portion of the internal coats of the artery sloughed away, and found on examination, just beneath the skin at *e*.

Fig. IV)

Fig. IV.



EXPERIMENT VIII.

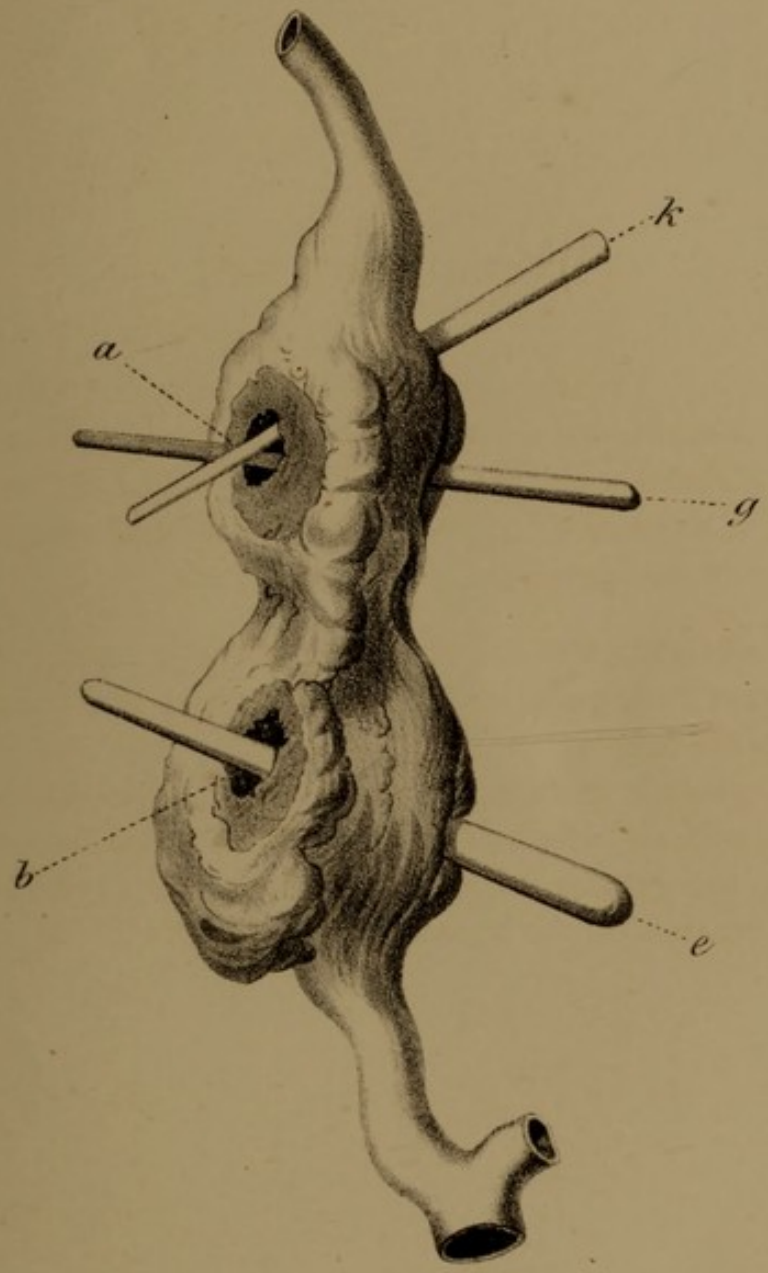
This, and Fig. VI., show comparative results from three silver ligatures applied to the same artery, and in the same manner as in Experiments IV., V., VI., and VII., but with three different degrees of tightness. The animal was killed 22 *days after the operation.*

a, *b*. Sinuses exposed on removing the specimen; found to start from points where the ligatures had been applied to the artery.

The greater amount of inflammatory deposit observed at *b*, will, on reference to Fig. VI., be found to correspond to the greater degree of tightness employed in the application of the ligature there, than in those near *a*.

(Fig. V.)

Fig.V.



EXPERIMENT VIII.

Interior view of the common carotid, seen at Fig. V.

e. Point at which the ligature was applied very tightly with intent to divide the internal coats; one end snapped off from the force employed.

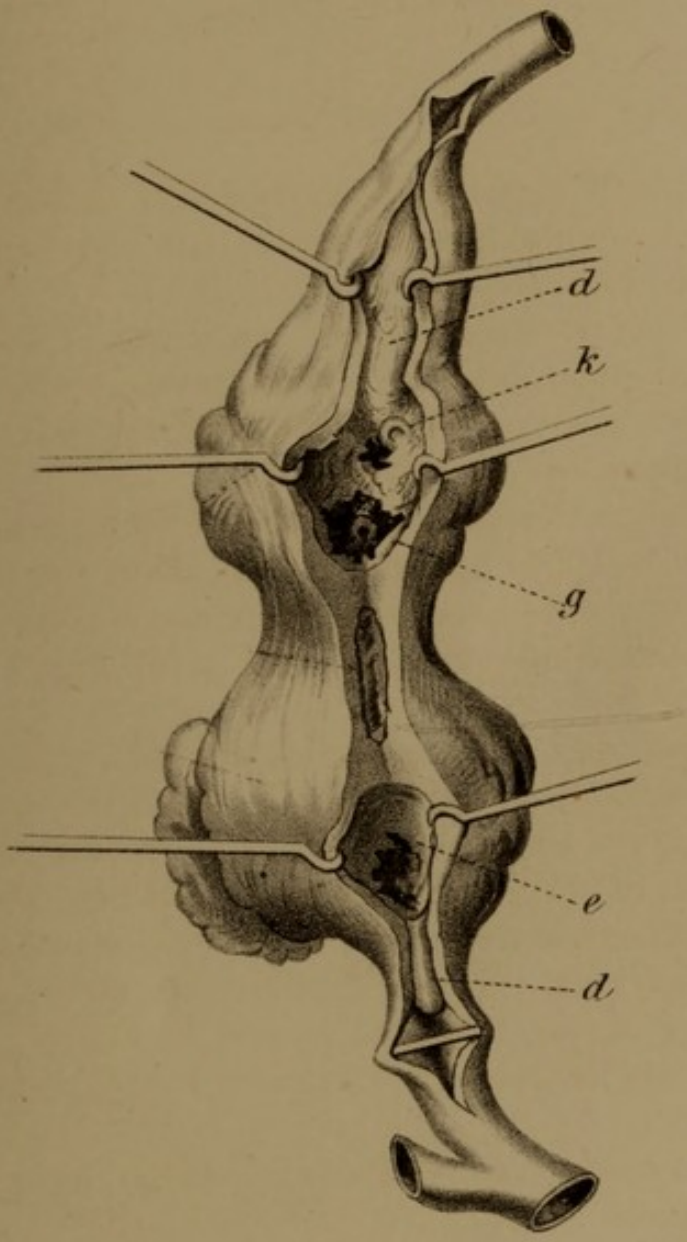
The ligature not discoverable; but the mouth of a sinus is seen at the bottom of an abscess through which, in Fig. V., rod *e* has been passed along the supposed track of the ligature, to the surface.

g. Point at which the ligature was applied with more moderate tightness. The ligature is seen about two lines advanced in a sinus proceeding from the bottom of a small abscess, through which rod *g*, in Fig. V., is passed.

k. The third ligature, which was applied with a view to close the canal without damaging the coats of the artery. It is seen at the point where applied, embracing the internal coats of the artery, joined to a clot hard above, but in a diffluent state below. Near it the mouth of a sinus is seen, as if prepared for extrusion of the ligature by the course indicated by rod *k*, Fig. V., the upper and middle sinuses meeting at *a*, Fig. V., beneath the skin.

d, *d*. Hard clots closing the artery above and below upper and lower ligatures.

Fig.VI.



EXPERIMENT IX.

Result from a silk constricting ligature, the diameter being diminished one-half. Specimen removed on 23d day after the operation.

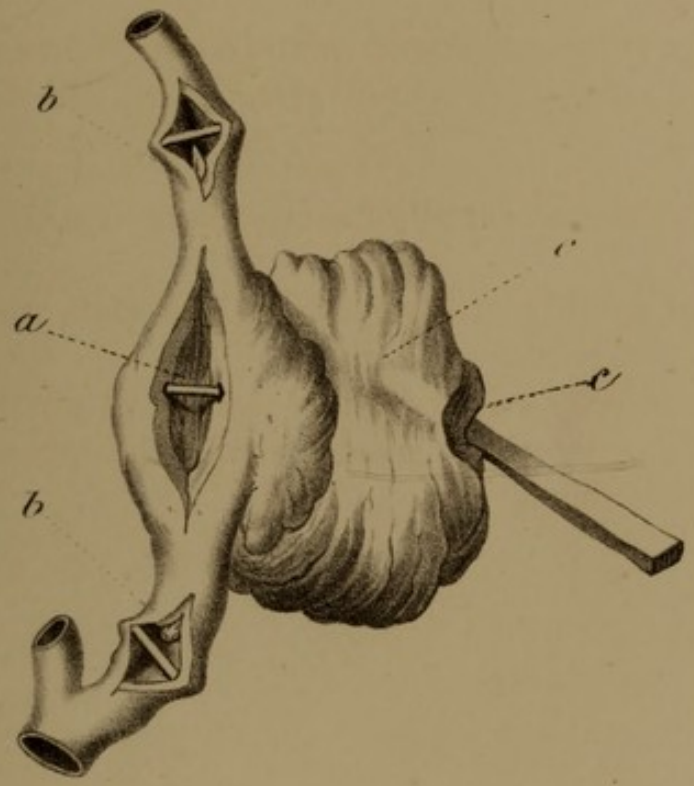
a. Point of common carotid of sheep where ligature was applied.

b, b. Extent of solidity of artery, from hard clots above and below.

c, c. Blind sinus; supposed to be the remains of the track by which the ligature passed through the inflammatory deposit to the surface.

(Fig. VII.)

Fig. VII.



EXPERIMENT X.

Result from a lead constricting ligature, applied in same manner as the silver constricting ligatures. Specimen removed 36 days after the operation.

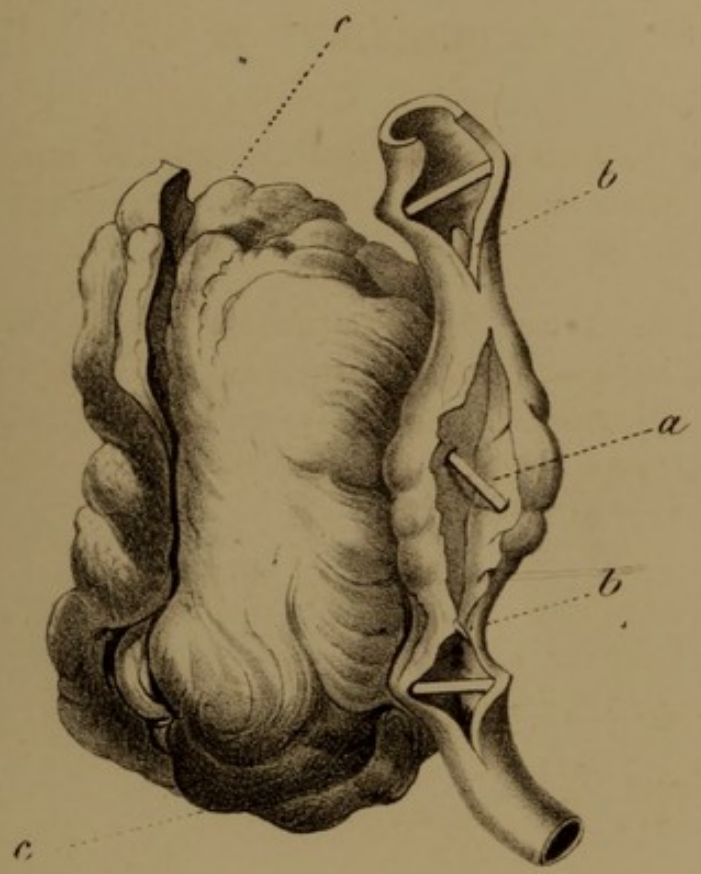
a. Point at which lead wire ligature was applied to common carotid of sheep, diminishing diameter about two-thirds.

b, b. Extent of permanent clot above and below ligature.

c, c. External view of mass of inflammatory deposit between the artery and the skin.

(Fig. VIII.)

Fig. VIII.



EXPERIMENT X.

Longitudinal section of fibrous deposit exhibited in Fig. VIII. c, c.

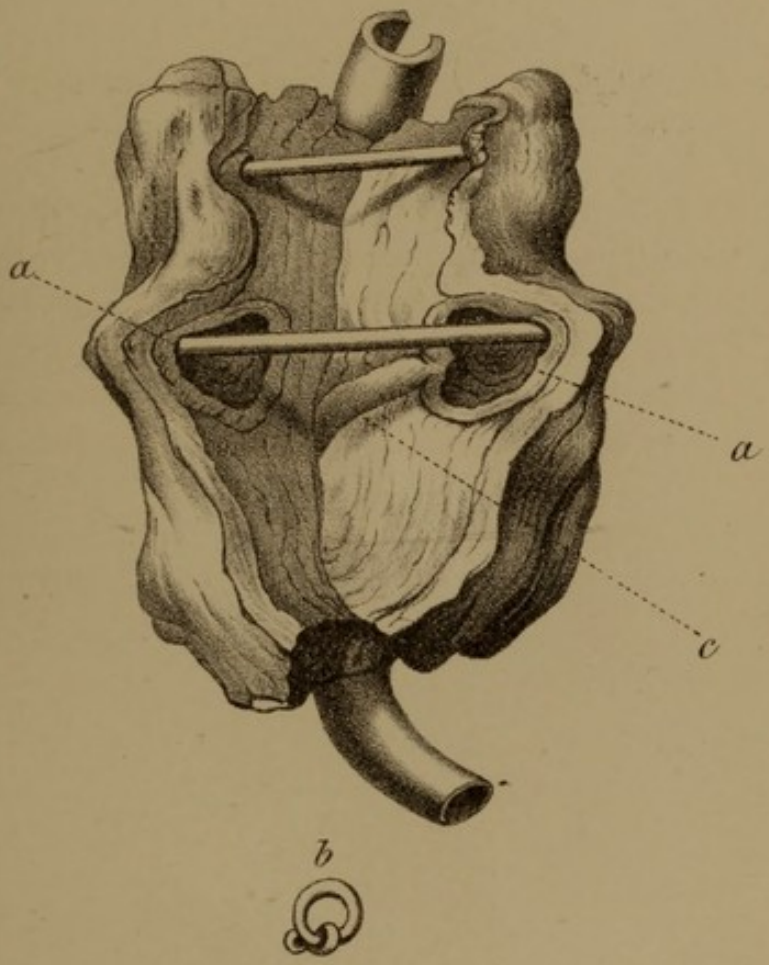
a, a. Small thick-walled abscess, which was filled with inspissated pus, and contained in its centre the ligature.

b. The lead ligature as removed from the abscess.

c. Rope of fibrin which appears to have closed up the rear in the track of the ligature as it advanced from the artery safely forwards to become encysted at *a*.

(Fig. IX.)

Fig. IX.



EXPERIMENT IV.

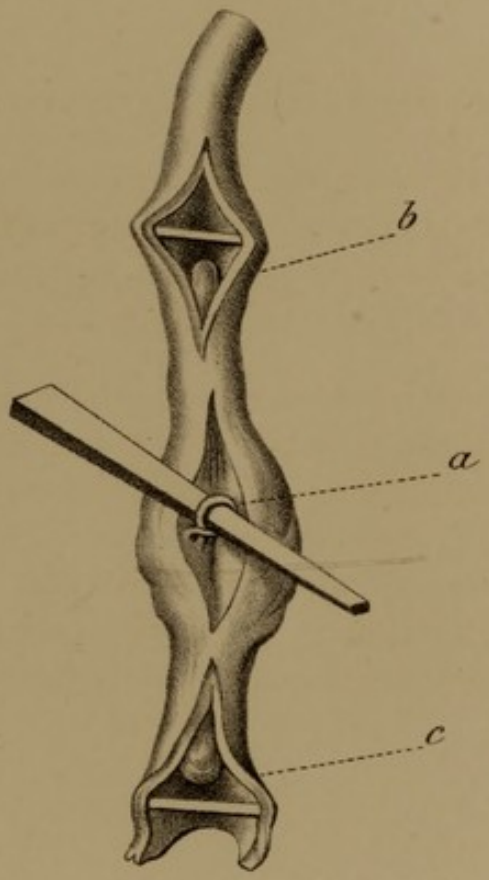
THE FIRST CONSTRICTING SILVER WIRE LIGATURE.

Result after constriction of common carotid of sheep to about one-third its natural diameter, by silver wire tied in a single knot, free ends cut off short and turned down. Specimen removed 27 days after the operation.

a. Ligature revealed by longitudinal incision where placed; wrapped evenly around with fibrin. A rod is forced through loop of ligature to show the looseness with which it was applied.

b, b. Clot seen to be longer above and below, also harder and whiter than in previous experiments. No sign of destructive inflammation discovered.

(Fig. X.)


b
a
c

EXPERIMENT V.

Appearance on 23d day after application of constricting silver wire ligature to common carotid of sheep, in same manner as in Experiment IV.

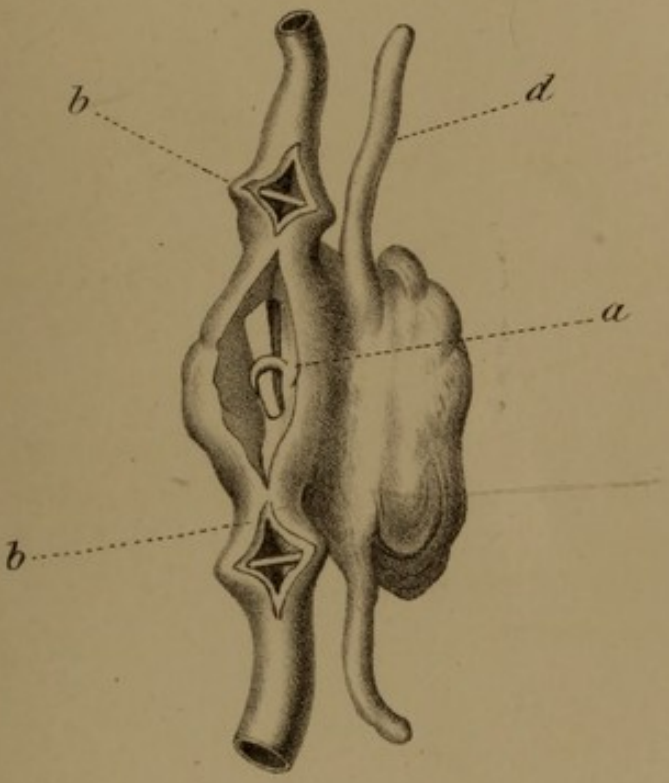
a. Ligature, as discovered unchanged and undisturbed, enveloped in fibrin. Rod introduced shows size of loop of ligature.

b, *b*. Extent of solidification of artery.

d. Pneumogastric nerve.

(Fig. XI.)

Fig. XI.



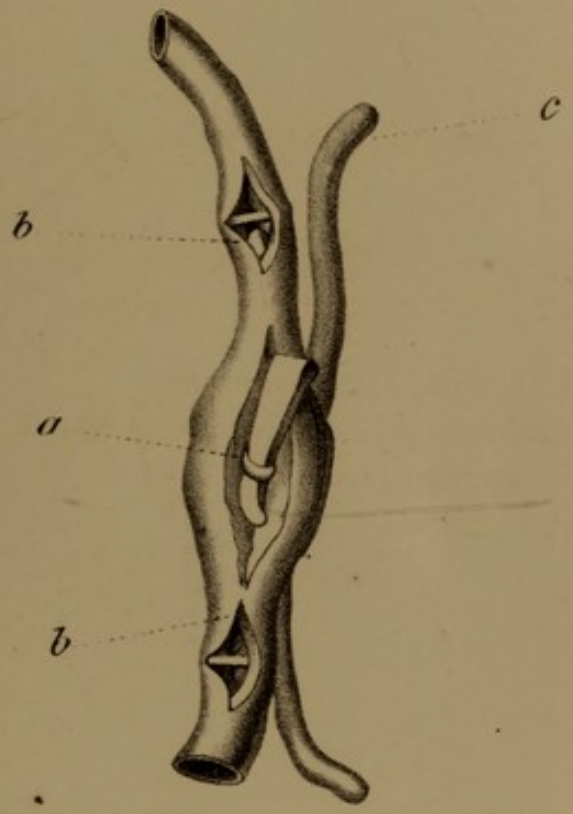
EXPERIMENT VI.

Repetition of Experiment V., the specimen being removed on the 10th day after the operation.

a. Ligature as applied, seen unmoved.
Rod of whalebone passed through its loop in specimen.
b, b. Extent of permanent clot.
c. Pneumogastric nerve.

(Fig. XII.)

Fig. XII.



EXPERIMENT VII.

Repetition of Experiment VI. on common carotid of sheep; animal killed on 10th day after the operation.

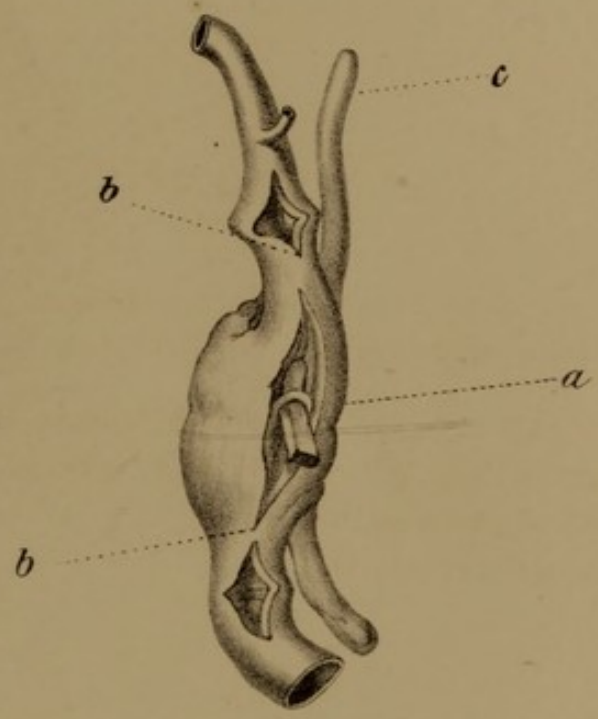
a. The ligature unchanged and unmoved, discovered by longitudinal incision through the enveloping fibrin.

b, *b*. Extent of permanent clot.

c. Pneumogastric nerve.

(Fig. XIII.)

Fig. XIII.



EXPERIMENT VII.

Enlarged view of interior of Fig. XIII., showing action of the ligature upon the arterial coats, and the manner in which it is inclosed in the bulb of fibrin.

a. Ligature, same as in Fig. XIII., producing slow absorption by pressure of the arterial coats, but unaccompanied with any pus or sign of destructive inflammation.

b, *b.* The fibrinous envelope is seen to be thickest just over the ligature.

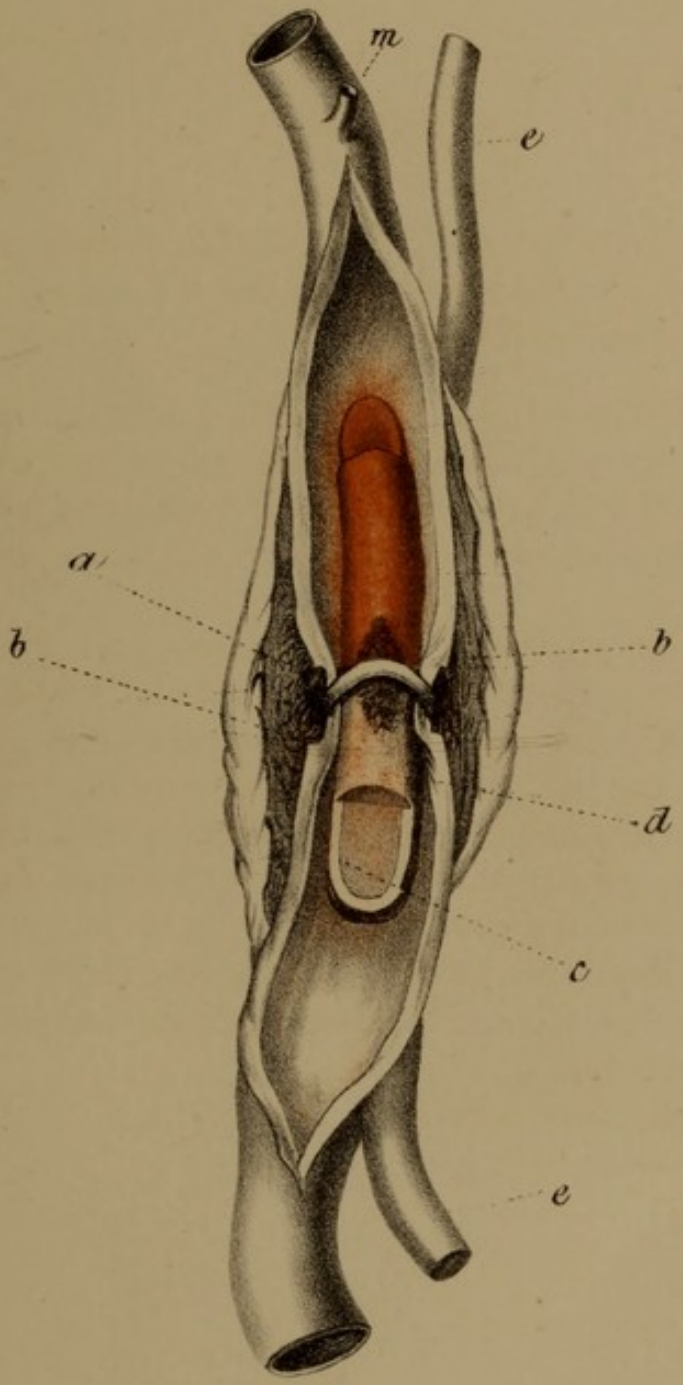
c. Removal of section of clot, shows that the lower end which is best supplied with arterial blood, is whitest and hardest, and has outer layers of greater density than the rest, forming a sort of capsule.

The redness and therefore the softness of the clot are seen to be greater the farther it is removed from a fresh supply of arterial blood.

d. From about this point to a little way above the ligature, the clot could not be detached from internal coat without cutting.

e, *e.* Pneumogastric nerve.

Fig. XIV.



EXPERIMENT XI.

Condition of common carotid artery of sheep and constricting silver wire ligature, ten and a half months after ligation.

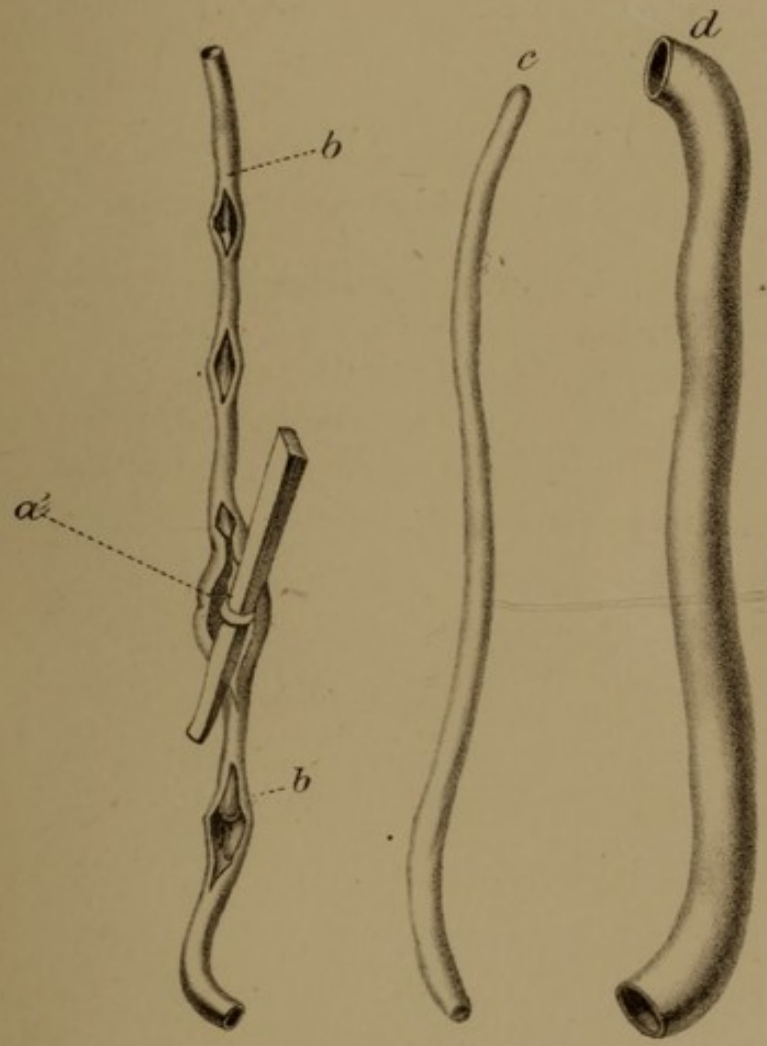
a. Ligature applied as in the previous similar cases, is seen unmoved and unchanged.

b, *b.* Shows great extent and permanence of clot.

c. The pneumogastric nerve, and *d*, the common carotid of the opposite side of sheep, showing relative size of the unused artery at time of removal.

(Fig. XV.)

Fig. XV.



EXPERIMENT XII.

Appearance of another common carotid of sheep fourteen months after ligation with constricting silver wire ligature by method of author.

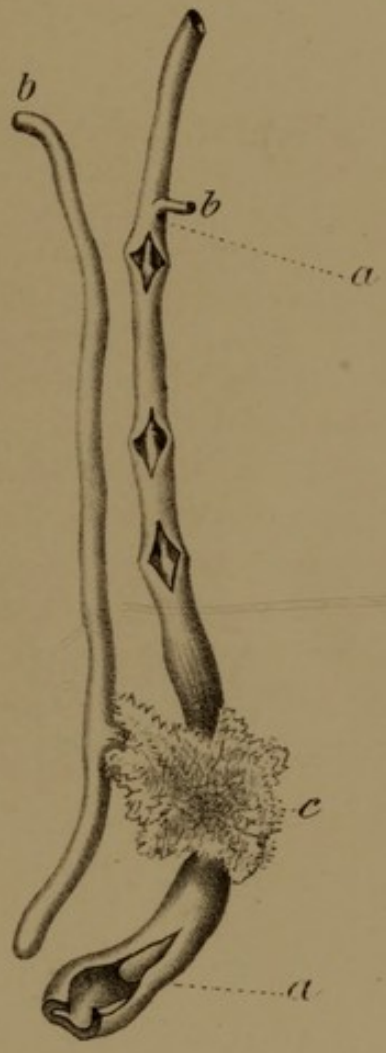
a, *a*. Extent of permanent clot.

b. Pneumogastric nerve, showing relative size of artery.

c. Point where ligature was applied. The fibrinous deposit appears to have become nearly absorbed, leaving only a mesh of fibro-cellular tissue. Ligature could not be found. There are no signs of any destructive inflammation.

(Fig. XVI.)

Fig. XVI.



EXPERIMENT XIII.

Showing comparative results from the application of a silver ligature with constriction, and of one without avoidable constriction. The specimen was removed thirteen and a half months after the operation.

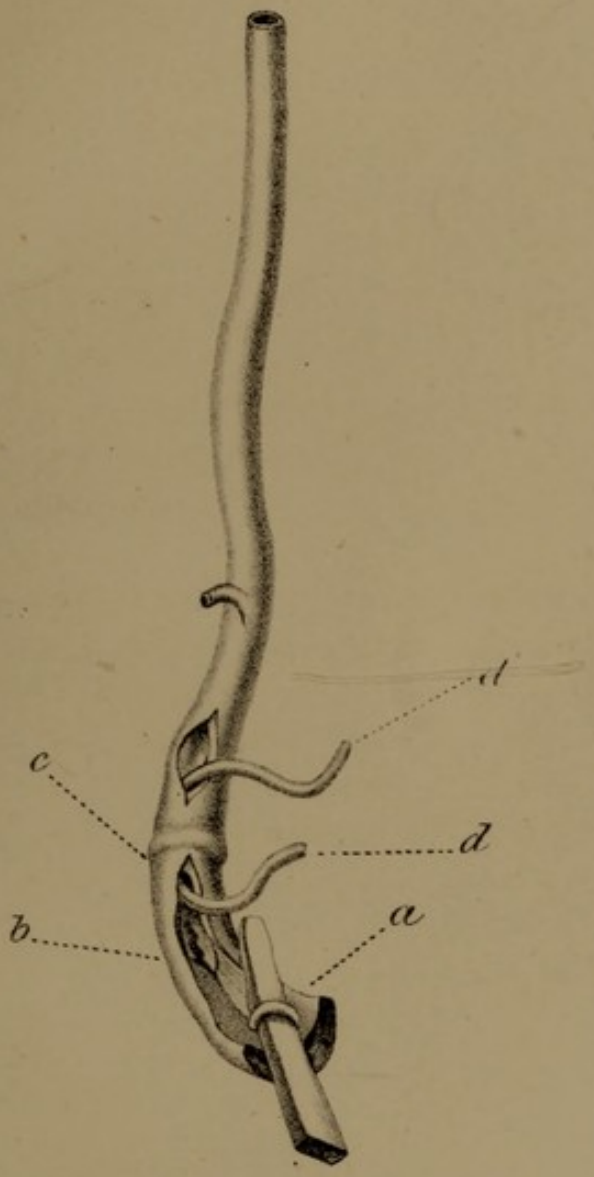
a. Constricting ligature applied to diminish diameter of common carotid of sheep about two-thirds; seen unchanged and unmoved in solid block of fibrin, which extends to *b*.

c. The ridge seen at this point consists of a silver wire ligature encircling the artery, and covered with a thin layer of fibrin. It was applied and tied in the same manner as the other constricting ligatures, only so as to make no avoidable pressure upon the arterial coats.

d, *d*. A piece of wire passed from above downwards, showing the arterial canal to be permeable beneath the ligature. Inspection showed no change whatever in the diameter of the canal at that point.

(Fig. XVII.)

Fig. XVII.



Method used in tying the constricting wire ligature.

a. Knot formed, ready to be tightened.

b. Appearance of knot when tightened, and free ends cut off and turned down to remain permanently.

(Fig. XVIII.)

Fig. XVIII.