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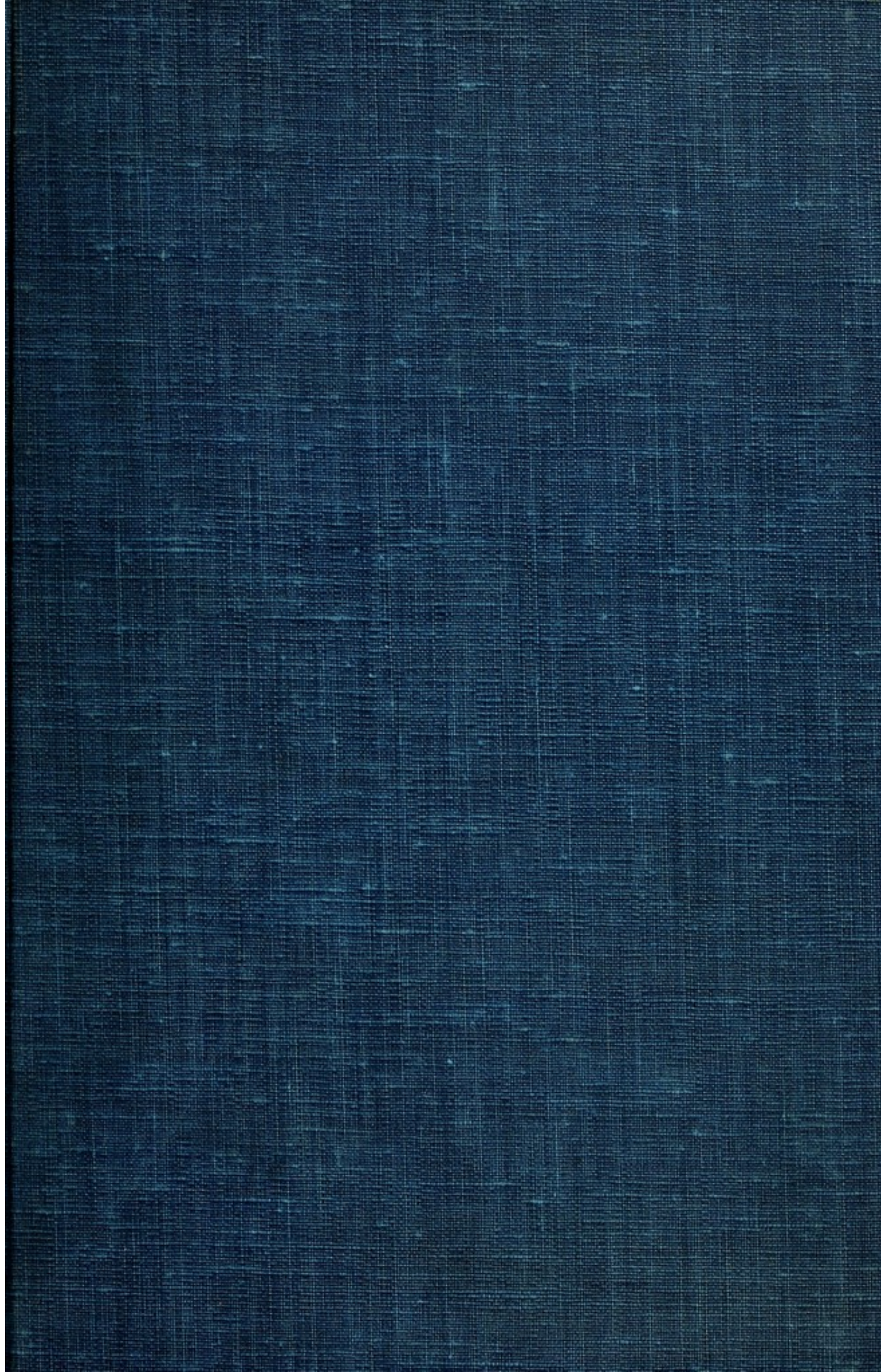
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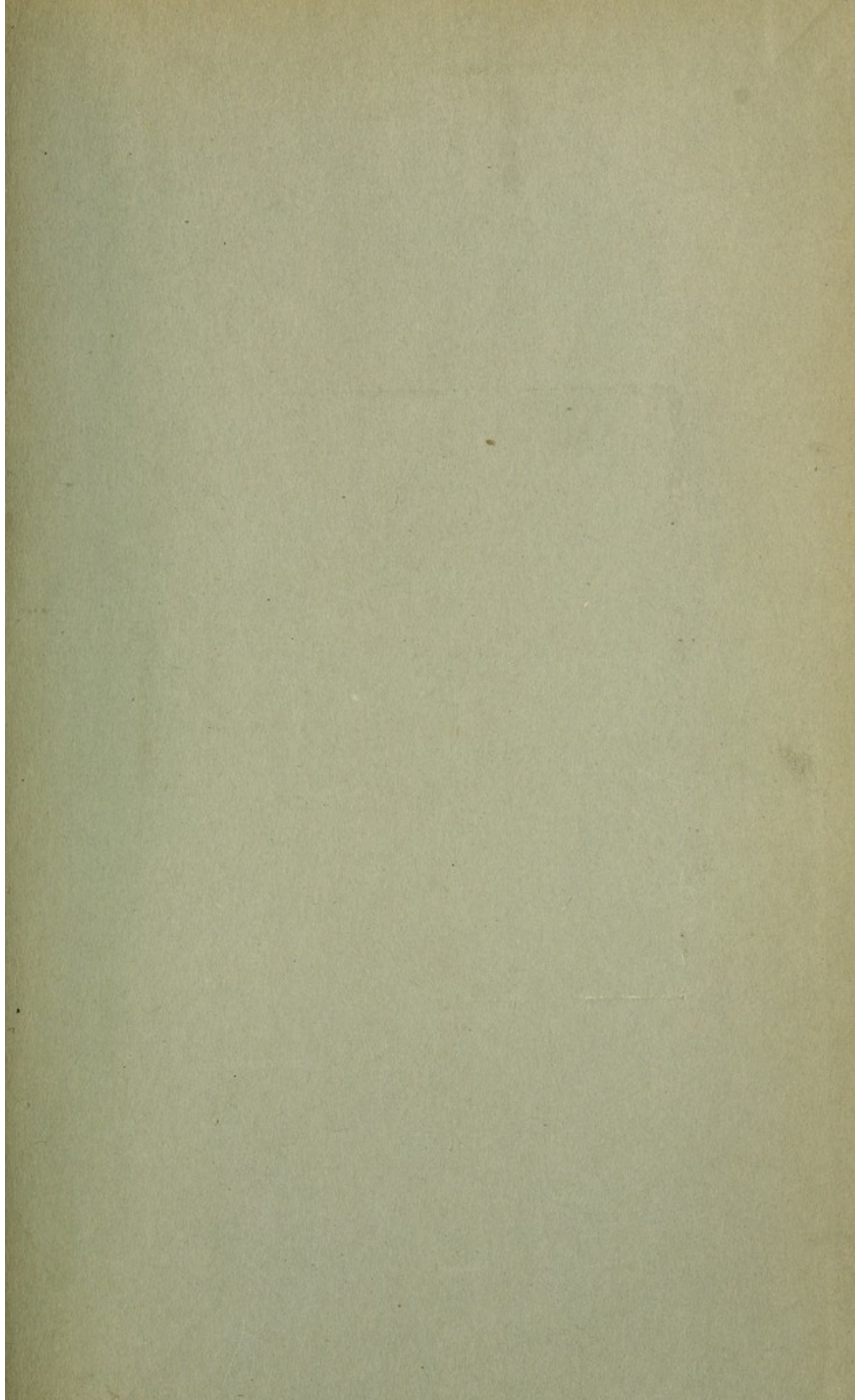


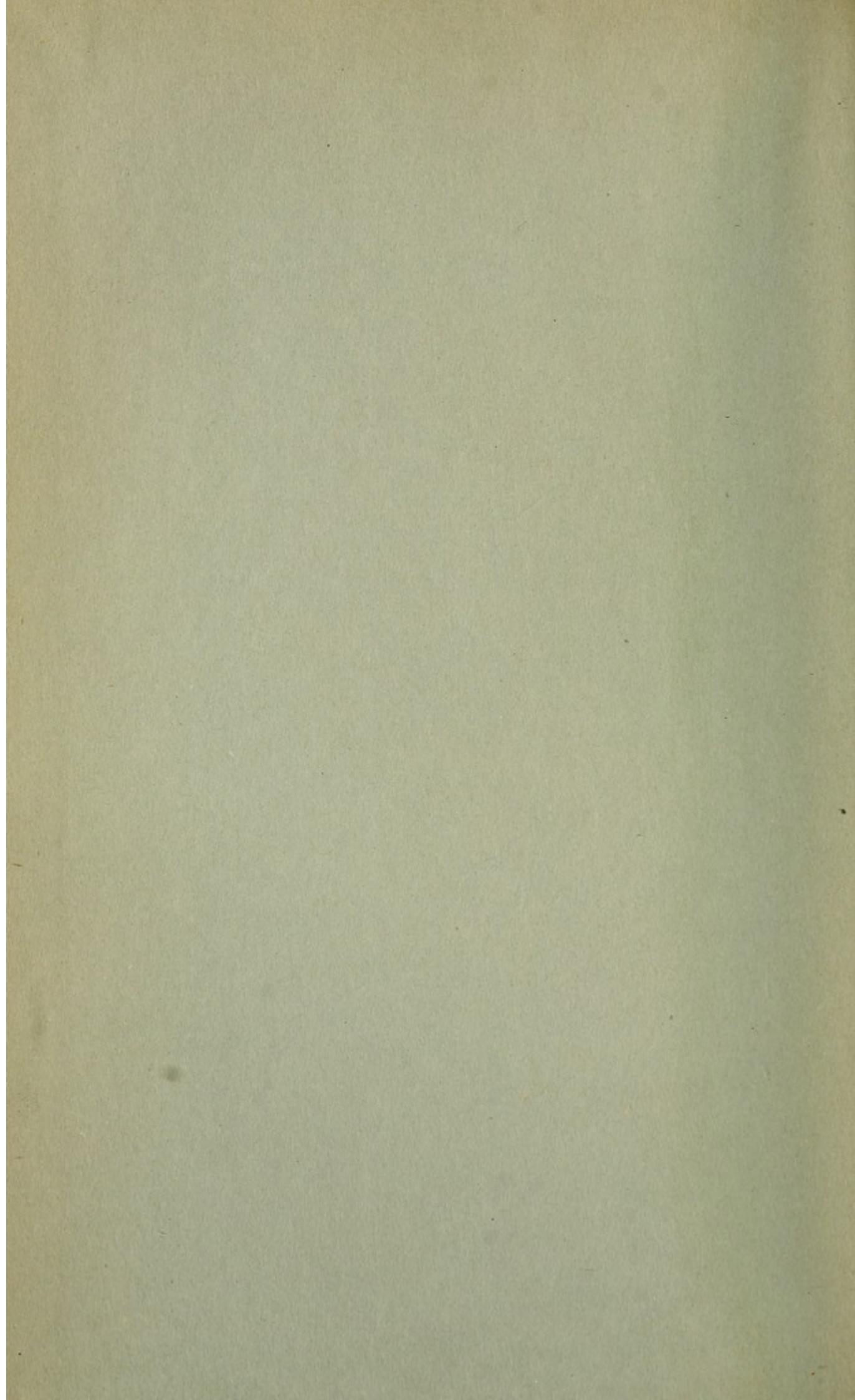
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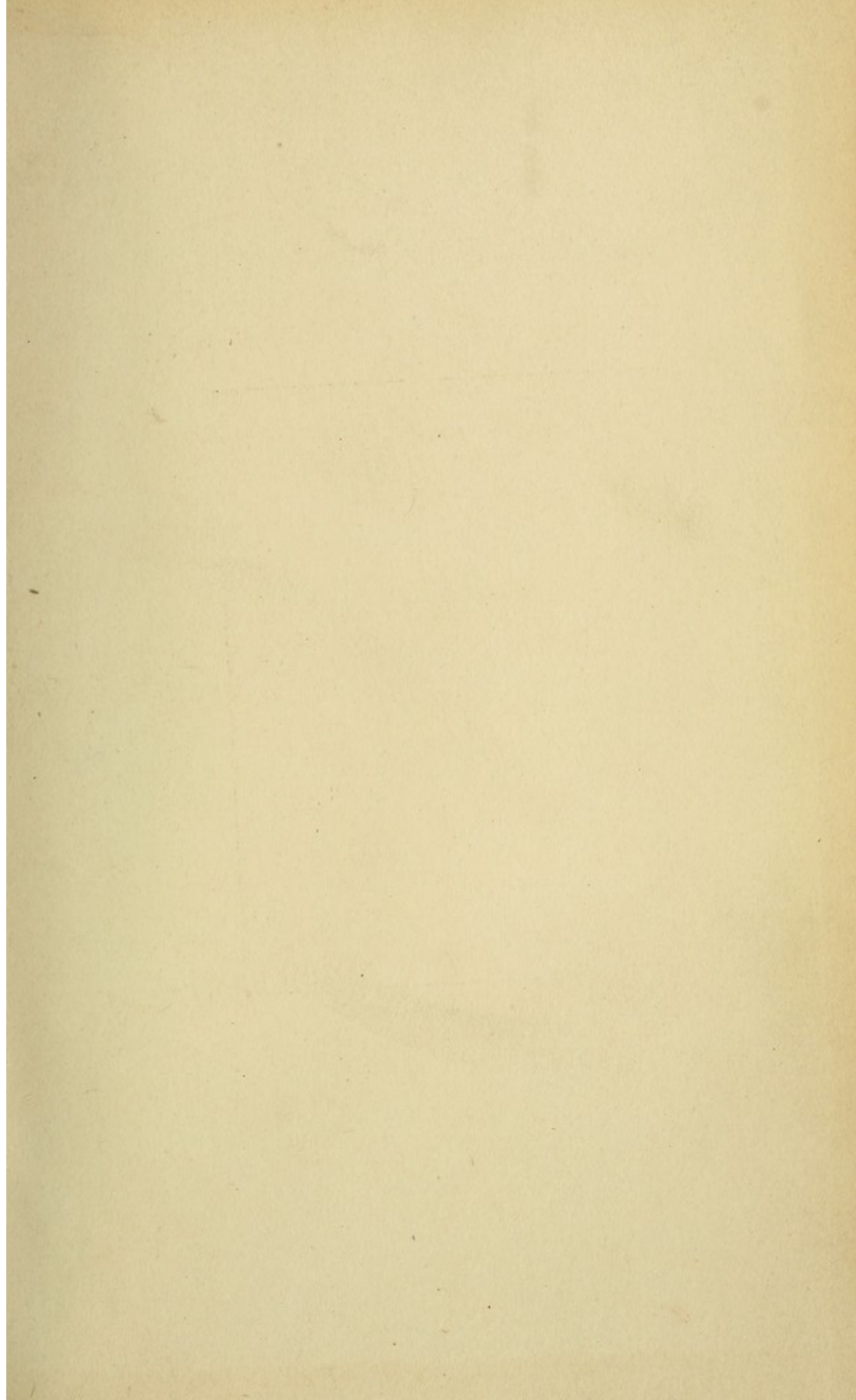
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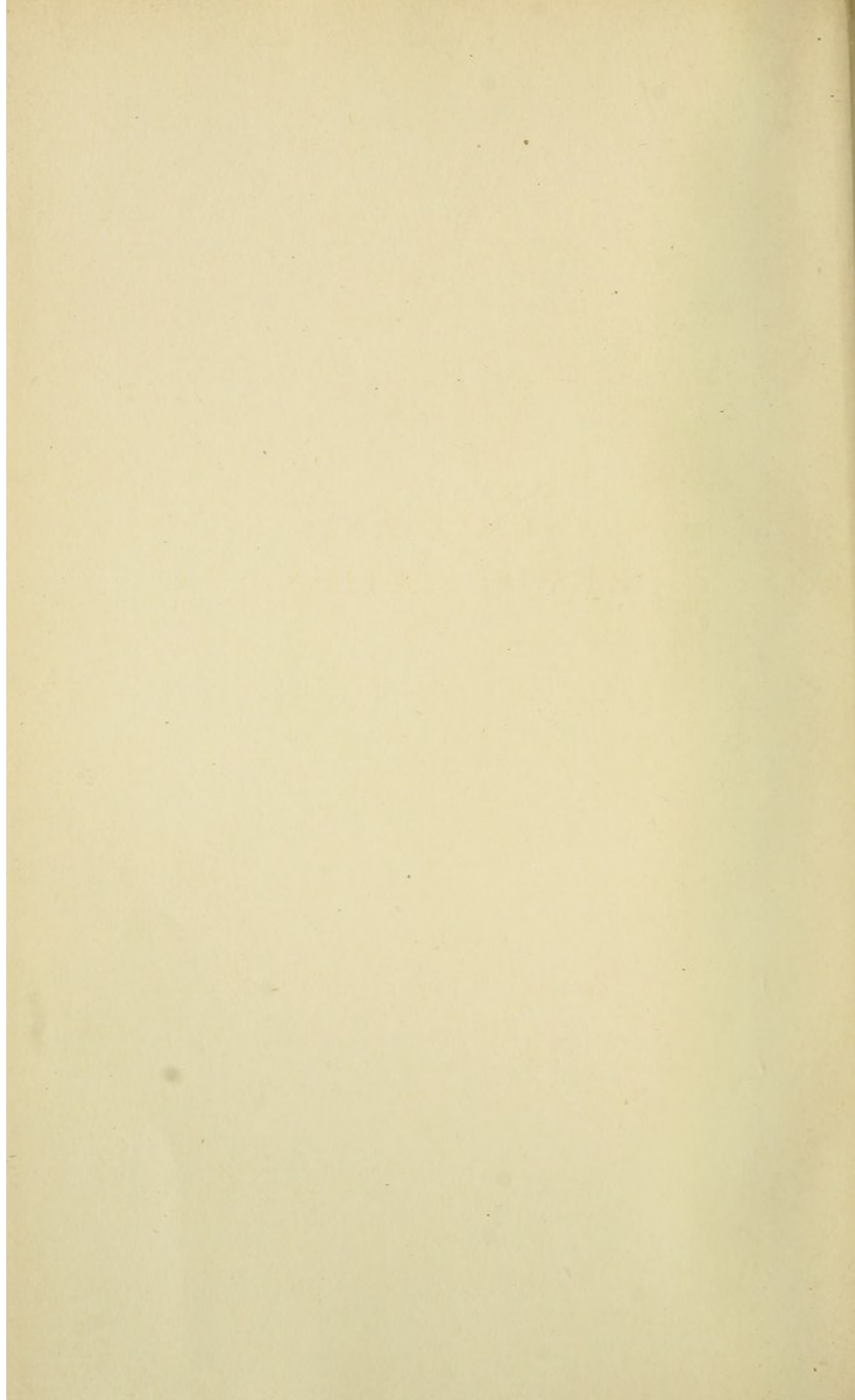
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ANEMIA AND
RESUSCITATION



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ANEMIA AND RESUSCITATION

*AN EXPERIMENTAL AND
CLINICAL RESEARCH*

BY

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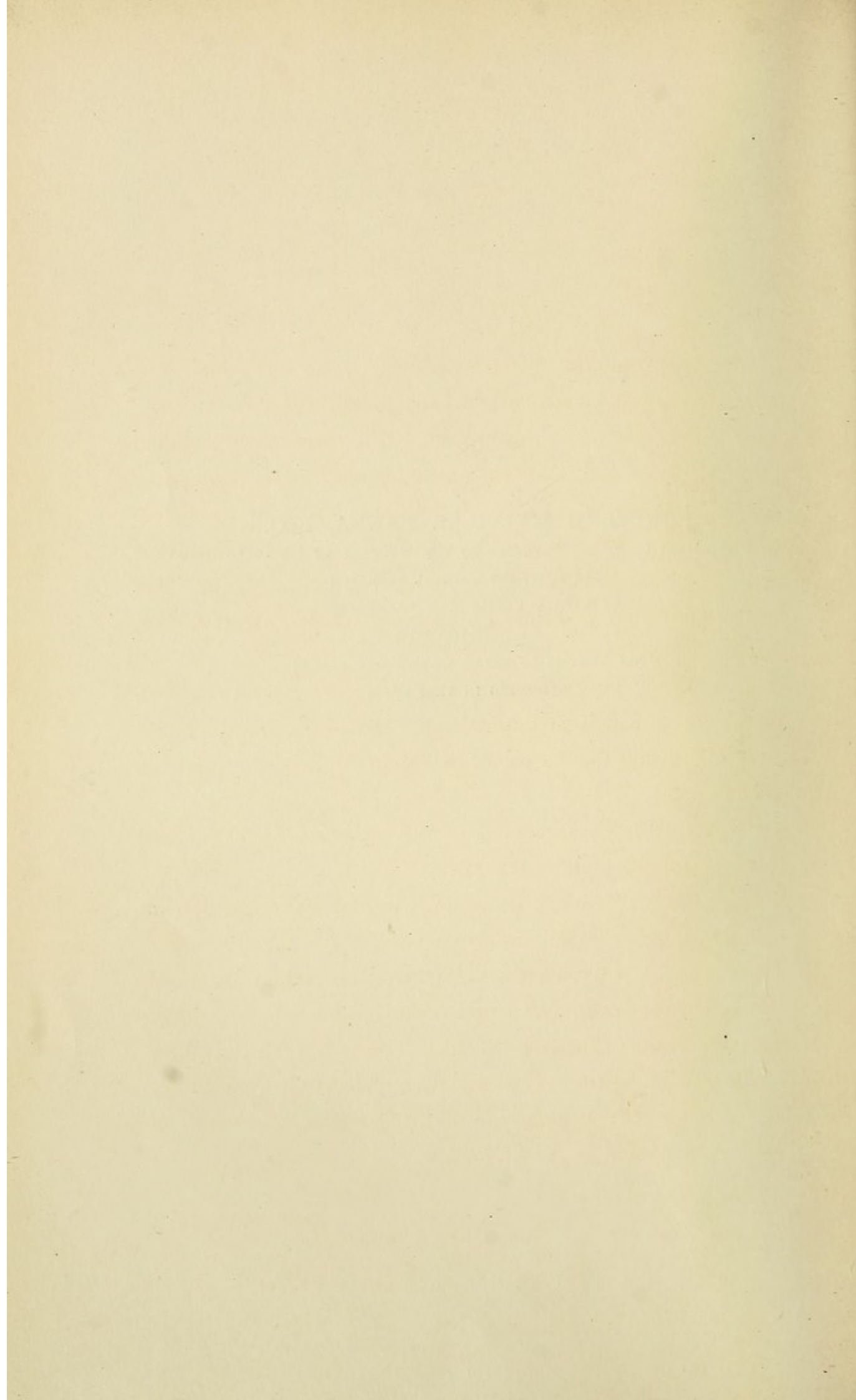
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TO
HOWARD MELVILLE HANNA, ESQ.
WHO IN HIS GENEROUS DEVOTION TO THE WELFARE OF HIS FELLOWMEN
HAS FOSTERED MEDICAL RESEARCH
BY WISE COUNCILS AND LARGE GIFTS
IS DEDICATED
ALL THAT IS OF VALUE IN THE RESEARCHES
RECORDED IN THIS WORK



PREFACE

IN presenting the material of this book for publication it gives me pleasure to express my many obligations to my associates. Although the problems originated in my clinic, and the experiments were planned by me, their accomplishment was made possible by the diligent labors of my associates. Part of the subject matter was presented before the College of Physicians, Philadelphia, in 1908 as the Mütter Lecture for that year under the title "Surgical Anemia and Resuscitation."

To Dr. D. H. Dolley's untiring efforts, for which appreciation has already been expressed in "Hemorrhage and Transfusion," is due the large accumulation of data on cerebral anemia.

In the research on anemia of the voluntary muscles I am indebted for the preliminary work to Dr. Lawrence Pomeroy, and for the later work to Dr. A. M. Tweedie. The research on anemia of the intestines was also in charge of Dr. Tweedie, Dr. H. G. Sloan conducting the experiments on certain phases of this important work. The neurocytologic work in this research, as well as some of the later work on cerebral anemia, was done by Dr. J. B. Austin. The drawings illustrating the changes in the brain cells in gangrene of the intestine were made by Miss Armenouhie H. Tashjian.

To Dr. Charles S. White, of Washington, D. C., are due my thanks for permission to use the three illustrations showing the relationship of the thoracic viscera, and also to "Surgery, Gynecology, and Obstetrics" for the blocks for the same.

To Dr. F. W. Hitchings I wish to express my especial appreciation for his tireless labor and enthusiasm in the arduous task of compiling the various tables, abstracting the literature, arranging the experimental data, and assembling all of the material into book form.

The final revision of the text was made by my editor, Miss Amy Rowland.

G. W. C.

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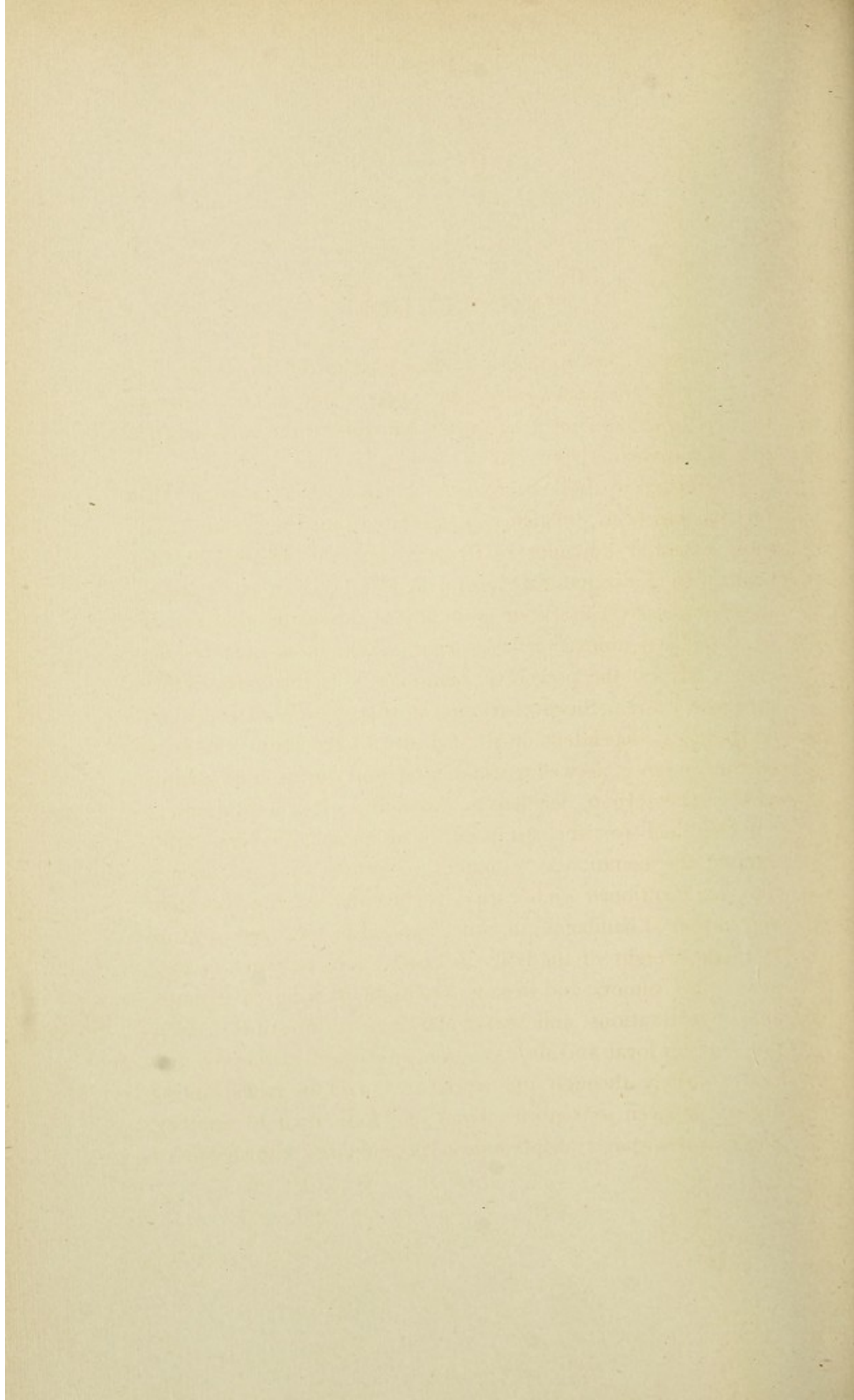
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SURGICAL ANEMIA AND
RESUSCITATION



INTRODUCTION

The following studies of anemia as it affects the body as a whole or its component parts have been made in an endeavor to solve practical clinical problems which both the surgeon and the internist often confront.

In regard to the resuscitation of the body as a whole, the fact has not been sufficiently appreciated that the greatest and most essential difficulty is to overcome the anemia of the brain. In apparent death from drowning, from gas poisoning, from electric shock, or from any of the many other causes of suspended animation, the organ which most quickly succumbs beyond the power of reanimation is the brain rather than the heart. Since continued normal action of the heart and lungs is dependent on the activity of the brain, the presence or absence, as well as the degree and duration of anemia of the latter organ, decides the possibility of resuscitation.

The field for the study of local anemia is very large. Among the commonest examples of causes of local anemia may be mentioned embolism and thrombosis, the too tight application of bandages and other apparatus, localized pressure from the weight of the body in unconscious patients, twisted pedicles of tumors and organs, too tight packing of wounds, and incarcerations and strangulations of intestines. New problems in local anemia have been presented in the last few years, largely through the work of Carrel in transplanting organs or even extremities from one individual to another. Successful organ transplantation presupposes knowledge of

the power of any given organ to resist anemia while the operation is being performed.

Kuliabko's brilliant work in making the heart continue to beat after its removal from the body, supplemented by the work of Hill, Batelli, d'Halluin, and others abroad, and of Stewart and his associates in this country, paved the way to further study of the automaticity of action of that organ. Attempts to resuscitate the body as a whole by massage of the heart, by artificial respiration, or by the injection of saline or other solutions into the circulation were the natural sequence of their results.

The experiments from the author's laboratory which are presented in this book are a continuation of those on surgical shock, in which it was shown for the first time that the blood pressure of a decapitated dog could be maintained for hours by means of the slow, continuous infusion of normal saline solution and adrenalin. This again led naturally to the use of the adrenalin-saline intravascular infusion combined with rhythmic pressure on the chest as a means of resuscitation, a method which, so far as is known, was first demonstrated by the author before the Cleveland Medical Society at Western Reserve University Medical College.

In this monograph, as in some of those already published, it has seemed best to publish the experiments in considerable detail. The labor and expense of producing them have been great, and their publication may save other workers unnecessary repetition.

CHAPTER I

ANEMIA OF THE CENTRAL NERVOUS SYSTEM. EXPERIMENTAL OBSERVATIONS.

INTRODUCTION

For a number of eminently practical as well as scientific reasons it is important to know the effects of total or partial anemia of the brain. For example, in the course of operation or as the result of injury the surgeon may be compelled to choose between ligating the common carotid artery or taking other hazards. It would assist him in making an intelligent decision if he knew the effect of anemia of the brain. In operating on the brain he may be obliged to retract a portion of it, thus causing localized anemia. How long will the brain safely endure such anemia? What will be the immediate and final results if he resorts to these measures? Will intermittent retraction be safe, when continuous retraction would be certain to cause injury from local anemia? In cases of cerebral compression from fracture of the skull, from tumors, from abscesses, from edema of the brain, from hemorrhage, anemia is in many instances the most important factor.

It would be of considerable practical value to know whether or not all parts of the brain and spinal cord endure anemia equally well. Do differences exist between the resistance of the lower and higher centers, and if there are differences, are they because the one has been established earlier in the course

of evolution than the other, and has become, as some one has expressed it, hardened by longer use, or is it because some portions of the brain are more delicately poised? Which will endure anemia longer, the sight or the auditory mechanism, an eye reflex or a tendon reflex, the emotional or the motor mechanism? Will a given amount of anemia abolish the memory and yet leave the motor mechanism intact? Among the medullary centers is the respiratory or the vasomotor, the cardio-accelerator or the cardio-inhibitory the more resistant to anemia?

In the following pages an attempt has been made to throw light on these various questions. The importance and the difficulty of the subject must be the excuse for presenting so large a mass of data in detail as well as in summary.

THE BLOOD SUPPLY OF THE BRAIN: GENERAL CONSIDERATIONS

In the course of evolution, the brain, more than any other organ in the body, has been evolved in such a way as to have a constant supply of blood under even pressure. The brain can expand but the skull cannot expand under the influence of increased blood-pressure. Consequently, unless there were a protective mechanism which would afford a constant margin of safety against over-expansion, cerebral anemia due to pressure of the brain against the skull would be produced. Such a mechanism is provided by the water-bed of cerebral fluid on which the brain rests, and by the large venous sinuses.

When the brain expands or when it shrinks in volume the cerebral fluid, which connects directly with the spinal fluid, ebbs and flows. At the same time the blood in the large venous sinuses is forced out or in. Under ordinary conditions this prevents undue pressure on the brain, but, as a protection against cerebral anemia, another mechanism has been evolved,

viz., the elevation of the arterial blood-pressure through stimulation of the vasomotor mechanism by anemia.

Aside from the volume factor of safety, the importance of the brain being abundantly supplied with blood is emphasized by the provision of a large artery, the common carotid, on each side of the neck. Moreover, each artery is well protected by being deeply buried under strong muscles and fasciæ, and is so placed as to be easily defended in case of attack on the individual. In addition to the great carotids there are also the vertebral arteries, which could scarcely be torn except by such an injury as would sever the head from the body. A still further addition to this quadruple supply is the small amount which passes through the arteries of the spinal cord.

Besides such adequate protection against cerebral anemia, provision for equalization of intracerebral pressure is necessary. This is secured by that wonderful adaptive arrangement at the base of the brain, the circle of Willis, by means of which blood is simultaneously received and delivered from the above-mentioned sources. Under normal circumstances the distribution is under even pressure although the halves of the brain may not receive exactly the same amounts of blood. Under certain other circumstances, however, such as fighting, in unusual exertion of one part of the body, in certain positions of the neck and head, and when one side of the neck is subjected to direct pressure, there may be inequality of pressure in the supplying arteries, but, subject to the laws of physics, the inequality must be largely eliminated in the circle of Willis and hence in the brain. The fact that cerebral arteries are straight and numerous and do not anastomose freely has an important and direct bearing. Closure of an artery between the heart and the circle of Willis is a very different matter from closure of one between the circle of Willis and the cerebral tissue.

To summarize the anatomical points which have a direct bearing on cerebral anemia: (1) Provision is made for cerebral expansion and contraction within the skull; (2) there is a blood-pressure-raising mechanism with which to combat anemia; (3) the four major arteries are placed in the most favorable positions for both active and passive protection against injury; (4) these arteries empty into a circular receiving vessel at the base of the brain which equalizes the pressure and from which an even start is made for the passage of the blood through the straight non-anastomosing arterial trees to every part of the cerebral tissue.

THE GENERAL EFFECTS OF COMPLETE ANEMIA OF THE CENTRAL NERVOUS SYSTEM AS SEEN IN DOGS RESUSCITATED AFTER RELATIVE DEATH

The method employed by the majority of investigators has been that of occlusion, either of the cerebral vessels or of the aorta at various levels. The objection to this method, which is frankly acknowledged, is that the factor of collateral circulation cannot be entirely eliminated, even in the most favorable animal, the cat. Further, the brain and the spinal cord have been investigated separately, a procedure which must make a vast difference, not in determining the relative viability of the various centers, but in fixing the limit of anemia, admitting of a complete recovery of the animal. Stewart says: "Division of the cord in the upper dorsal region (III to VI dorsal vertebræ), if done before fairly complete recovery of the cerebral centers, is followed by collapse, dilatation of the pupil, cessation of respiration, cardiac failure, and death. The integrity of the spinal centers is necessary for the resuscitation of the cerebral centers."

Other methods of investigation employed, such as artifi-

cial circulation through the decapitated head, and the introduction of emboli, preclude the possibility of recovery studies. Within the last decade, with the more or less successful attempts at resuscitation of the heart, contributions to the subject of anemia of the whole central nervous system have been made by several observers, notably Prus and Batelli.

The author's study of brain anemia was the sequence of work on the resuscitation of animals killed by anesthetics and asphyxia, which may be briefly summarized as follows: By means of a centripetal infusion of salt solution into an artery together with the simultaneous injection into the stream of one or two cubic centimeters of 1-1,000 adrenalin chlorid, the simultaneous employment of vigorous artificial respiration and rhythmic pressure on the thorax over the heart, the animal may, within certain limits, be resuscitated. For as long as five minutes after total cessation of function resuscitation is usually successful; for as long as from five to ten minutes there are more failures; while after ten minutes the chances of success are progressively less. As will be seen later, this method is uniformly successful within the limits which are compatible with viability of the central nervous system. The method is necessarily self-limited, for, in the case of a heart which is losing its irritability owing to lapse of time, dilatation may occur from the infusion before the beat is inaugurated. Even in dogs with rigid chest walls compression of the chest has proved satisfactory. In periods under five minutes but little compression is necessary. Direct cardiac massage is, therefore, not essential.

The primary purpose being to determine the period of anemia which the central nervous system can endure with subsequent recovery, the method offers the advantage that no operative procedure is necessary except the small incision for inserting the infusion cannula. The author's results are

based, first, on a series of thirty unselected dogs, resuscitated after the lapse of various periods of time, in all but five of which the subsequent course of events was not disturbed. These five were killed after different times for the purpose of histologic examination. Secondly, the series of sixty experiments on dogs, previously reported in the paper on resuscitation, was drawn upon for data pertaining to this work. In the latter experiments blood-pressure and respiratory tracings were made.

Technique

For the recovery experiments, with one exception, the dogs were killed with chloroform. While open to objection on account of the paralyzing effect on the nervous system, and non-elimination of the chloroform until after the resuscitation, this method was adopted in imitation of the condition most likely to afford opportunity for resuscitative measures in failure of the heart in the course of surgical operations. All procedures were done with the customary aseptic precautions. The infusion cannula was inserted into the axillary artery.

In order to estimate in some measure the effect of the anesthesia on the subsequent recovery of the dogs, two experiments were done in which the dog was anesthetized in the usual way to the point of respiratory failure and was then resuscitated by artificial respiration without cessation of the circulation being permitted. The first dog showed full return to intelligence in sixteen minutes. The second one took ether like an alcoholic patient, it being forced for ten minutes before struggling ceased. However, in twenty minutes after recurrence of the respiration, the animal walked about and showed return of function, though extremely "groggy."

The period of total anemia was estimated to start from the moment when the first heart sound ceased to be audible

with the stethoscope, this sound sometimes persisting for several minutes after the failure of blood-pressure as recorded upon the drum and the disappearance of the carotid or femoral pulse and the second sound. While this is only the statement of a well-known fact, attention is called to it, because very possibly in some experiments it made the stated period of anemia shorter than it actually was, the circulation being too feeble to reach the brain, although the first heart sound was still audible. In some cases on account of the heart sounds becoming fainter, it was impossible to record the actual moment of failure. In these a leeway of at least one-half minute was allowed from the last distinct sound to the recorded cessation. From the time of starting the chloroform to respiratory failure there was an average of two and three-fourths minutes, with a minimum of fifty seconds and a maximum of seven and five-twelfths minutes. (See Table I, page 50.)

The cessation of respiration and the final failure of the heart were synchronous in five cases; from which the intervening time varied up to six and three-fourths minutes, with an average of one minute and fifty-seven seconds. From a study of the tracings of the first series it was found that the blood-pressure was at the base line during a longer average time than the latter half of this period. It is probable, therefore, that during this period the cerebral circulation was reduced nearly to the vanishing point, and while a small amount of blood goes a long way in the brain, Leonard Hill saying, "It is obvious that the cortex can be kept from death for hours by the merest dribble of blood," this marked anemia of several minutes' duration had an effect which was apparent in that the cases with prolonged partial anemia did not recover as readily as did the average dog subjected to total anemia of equal duration. It is worthy of note that in the dog showing the maximum recovery period, which was one and one-third

minutes above the time of the second best result, only twenty-two seconds intervened between respiratory and cardiac failure.

In five out of the twenty-nine animals killed by chloroform there was a brief spontaneous recurrence of the heart sounds, occurring from twenty seconds to one and one-half minutes after they had entirely ceased, and accompanied in two instances by two or three faint respiratory efforts. In only one instance was the carotid pulse palpable. As the total duration of anemia cannot be exactly classified, both the absolute and practical duration will be given. The time spent in resuscitation is included in the period of total anemia.

While it seems reasonable to suppose that centripetal arterial infusion of salt solution aided by indirect massage of the heart would hardly reach the brain to any extent during a period of administration of from one to three minutes, and, further, as if it did there would be very little blood in the salt solution, the question was put to the test of experiment. In a dog which had been dead for twelve minutes a solution of methylene blue was infused into the axillary artery, and the usual procedures, with the exception of adrenalin injection, were carried out for double the average time. No indication of its having reached even the bulbar centers was found. This is in contradistinction to direct massage, which, according to d'Halluin, effects a veritable artificial circulation, which is sufficient to reanimate and maintain bulbar activity. Study of the tables of Prus shows that as a result of direct massage respiration returned in twenty-nine out of thirty-five experiments in one series, though there was no return of effective heart beat, and, in seven cases, reflexes and muscular movements reappeared.

The definition of the end of the period of total cessation of the circulation was, however, sharp, the resumption of func-

tion on the part of the heart being abrupt and visible as well as palpable. After a few initial heart sounds blood-pressure rose rapidly, often within ten seconds, to as much as 200 mm. of mercury or over, this rise being due to the adrenalin.

Recovery Results (Tables I and II, pages 50 and 51.)

Permanent and complete recovery was obtained after five minutes, six minutes,¹ six minutes and ten seconds, six minutes and fifteen seconds,² and seven minutes and thirty seconds of total cessation of the circulation. That is, one dog out of twelve with total cessation of circulation between the periods of seven minutes and eight and one-half minutes recovered, whereas only one out of seven between the periods of five minutes and six and one-half minutes died apparently as a direct result of the anemia. Complete recovery was presumptive in another dog after cessation of circulation for seven minutes and thirty seconds. One dog of the second series, after cessation for five minutes and thirty seconds, was killed after twenty-four hours for the purpose of histological examination. As compared with the others of the same degree his condition assured a probable recovery. The asphyxiated dog, after cessation for five minutes and forty-five seconds, was killed on the fourth day. A second animal of the first series, after seven minutes' cessation, was killed on the third day.

Our experience showed no intermediate condition uncomplicated by accidental organic lesion; in other words, no slow decline to death. The demarcation between recovery and death was sharp. In practically all the experiments the crisis was reached in from twelve to twenty-four hours. Then

¹ Recurrence of heart sounds interjected for thirty seconds; practical time, six minutes and thirty seconds.

² Recurrence of heart sounds for one minute and twenty seconds; practical time, six minutes and thirty-five seconds.

death ensued quickly, or else distinct improvements of nervous functions began shortly, continuing more or less rapidly until complete restoration, though the convalescent period lasted in two dogs four and six weeks respectively.

From his studies on the effect of different degrees of anemia produced by occlusions, Leonard Hill says: "The degree of anemia required to produce dementia is separated by the narrowest line from that which produces coma and death of the respiratory center. There are either no symptoms or death in a few hours." Our results accord with this statement. Up to a certain point, not to be exactly limited, but, roughly, six minutes, the after-effects are not marked, and the second, third, or fourth day brings complete recovery. For example, one dog (Experiment 10), after four minutes and ten seconds' cessation of circulation in less than one hour showed entire return of intelligence, which was evinced partly in well-defined efforts to escape from the laboratory; while another, after six minutes and ten seconds (Experiment 29), showed general return of function within twenty-four hours. Beyond the six-minute limit, however, there is a great deal of after-effect, which increases disproportionately with the increase in the duration of the period of anemia, in some instances reaching a state in which the animal is little more than a cardio-respiratory mechanism.

Beyond this limit recovery is altogether uncertain, but our experiments indicate that the stage of depression is tided over, and that recovery will be complete eventually, though the narrowness of the escape is shown by the degeneration of a certain number of neurons in the recovered dogs, whose brains were studied by the Marchi method. This does not exclude the possibility of a partial recovery with a permanent localized after-effect, such as the paralysis of one foreleg, a result described by Stewart in two animals which, however, were under

observation only seven and nine days, respectively. In our dog, which recovered after anemia of the maximum duration, the degeneration predominated in the pyramidal fasciculus. The distinction here has reference to the ability of the whole organism to maintain any life. The viability of the vital centers, as well as of other centers, is considerably above that of the brain as a whole, as the recovery-results prove, and the immediate outcome must depend on the maintenance of the interrelation and association of all brain centers, cortical and subcortical. Stewart says that, when exposed to adverse influences, the synapse proves the weak link in the nervous chain.

In general the following sequence of return of the various functions and reflexes was exhibited: respiration, vasomotor control, corneal reflex, and knee-jerk (tendon reflexes in general), winking, cutaneous reflexes, partial or complete contraction of pupils, and light reflex. This order was subject to considerable variation, which will be considered under the special discussion of functions and reflexes. Hypertonicity of the voluntary musculature immediately succeeded the recovery of a normal tone, and was manifested by exaggeration of the knee-jerk, if not by a more or less widespread spastic condition. This hypertonicity always immediately followed the reappearance of the knee-jerk.

Reflex muscular movements, the result of skin or tendon stimulation, always preceded those of spontaneous origin. Spontaneous incoördinate movements appeared sometimes before, sometimes after, the light reflex, but their later appearance occurred only when the light reflex returned relatively early. Succeeding the coördinate movements appeared what may be classed as purposeful movements, attempts to turn over, to arise, or to crawl forward—movements involving all the muscles of locomotion. Usually after the appearance of coördinate movements, auditory and visual reactions reap-

peared, the former being always the more definite, and usually returning first. In many of the dogs that succumbed after some hours there was more than a mere revival of the reflexes; some of the higher faculties reviving also.

The course of events after resuscitation may be summarized as follows: A state of hyperexcitability follows reanimation, reaching its maximum in from one to three hours, when retrogression begins. This second stage is characterized by uncontrolled muscular movements, either coördinate or convulsive, lasts a longer time, and passes gradually into the third stage of depression and paralysis, in which the reflexes are more or less impaired. The dogs which recovered never exhibited as much mentality nor such active reflexes on the second day as they did immediately after resuscitation.

The average picture toward the end of the first stage in a recovery dog is of an animal in a condition of stupor, lying quietly for the most part, with an accelerated pulse and quickened respiration, expiration being prolonged and labored; with normal conjunctival reflexes; with cutaneous reflexes constantly present in the limbs; with exaggerated tendon reflexes; and with pupil reflexes uneven and tardy if expressed at all. There is a general spastic condition of the muscles, the legs being commonly held in extension. After loud sounds in close proximity the head may be raised, the eyelids opened with dilating pupils, and the ears pricked up, the attitude being simply one of attention without localization or any indication of ideation. As a result of a flash of light the head may be withdrawn, but usually there is only a lid reflex. When disturbed, and sometimes without apparent cause, the animal rouses, barks, looks around, and exhibits coördinate and even purposeful and propulsive movements of the legs and body, attempts to rise or to crawl, usually unsuccessfully, but at times succeeds in standing or in making short progression for

a few seconds, depending on the extent of the paralysis, and then again falls into stupor.

The second stage, retrogression, was a constant phenomenon in all the dogs, but was much less marked after the shorter periods of anemia. The animal becomes progressively more comatose; the spastic condition, which had largely disappeared with the reanimation, returns; visual and auditory reaction disappear; and the skin reflexes become inconstant. Muscular movements, however, are kept up, but are less coördinate and less spasmodic, their character apparently depending on the duration of the anemia, as convulsive movements are slight after the shorter anemias, while, on the other hand, the dog which recovered after anemia of the maximum duration had definite tono-clonic convulsions. When such convulsive movements are well marked, the animal later passes into a deep coma, with a general condition from which recovery hardly seems possible. This coma lasts from 6 to 12 hours, but on the second morning a distinct improvement is apparent.

Up to this point the course of events in the animals which succumbed was similar to that in the dogs which eventually recovered. In the fatal cases a few did not attain a light reflex, and the majority recovered as far as to exhibit coördinate movements and auditory reaction; in but two, however, was there apparently dim consciousness. Reanimation of the higher faculties was much more transient, if present at all, and the animal passed quickly into coma, from which it was impossible to arouse it. There were sometimes periods of violent convulsive movements alternating with periods of quiet and stupor. While these muscular movements were partly clonic and tono-clonic in character, they were distinctly propulsive and progressive, though violent and uncontrolled.

Of the coördinate movements, the running motion of the legs, such as is frequently seen in the early stages of anes-

thesia, was the best example, and was performed with extreme rapidity, the dog lying partly on its back with its legs waving rhythmically in the air. Sometimes only the forelegs were involved, but usually the movement was general. If the dog was not too much paralyzed, this resulted in a crab-like progression about the room. The strictly convulsive movements were very complex, clonic and tonic types being mingled, with a resultant violent thrashing about. In several instances there was some opisthotonos. The slightest disturbance provoked movements characteristic of the animal.

The quiet periods in the early stages were of short duration, but the intervals between them were distinct. In the later stages the intermediate periods of rest became more and more prolonged. Finally, as if worn out, quiet would ensue, the animal being perfectly limp; tendon and skin reflexes disappearing first, next the eye reflexes, until only the cardio-respiratory functions were left complete, with respiratory failure near.

To show the slow return of faculties and the paralyzing effect of the maximum period of anemia from which recovery was made (seven minutes and thirty seconds in Experiment 27), the subsequent course of the animal in this experiment will be given in some detail. On the second day she was awake but paid no attention to her surroundings. To loud sounds there was only an occasional response, and blindness appeared absolute. The hind legs were entirely paralyzed, but when the hind quarters were supported she was able to walk on the forelegs, though the progression was cross-legged or sprawling. Sensation was much more deficient than motion, no attention being made to the prolonged immersion of any foot in cold water. A strong bulldog clamp on a hind paw provoked restlessness only, though on a forepaw it was vaguely localized, but only to the extent of a reflex from the leg itself,

there being no coördinate attempt at removal. Food was not recognized when placed in the mouth, and was held there passively. No notice was taken of tobacco smoke or ether vapor. On the third day she walked about, though unsteadily, and with a decided stringhalt gait of the hindlegs. She recognized water after standing in it for several minutes. The legs gave way when she jumped off a chair. Hearing was very acute, but vision appeared to go no farther than the mere perception of light. That localization of sensation was improved was shown by the clamp test, as she bit rather aimlessly and very incoördinately at the foot affected, very frequently attacking the wrong leg. It was not until the seventh day that the clamp was recognized, grasped and pulled off. On the third day the feet were withdrawn from cold water, but the sense of position was not evident until the fourth day, this being tested by resting the feet on boards at different levels. Only maximum differences of levels were recognized. While the animal appeared hungry, constantly licking her chops, food was not recognized until the fifth day. Tobacco smoke and ether vapor were not noticed until a week after resuscitation. While within a week the return of all the faculties with the exception of vision was indicated to a greater or less degree, the animal was by no means normal, but exhibited great hebetude in all respects. She was very lethargic, would not run nor play, and response to any stimulus was delayed and feeble. How much of this lethargy was due to the blindness it was impossible to say, but certainly not all. For two weeks there was hardly any perceptible improvement in vision. She paid no attention to the attempts to test her vision, and she moved about slowly, feeling her way, though at about the end of the second week she noticed moving objects if within the range of a foot or two, especially when they were held above the level of her eyes. From this time on improvement continued stead-

ily, and, at the end of the fourth week, recovery of vision was complete. With the recovery of vision the condition of dementia entirely disappeared, and then for the first time the psychical faculties of fear, pleasure, and memory became normally evident.

In the case of the dogs which succumbed the following observations were made: Among seven dogs subjected to anemia lasting from five to seven minutes, one died after twenty-four hours. Of those which died after anemia from five to seven minutes in extent, two revived enough to exhibit spontaneous coördinate muscular movements, without visual or auditory reactions or return to consciousness. Of five which succumbed after eight-minute to nine-minute periods of anemia, one did not recover sufficiently to show even the light reflex, and did not come out of coma; two recovered to the extent of muscular motion; a fourth recovered auditory reaction; while in only one was there a suggestion of a return to consciousness. Among three subjected to from nine- to ten-minute periods of anemia one recovered so far as to exhibit apparent consciousness, one failed to recover the power of vision, and in the third the light reflex returned. One dog after anemia, lasting for twelve minutes and ten seconds, showed only a revival of the reflexes, and in the dog which recovered after the longest period of anemia only coördinate muscle movements appeared in addition to the reflexes.

Special Phenomena Following Resuscitation

Respiration.—(See Table III, page 52.) Respiration has recurred in every animal in which the circulation was restored and maintained for a sufficient period. The maximum case, thirty-two minutes of total anemia, twenty-one minutes after the circulation was established, showed return of respiration to the extent of three faint gasps, but cardiac failure imme-

diately ensued. Comparison of the time of restoration of respiration in our experiments shows a much more rapid recovery than that recorded by several other observers. In our experiments the average time for the restoration of animals subjected to anemia for periods of from three to eight minutes was three minutes and fourteen seconds. The average recovery time in Stewart's cats and dogs after occlusion of vessels for the same periods was seven minutes and forty-one seconds; for Prus's chloroform series with periods from three to five and one-half minutes was seven minutes and nineteen seconds (with frequent return of respiration before efficient heart beats). Batelli's successful chloroform cases with the same periods are too few for comparison, but, in general, both these and the electrocuted dogs gave data in concordance with the above results. Hill says that a certain arterial pressure is necessary to invoke respiration. This explains the increased effectiveness of the higher blood-pressure due to the adrenalin used in the author's experiments.

The first respiratory gasps were distinct and fairly strong. In the majority of the animals after a few gasps, inspiration exhibited a triple character, with the inspiratory-expiratory ratio of three to one, such as occurs in sobbing. This lasted for several minutes. Gradually the rate increased and the rhythm became regular. A sudden resumption of the normal type of breathing sometimes happened in the dogs subjected to short duration of anemia, and was always associated with the simultaneous recovery of the eye reflexes. A rapid increase of rate was the rule in all cases, as much as 100 per minute being recorded, but usually the high rate did not long continue. For example, it was 72 per minute sixteen minutes after resuscitation in the dog which recovered after anemia of seven and one-half minutes and fell to 36 in about twenty minutes. Later it was subject to frequent changes, and in

some cases a normal rate was not established until the third day. As the rate slowed, a prolonged and labored expiration was characteristic. The changes of rate in the initial respirations will be best illustrated by reference to the protocols of two experiments.

EXPERIMENT 27

Hound puppy, about eight months old. Seven and one-half minutes total cessation of the circulation.

11.45.30.—Return of pulse was first noticed.

11.47.30.—First respiration. The first four respirations occurred at thirty-second intervals, and then, for about three minutes respirations occurred at seven-second intervals, each inspiratory act comprising three distinct efforts. Fibrillary contractions of the tongue occurred after beginning of respiration.

11.55.00.—Lacrima secretion began. The right pupil was distinctly contracted.

11.58.00.—Respirations rather suddenly assumed normal character and rhythm, with rate of 24.

12.00.00.—Respiratory rate jumped to 48.

EXPERIMENT 30

One-year-old puppy. Twelve minutes and ten seconds total cessation of circulation.

11.30.15.—The heart began to beat, recording from first observation of the pulse in the axillary cannula. Though the infusion tube was partly clamped by the finger, pressure was sufficient to drive the blood into the infusion bottle at a height of five feet.

11.32.25.—First respiration occurred. This movement and those following for several minutes were deep and gasping. For four minutes the rate was very irregular, at intervals varying from five seconds to one minute. Artificial respiration was kept up continuously during this time, but was stopped as soon as spontaneous respirations became more regular.

11.37.00.—Respirations now occurred at three to five-second intervals.

11.38.00.—Respiratory rhythm was more steady (20 per minute), and movements were more shallow.

11.44.22.—Respirations, 28 per minute.

12.00.00.—Respirations, 32 per minute, were somewhat more irregular and spasmodic. Expiration was distinctly labored.

12.13.00.—Respirations, 40.

12.40.00.—Respirations, 32. The dog was evidently failing, and about one hour later was found dead.

Blood Pressure.—(See Table III, page 52.)—The use of adrenalin complicated the study of the blood-pressure changes. In a successful resuscitation, as already noted, the blood pressure rose rapidly, often within ten seconds, usually to a height of 200 mm. of Hg, and in one case to 250 mm. This level was maintained from two to five minutes in all but the dog with 250 mm. of pressure, and then it began to fall as the effect of the adrenalin wore off. From ten to forty minutes elapsed before the lowest level was reached. Depending on the extent of the vasomotor reactivation, either a tendency to rise was immediately exhibited or the low level persisted for from ten to twenty minutes, in the latter case with a subsequent rise. In two animals, after total anemic periods of seven minutes and thirty seconds and eight minutes and thirty seconds, one of which at least may be credited with presumptive recovery, this second level was maintained until the animals were killed—in twenty-four hours and in five and two-thirds hours respectively—but in the others, all with anemia of longer duration, it was only a temporary reanimation and, along with the reflexes, steadily declined until death.

On account of the adrenalin effect in overlapping the return of normal vasomotor activity, particularly after the shorter periods of anemia, the relative time of the reactivation of the vasomotor center could not be absolutely determined. Stimulation of the sciatic nerve did not cause the usual rise of pressure until the secondary rise had begun, and respirations were well established (see Table IV, page 53).

With one exception respiration in all experiments returned well before the end of the first fall in blood pressure. In one experiment of the second series as little adrenalin as possible

was used: the anemia lasted five and one-half minutes and respiration began in two minutes after restoration, while reaction to sciatic stimulation was not obtained for four minutes. Synchronously with the pressure reaction, respiration rather suddenly assumed a more normal type. It appears, therefore, that the return of activity in the vasomotor center is nearly synchronous with the return of respiration after the shorter periods of anemia, but is more delayed after the longer periods. In the puppy subjected to thirty-five minutes of anemia there was apparently no vasomotor reactivation.

Reflexes.—(See Table IV, page 53.) While varying considerably in the time of their recurrence, after equal periods of anemia, the corneal reflex and spontaneous winking returned in all but the three experiments which were not sufficiently protracted. The light reflex reappeared constantly after eight minutes of anemia, though it was the least uniform in time of its return and in its degree of activity. In periods of anemia of more than eight minutes the recovery of the light reflex was inconstant. The maximum anemia period after which the corneal reflex reappeared was twenty-four minutes (maximum resuscitation in adult dogs), and for the light reflex the maximum time was fourteen and one-half minutes.

The knee-jerk varied the least in its recovery periods. It was also noted in the resuscitation after the maximum anemia period. Not infrequently there was a difference in the time of recurrence of the bilateral reflexes, in two cases one corneal reflex reappearing three minutes before the other, though for the knee-jerks no difference of over one-half minute was noted.

As to the relative time of the reappearance of reflexes, the knee-jerk usually appeared before the corneal reflex, though they were synchronous four times. The corneal reflex always

preceded spontaneous winking, while in every case the cutaneous reflexes returned before the light reflex.

Temperature.—While not recorded as a matter of routine, sufficient data have been obtained to indicate that the temperature continues to fall for several hours following resuscitation. The lowest rectal temperature was 32.9° C. four hours after anemia of nine and one-fourth minutes (Experiment 1), and 33.8° C. was reached in sixteen minutes after thirteen and one-third minutes of anemia (Experiment 5). From this point the temperature gradually rose to a state of hyperpyrexia, which was more marked in the animals which succumbed. In the dog which recovered after the maximum period of anemia the maintained level was reached the second day.

Phonation.—Nine and one-quarter minutes of anemia (Experiment 1) was the maximum period after which this faculty returned. Actual barking, indeed, occurred in but one other case of over seven and one-half minutes of anemia (Experiment 14), though there was whining or imperfect attempts at vocalization in three cases. Phonation usually appeared synchronously with or shortly after the exhibition of spontaneous muscular movements, that is, one-half to one hour after resuscitations following anemia of about seven minutes.

Micturition and Defecation.—Micturition or defecation occurred in the majority of animals during the period of hyperexcitability.

Auditory, Visual, and Olfactory Senses.—As already indicated, the reaction to auditory stimuli was definite and unmistakable during the period of hyperexcitability in the recovered dogs, while to various visual stimuli during the same period the only response was a lid or pupil reflex, but out of fifteen animals subjected to anemia for seven minutes or more, only six gave even a temporary recovery of hearing.

Further, in the animals which recovered the later effects on vision were much more marked, in general increasing as the limit of possible recovery was approached. For example, in the dog with recovery after the maximum anemia period, hearing was reasonably acute on the third day, though vision was not fully restored for three weeks, while in the animal with anemia of six and one-sixth minutes (Experiment 29), the best example of early visual recovery, hearing was normal on the second day, though a day more was required before the animal ran about without colliding with obstacles. The maximum duration of anemia after which hearing was observed was nine and three-fourths minutes (Experiment 15). The sense of smell came back at a point between hearing and vision, though the test was never definite unless irritating fumes were employed. The first reaction to these was on the third and seventh days, respectively, in dogs with anemia of six and of seven and one-half minutes (Experiments 2 and 27).

Phenomena Referable to the Cortex.—Most of the animals which recovered passed through a final stage comparable in many respects to the condition of Goltz's decerebrates. Such a period was characterized by dementia and loss of intelligence, the lack of any psychic response to stimuli, and the inability to recognize food and drink. Response to stimulation was purely reflex, or was absent if memory of past experiences was involved. For example, meat placed in the mouth was held there passively or in one case forcibly spat out, a flash of light was answered by a lid reflex, and there was indifference to the relative position of the fore legs. Power to localize stimuli was of gradual acquirement. Restlessness, however, was generally not observed.

That the temporary paralysis was of cortical origin was indicated by the associated exaggeration of the knee-jerks.

The motor function did not suffer as much as the sensory, for the paralysis disappeared before the return of intelligent and normal response to stimulation. The clinical observation that the cortex suffered the most and was the last to recover is supported by the fact that the histological alterations were more marked in the cortex than in the lower centers.

The other dog which recovered also gave a picture of degeneration, but of a different character. While the actual number of nerve fibers involved was greater, not only was there no localization but there was an early stage of degeneration with droplets of varying size, scattered in longitudinally cut spinal nerves at intervals along the course of the fibers affected. This animal, which was killed in six days, was, at the time of death, partially blind and deaf and, though it could stand, it was too paralyzed to maintain the upright posture or to walk. The question arises as to whether it would have eventually recovered. Judging from the other animals which, with final recovery, passed somewhat more rapidly through a similar condition, and from the fact that there was a noticeable improvement from day to day in the animal just mentioned, general recovery, with a complete destruction of a few neurons, is probable.

An early degeneration similar to that mentioned occurred in the fatal cases, though the number of fibers involved was considerably less. None of these animals had lived over thirty-six hours at the outside. On account of the shortness of the time which had elapsed, this appearance was unexpected and will be further investigated. However, it corresponds with the organic changes in the cell-bodies which occurred during the same time.

Comparison of the Authors' Results with the Results of Others

Mayer concludes that from ten to fifteen minutes of anemia is the maximum period admitting of general resuscitation, though respiration and the vasoconstrictor activity may recover after that time. Stewart, with complete recoveries after occlusion of cerebral vessels for five, six, eight, nine and four-fifths, and sixteen and one-half minutes, agrees with Mayer's conclusion. Hayem says that, in general, brain functions are not recovered after from ten to eleven minutes. The conclusions of Batelli and of Prus are the only ones drawn from observation of animals resuscitated from apparent death. None of Batelli's dogs survived, and he ascribes this fact to the severity of the operation on the thorax necessary for his resuscitative measures of electrical stimulation and heart massage. He states that its condition being aggravated by the violent respiratory efforts, the animal passes into coma and dies. However, from the extent of reanimation exhibited, he concludes that the functions of the central nervous system may be reestablished after ten minutes of total anemia, but not constantly after fifteen, and that the maximum limit is twenty minutes. Prus does not fix a definite limit. Stewart suggests that, in such prolonged periods of one and two hours as those of Prus, the auricles must have kept up a slow, but in some degree efficient, movement of the blood through the brain. On account of the injury from opening the thorax, Prus attempted recovery in only thirteen out of fifty-two reanimated dogs, the others being killed after a short time. Two of these survived. One was killed by asphyxiation, after a period of total anemia of six minutes, estimating from the stoppage of the heart to the beginning of direct massage, as considered under "Technique." From the

data given, the subsequent course of this animal corresponds closely to the author's six-minute anemia cases. The other of Prus's recovery dogs after an anemia period of four minutes was killed by chloroform. The dogs that survived from three to five days were all subjected to anemia of short duration, and of the two cases subjected to ten minutes of total anemia, one died in six and one-half and the other in twenty-four hours, all the deaths being ascribed to infection.

From the author's experience, it seems justifiable to say that the observation of an animal resuscitated from a state of completely suspended animation is very misleading *unless carried far enough*, and that such observation does not permit of conclusions regarding the limit of anemia admitting of recovery. The reason is that there quickly ensues a condition of hyperexcitability of reflexes associated with voluntary movements and with greater or less return of the special senses, even with an apparent return to consciousness; consciousness may be transient, but appears in animals which succumb as well as in those which eventually recover. This phenomenon was exhibited in dogs subjected to nearly twice the duration of anemia from which recovery was made, and in several instances the appearance of reanimation was so decided as to make the prognosis very hopeful. But after a few hours, more or less, the special senses failed, the dog became progressively stuporous, convulsions ensued, then loss of reflexes, and, finally, respiratory failure. The decline to death indicated definitely a nervous origin; and autopsies on all the cases fatal immediately after the resuscitation showed in only one case any organic lesion to which death could be attributed. This was a dog which had been subjected to anemia of eight and one-half minutes (Experiment 14) and which died between thirty and forty hours later, with an early and irregularly dis-

seminated bronchopneumonia. As long a survival as this was exceptional.

By the occlusion method, the general conclusion appears to be that ten to fifteen minutes of anemia is the maximum period after which resuscitation is practicable. This conclusion is not unassailable for two reasons; first, because of the impossibility of absolutely eliminating the factor of collateral circulation, and, second, because the brain and cord have been investigated separately. In the latter connection, apart from the interrelationship of the two, the possible percolation upward of the cerebrospinal fluid, with the circulation of the cord unimpeded, is worthy of consideration.

As a result of the authors' experiments with an undoubtedly total anemia and little opportunity for infectious accidents—conditions the most favorable for investigation of the possibility of recovery—the opinion is that the limit should be reduced one-half. For dogs killed by chloroform the average duration of anemia from which recovery may be made is between six and seven minutes. The extreme limit appears to the author to be under ten minutes, and any recovery after more than seven and one-half minutes would be exceptional. The accurate fixation of the limit beyond which recovery is impossible is of great practical importance.

Summary

To determine the limits of recovery after a total anemia of the central nervous system, thirty dogs were killed by chloroform and resuscitated after the lapse of varying times of from three to fourteen minutes. If resuscitated in less than five minutes the recovery of function was rapid and was strikingly free from the after-effects which characterized longer periods. Of seven animals anemic from five to six and one-half minutes, only one died apparently as a direct result of

the anemia, but of twelve subjected to anemia from seven minutes to eight and one-half minutes, only one recovered after seven and one-half minutes of anemia. The remaining dogs all died. Further corroborative data are drawn from the previously published paper on the technique of resuscitation.

Histological examination both of presumptive recoveries and of fatal cases was made by ordinary methods and by those of Nissl and Marchi. The neurocytes of the fatal cases uniformly presented the greatest change, being not merely chromolytic but here and there definitely indicative of cell death. Marchi's method further supports these findings by proving the existence of fiber degeneration. Finally, showing the narrowness of the escape, in the animal showing the best recovery-result after seven and one-half minutes of anemia, which at the end of four weeks had apparently entirely returned to a normal state, histological examination by the Marchi method showed the degeneration of a number of fibers in the pyramidal fasciculi, which were traced from the cord to the cortex, and in Flechsig's fasciculus, while a more sparsely scattered degeneration of both ascending and descending fibers was evident elsewhere. In recent works (1911) all changes due to cerebral anemia have been much more extensively studied.

*Protocols of Ten Selected Experiments*¹

EXPERIMENT I

*Death from Chloroform; Resuscitation Begun 5 Minutes After
Cessation of Circulation; Total Duration of
Anemia, 9¼ Minutes*

JULY, 1906.

Small mongrel dog; fairly nourished, but with a general vesicular and pustular eruption. A cannula was inserted into the axillary artery, and connected by means of rubber tubing with the saline in-

¹The numbers of these experiments do not correspond with those given in the foregoing pages, the former referring to the tables.

fusion bottle, at a height of five feet above the operating table. Ether was given at first, and then chloroform in lethal dose. After cardiac failure a tracheal intubation tube was inserted, so that artificial respiration could be given with bellows.

10.20.30 A. M.—Respiration ceased.

10.21.30.—Respiration began again. More chloroform was given.

10.22. —Respiration ceased.

10.27.15.—Heart sounds ceased, and pulse was no longer palpable (5 minutes and 15 seconds after final cessation of respiration).

10.32.15.—Began to resuscitate; 5 minutes after cessation of circulation normal saline solution was given through the axillary cannula, 2 c. c. of 1-1,000 solution adrenalin chlorid solution were injected through the rubber tubing, just above the cannula, into the saline stream, by means of a hypodermic syringe, and artificial respiration was begun with the bellows.

10.36.30.—The heart began to beat, making the total duration of cessation of circulation 9 minutes and 15 seconds.

10.40. —Spontaneous respiration began, 4 minutes 15 seconds after return of circulation.

10.50. —The heart sounds were distinct, but slow and somewhat irregular, improving from this time on. The respiration was regular and normal.

10.55. —The respiration suddenly became irregular. Artificial respiration was begun, with rapid improvement of the respiration following.

11.37. —Conjunctival reflexes were first obtained, 1 hour 1½ minutes after return of the circulation. The heart was apparently acting in an entirely normal manner. The blood-pressure, which had been very low, was about 100 mm. of mercury, in so far as it could be judged from the pulse.

11.43. —Knee-jerks were obtained in the left hind leg, 1 hour 7½ minutes after return of the circulation. They were then obtained in the right hind leg, but more feebly.

11.45. —Respiration was normal. The intubation tube was removed. There was some slight resistance to flexion and extension of the hind legs, but the fore legs were completely relaxed.

11.47. —The knee-jerks were slightly stronger. The pupils were widely dilated and with no reaction to light.

- 12.15. —The pupils were becoming narrow, and were just beginning to react to light, 1 hour 38½ minutes after return of circulation. The general muscular tone was better, but the fore legs were still relaxed, except at the shoulders. Moving the neck, especially flexing it, was resisted. The spinal muscles resisted when the back was bent.
- 12.50. —The hind legs were somewhat spastic, flexed at the thigh and extended at the knee. The fore legs were still more so. The muscles of the back were not spastic on flexion, but were somewhat so on extension. The reaction of the pupils to light was active. The right pupil was much more active than the left. The respiration and blood-pressure were normal. Spontaneous defecation occurred, 4 hours 3½ minutes after return of the circulation. The temperature by rectum was 32.9° C. The skin was very cold.
- 1.50. —Temperature 33.3° C. The condition of the muscles was the same. On being moved the dog seemed to utter purposeful moans, and showed some apparently purposeful movements of the fore legs, as if trying to get up. The pupils were of normal size, the left being slightly more dilated than the right. When not disturbed immediate general relaxation, followed by sleep, took place.
- 2.00. —At about this time and shortly after, several spontaneous periods of awakening from the stupor occurred, the eyes being widely opened, while purposeful but futile attempts were made to turn over and stand up. After several of these attempts had been made at irregular intervals one was induced by pounding on an adjacent table. The dog evidently heard the noise, as he opened his eyes and tried to rise. When quiet ensued he relapsed again into stupor. When the hand was passed rapidly in front of his eyes he blinked.
- 4.00. —The dog was sleeping, with grunting respirations. On being disturbed, he rose to his feet, but relaxed at once into a stupor, and fell down. Also when left alone he relaxed into stupor. Apparently he was able to see, for, when aroused, he looked fixedly but vacantly. A moving object did not cause winking until the eyelids were touched.
- 5.30. —The spastic condition had passed off. The knee-jerks were

active, but there was no clonus. A comatose condition was present. Loud noises did not disturb. Under stimulation spontaneous attempts at forward locomotion occurred, the movements of the fore legs being coördinated. Relapse immediately followed the efforts.

9.00. —Temperature not taken, but dog in high fever. He lay stretched out in a spastic condition, with labored, stertorous, rapid breathing, which soon became rapidly irregular and gasping, although the pulse was still good. The knee-jerks had almost disappeared. Death was evidently near at hand.

9.15. —Respiration ceased. The heart continued to beat rhythmically for about three minutes more. Autopsy was performed before the heart action had entirely ceased.

Autopsy: The heart was empty and apparently normal. No clots were present. The lungs showed nothing of importance except slight congestion at the base. In two places the liver had been slightly injured by the massage. Both liver and spleen showed a chronic inflammatory change of no interest in the present connection. The other organs appeared to be normal.

EXPERIMENT 2

Death from Chloroform; Resuscitation Begun 3 Minutes After Cessation of Circulation; Total Duration of Anemia, 6½ Minutes

JULY 25, 1906.

Black mongrel bitch; weight, about 7.0 kilos. Experiment conducted as in Experiment 1, using ether at first and then the lethal dose of chloroform.

11.52.30. A. M.—Respiration ceased.

11.53.30.—Heart action no longer perceptible.

11.54.30.—Heart beats appeared again, but the pulse was barely perceptible.

11.55. —Heart beats ceased. Pulse no longer palpable. The circulation practically ceased at 11.52.30.

11.58. —Began to resuscitate in the usual way, 3 minutes after final cessation of circulation.

12.00. —Heart beats appeared, making the duration of complete cessation of circulation 6½ minutes.

12.01. —Spontaneous respiration began 45 seconds after return of the circulation.

- 12.09. —Knee-jerk appeared in the left hind leg, 8 minutes 45 seconds after return of the circulation, and $\frac{1}{2}$ minute later in the right hind leg, 9 minutes 15 seconds after return of the circulation.
- 12.11. —Conjunctival reflex appeared on stimulation, 10 minutes 45 seconds after return of the circulation.
- 12.13. —The fore legs began to stiffen, and incoördinate muscular movements occurred. In connection with the latter and in conjunction with the respiratory efforts movements of the head first appeared. The muscles of the hind legs became tonic, but were not stiff.
- 12.15. —Spontaneous winking occurred.
- 12.18. —General slight spasmodic muscular contractions occurred, while the muscular movements became more coördinated and purposeful. The pupils were still dilated.
- 12.20. —The respirations were still labored. The pulse was of good quality. The pupils began to narrow, and the general muscular movements continued.
- 12.25. —In response to touching the skin the leg was drawn away, showing that the cutaneous reflex had returned, 25 minutes after return of the circulation.
- 12.27. —On lifting the dog from the table to her box she raised her head and looked toward the bearer. The breathing had just become fairly quiet and normal.
- 12.32. —A spontaneous attempt to get up was made.
- 12.35. —The dog barked. The head was held in marked extension.
- 12.40. —It was shown by slight movements of the eyes or head that attention was paid to loud sounds made by hammering on a box. To loud whistling there was but slight response. The pupils were still dilated greatly, but showed faint reaction to light, 40 minutes after return of the circulation.
- 12.45. —Notice seemed to be taken of the surroundings. The animal's general appearance might be described as being stupid. Water was not drunk, even when the nose was placed in it.
- 5.00. —The dog was apparently brighter, languidly following movements in her immediate vicinity, but spent the time in quietly sleeping, if not disturbed. The spastic condition had almost disappeared.
- 9.30. —She was found ten feet away from her box, egress having been barred by a side six inches high, over which she

had climbed. She was unconscious, barely arousing when returned to the box, when she immediately relapsed into deep stupor. Loud sounds only called forth subdued groans. Defecation occurred. Temperature, 40.1°C . Respirations were quiet and easy. The pulse was of high tension and somewhat thready. Constant shivering was present. The knee-jerks were again exaggerated, but most of the spasticity of the legs was lost. On being pinched the general spastic condition returned. Various muscular movements occurred, and occasionally they seemed to be in response to loud sounds.

JULY 26, 1906.

9.00 A. M.—The dog was found quietly sleeping. The pulse was normal in character, the respiration easy, the temperature 39.5° by rectum. The knee-jerks were still exaggerated, but the legs had lost most of their spasticity. For the first time an exaggerated scratch reflex was obtained. When annoyed by flies she tried to wipe them away with her paws, and threw her head toward the point of irritation, but without trying to bite at them. On loud whistling the eyes were barely opened. On suddenly striking a match in front of her eyes only a delayed conjunctival reflex was caused. Attempts to disturb her merely roused her slightly from her stupor. Petting apparently did not arouse any cerebral ideation. The general appearance was that of moderate morphin anesthesia. The same condition was maintained all day, the dog sleeping quietly when undisturbed. Twice milk was given her by means of a stomach tube—300 c. c. at noon and 500 c. c. at night.

JULY 27, 1906.

9.00 A. M.—The dog was lying outside her box. When put on her feet, she walked aimlessly, being rather shaky and ataxic, and did not see obstacles in her path in time to avoid them. Striking a match suddenly before her face caused opening and blinking of her eyes, but she was perfectly indifferent to a light moved slowly in front of her eyes. Only once did loud sounds cause her to move away into a corner. After that time she paid no attention to whistling, or to stamping, even immediately in front of her head, regarding such actions with a vacant

stare. The odor of an old pipe had no effect. Chloroform and tobacco smoke caused her to draw her head away, but this was considered to be a reflex action. Patting and petting brought forth only a scratch reflex. Water was refused, even when put into the mouth. She very quickly became tired, and lay down to sleep. She was given 500 c. c. of milk, as before.

- 12.00. —She licked the orderly's hand, and when her nose was put into some milk she drank abundantly, and continued to be fed in this way. Later in the day it was noted that when she was disturbed she observed things around her, but, if left alone, she slept.

JULY 28, 1906.

- 9.00 A. M.—This morning she appeared more lethargic. The wound in the axilla, where the cannula had been inserted, was discharging freely. Temperature, 39.1°C . The scratch reflex was not satisfactory, only a head reaction being obtained. At times the dog seemed to be conscious of petting, but very vaguely so. In some instances threatening motions apparently caused slight cowering, but usually they were regarded with complete indifference. When left alone she slept all the time. She was very sensitive to pain. Sometimes she reacted to the odor of the old pipe. Sounds attracted attention only when made close to her. She still regarded with indifference a lighted match in front of her eyes. She drank milk only when it was put into her mouth. After being examined she sank into a deep stupor.

JULY 29, 1906.

- 9.00 A. M.—When a door near her was opened she raised her head. She appreciated the proximity of milk, drinking spontaneously when it was set near her head. She gave a slight scratch reflex. Whistling and calling caused her to raise her head, but otherwise she paid no attention. For the first time a lighted match near her head caused her to withdraw it. Threatening motions produced cowering and trembling. Petting produced nothing definite except a head reflex, as though she were going to catch a fly.

JULY 31, 1906.

- 9.00 A. M.—Since the last note the dog was practically in a uniform state of hebetude, although her physical condition was

almost normal. She walked with very little unsteadiness when examined on the above date. Her sense of sight was very feeble, as she had no perception of objects so close to her nose that she could not turn aside quickly enough to avoid bumping into them with force. She would walk across the laboratory floor in a straight line until she hit whatever happened to be in her line of progress. Then she would have her direction changed, only to repeat the performance over and over again. To loud whistling she made only a delayed, indifferent, ideationless turning of her head. At times she seemed to appreciate being petted, while at others she was absolutely indifferent, only a scratch reflex being brought forth. On one occasion she rubbed against the observer's leg, as if petting gave her pleasure.

For several weeks longer improvement of the mental state was so slow as to be almost imperceptible. The dog was utterly listless, sleeping, or at least lying down most of the time, occasionally walking about in a very constricted area, or standing still with the head lowered. How much this was dependent on her almost total blindness it was impossible to say, but, with the return of vision, at least a vision sufficient for her purposes, ideation began to be apparent, and later appeared what might be called, for lack of a better phrase, a conscious initiative, an acting for herself. Inside of six weeks, to all appearances, her mental and physical functions were as before her period of relative death.

EXPERIMENT 3

*Death from Chloroform; Resuscitation Begun 3 Minutes After
Cessation of Circulation; Total Duration of
Anemia, 5 Minutes*

JULY 27, 1906.

Mongrel dog; weight, about 7.0 kilos. Experiment conducted as in Experiment 1. Total duration of anesthesia, 15 minutes.

10.16.15 A. M.—Respiration ceased.

10.20. —The heart began to fail rapidly.

10.20.15.—Circulation ceased.

10.23.15.—Began to resuscitate in the usual way, 3 minutes after cessation of circulation.

10.25. —The heart began to beat again, making the total duration of cessation of circulation 5 minutes.

- 10.25.40.—Spontaneous respiration began, 40 seconds after return of the circulation.
- 10.27. —Conjunctival reflexes were first noted, 2 minutes after return of the circulation. The knee-jerks returned a little later, but were not uniform for some time, although the dog rapidly became rather spastic, with clonic muscular spasms and continuous barking.
- 10.40. —The pupils were contracted. On account of the struggles of the animal the pupillary reflexes were not satisfactorily obtained.
- 10.42. —On being disturbed there was an ataxic effort to get up on his feet.
- 10.45. —An unsuccessful, spontaneous effort to get up occurred. The pupils did not react to light. There was no scratch reflex.
- 10.50. —On being disturbed the dog struggled and tried to get away. The breathing, which had previously been very rapid and labored, was now quiet.
- 10.55. —The spasticity had diminished. When placed on the floor loud whistling caused the dog to stand on his feet and move away. The motion, however, was of a semi-crawling character, there being very little control of the front legs. A lighted match held in front of the eyes caused the head to be jerked away.
- 2.00. —There was no scratch reflex. The knee-jerks were again somewhat exaggerated. The dog was in a somnolent state, paying no attention to loud sounds. A lighted match before the eyes produced only a conjunctival reflex. Warming the paw to the point of slight discomfort only caused it to be moved away, and there was apparently no evidence of pain being caused. Warming the ear caused only a muscle reflex.

JULY 28, 1906.

9.00 A. M.—Earlier in the morning a feeding through the stomach tube was vomited, only a little of the milk being retained. The dog was found out of his box, suffering severely from snuffles, and with a respiratory defect, as shown by the slow and labored respiration. The heart action and blood-pressure were of good quality. The temperature was 39.1° C. On account of the lethargic condition little was brought out by the examination. He was indifferent to a lighted match held in front of

the eyes, hardly more than a conjunctival reflex being called forth. On loud sounds being made, he reacted but slightly, with coördinated muscular movements. To loud whistling at any distance he was indifferent. The smell test with the old tobacco pipe was negative. There was no scratch reflex. Apparently he was not conscious of pain. It was impossible to make him angry. He walked normally. On holding him he pulled away, and when let alone he at once went to a corner and lay down. To threatening motions with a broom he was absolutely indifferent.

JULY 29, 1906.

9.00 A. M.—When the observer came into the room the dog regarded his entrance with ordinary intelligence. Hearing and vision were apparently good. An error of judgment was made on the part of the observer in making threatening motions before conducting the rest of the examination. As a result the dog cowered and walked into a distant corner under a table, and the subsequent examination was not satisfactory, on account of his fear. Attempting to pull him out of the corner made him snarl, but he did not attempt to attack the observer. After prolonged petting, he finally wagged his tail, but he still seemed cowed. He would not drink milk when it was put into his mouth. He reacted poorly to the smell of the tobacco pipe. There was no scratch reflex.

JULY 30, 1906.

9.00 A. M.—The dog refused milk, but ate an abundance of meat. He responded normally to petting and threatening. All his muscular movements seemed normal. In some unknown way he escaped from the laboratory to the street, and was chased by the orderly for half a mile before he was caught. While escaping he showed all evidences of normal canine intelligence in eluding capture. In about two hours he escaped a second time, probably through an open first floor window, and reached the street by a very devious route. He was seen no more, but there is no doubt but that he was well able to take care of himself.

EXPERIMENT 4

*Death from Chloroform; Resuscitation Begun 6 Minutes After
Cessation of Circulation; Total Duration of
Anemia, 8½ Minutes*

JULY, 1906.

Young fox terrier; weight, 7.3 kilos; condition, good. Experiment conducted as in Experiment 1. Total duration of anesthesia, 15 minutes.

9.57 A. M.—Respiration ceased.

9.58. —Circulation ceased.

9.59.30. —Several weak respiratory movements occurred, and the heart beat feebly again for about 10 seconds. The action was too weak to produce a palpable pulse in the carotids.

10.04. —Began to resuscitate, 6 minutes after cessation of circulation.

10.06.30.—The heart began to beat again, making the total duration of cessation of circulation 8½ minutes.

10.09. —Spontaneous respiration began, 2½ minutes after return of the circulation.

10.20. —The respiration was regular.

10.23. —The conjunctival reflex was first obtained and normal spontaneous winking noted, 16½ minutes after return of the circulation. The fore leg reflex was first obtained ½ minute later, and was more marked in the right leg. (Note.—This was the first experiment in which the leg reflex was obtained in a fore leg before being obtained in a hind leg.) The knee-jerks appeared somewhat later, and first in the right leg.

11.26. —The right knee-jerk was strong, the left weak. The dog began to utter an inarticulate cry. Rectal temperature, 36.1° C.

11.32. —The fore legs began to stiffen. The hind legs were still relaxed.

11.45. —The hind legs were considerably more spastic. There was no definite pupillary reflex. Temperature, 36.6°.

2.30. —Temperature, 36.1°. The dog was still unconscious, with no indication of even incoördinated muscular movements. The hind legs were very spastic, while the fore legs had become flaccid. The knee-jerks were exaggerated. There was no scratch reflex. The pupils were con-

tracted, but the light reflex could not be obtained with certainty. The dog both vomited and defecated.

- 4.30. —A condition of complete coma was present. No muscular movement had been made, and the spastic condition had disappeared. Vomiting occurred again. The morning of the succeeding day the dog was found dead, and had evidently died early in the preceding evening, as the body was much distended with gas from an infection with *Bacillus aerogenes capsulatus*.

Autopsy.—The heart had stopped in systole. There was no evidence of any injury of the thorax or its contents. In the heart a post-mortem clot was found in the right side, while in the left a small, firm, ante-mortem clot was entangled in the auriculoventricular valve. It was not large enough, however, to interfere with the circulation. The lungs were moderately congested—on the left side hypostatically so. Otherwise the viscera were negative.

EXPERIMENT 5

Death from Chloroform; Resuscitation Begun 9 Minutes After Cessation of Circulation; Total Duration of Anemia, 14 Minutes.

JULY, 1906.

Mongrel dog; weight, about 5 kilos. Experiment conducted as in Experiment 1. Total duration of anesthesia, about 20 minutes.

II.28.30. A. M.—Respiration ceased.

II.28.40.—Circulation ceased.

II.37.40.—Began to resuscitate, 9 minutes after cessation of circulation. Ringer's solution was substituted for normal saline solution, and only 0.5 c. c. of adrenalin chlorid solution was used.

II.42. —The heart began to beat again, making the total duration of cessation of circulation 14 minutes.

II.46. —Spontaneous respiration began, 4 minutes after return of the circulation.

II.52. —Stopped giving artificial respiration.

II.56. —The knee-jerk was obtained in the left hind leg, 14 minutes after return of the circulation.

II.56.30.—The knee-jerk was obtained in the right hind leg, and was faintly present in the fore legs.

II.58. —On touching the left eye the conjunctival reflex was obtained, 16 minutes after return of the circulation, and

in the right eye a little later. If the nose were pinched the right fore leg was moved. The pupils had become very much contracted. Temperature, 36.1° C. by rectum.

1.45 P. M.—Temperature, 36.1° . The dog was generally more spastic. The pupillary reaction to light was distinct, although slight and delayed, less than 2 hours after return of the circulation. Respirations were somewhat groaning in character. Voluntary movements of the legs, such as occur in the early stages of ether anesthesia, were made, and at times the head was raised, as if in an attempt to rise. Warming the paw to a moderate degree only caused withdrawal of the limb, and there was apparently no consciousness of pain. Temperature, 37.8° .

5.30. —Temperature, 39.0° . The condition was about the same.

10.00. —The dog was found out of his box on the floor. He made unconscious propulsive movements of the legs, and at times raised his forelegs, as if trying to get up. The latter movements did not seem to be purposeful. There was a general spastic condition of the muscles, and the knee-jerks were exaggerated. The pupils reacted, although slowly. There was no evidence of perception of pain, and the dog neither saw nor heard. Disturbing by touching evoked only reflex movements. The next morning the dog was found on the floor in deep stupor, with thready pulse, quiet respiration, and temperature of 39.0° . He started when touched at any point, although the knee-jerks were not so exaggerated, and the spastic condition had disappeared. He was oblivious of stimulation through any of the special senses. There was no scratch reflex. Death occurred at about 11.30 A. M. Duration of recovered animation, 24 hours.

EXPERIMENT 6

Death from Chloroform; Resuscitation Begun $5\frac{1}{2}$ Minutes After Cessation of Circulation; Total Duration of Anemia, $7\frac{1}{2}$ Minutes

JULY, 1906.

Mongrel dog; weight, about 8 kilos. Experiment conducted as in Experiment 1.

10.11 A. M.—Respiration ceased.

10.12. —The heart almost stopped, and then beat more strongly. The pulse was barely perceptible.

- 10.14. —The heart sounds ceased, and the pulse was no longer perceptible.
- 10.19.30.—Began to resuscitate, $5\frac{1}{2}$ minutes after cessation of the circulation.
- 10.21.30.—The heart began to beat again, making the total duration of cessation of circulation $7\frac{1}{2}$ minutes.
- 10.30. —Rectal temperature, 37.0° C.
- 10.35.30.—Spontaneous respiration began, 14 minutes after return of the circulation.
- 10.38. —Stopped giving artificial respiration.
- 10.50. —The knee-jerks were obtained, most marked in the right leg, $28\frac{1}{2}$ minutes after return of the circulation.
- 10.51. —A faint conjunctival reflex was obtained on touching the eyes, $29\frac{1}{2}$ minutes after return of the circulation. The pupils were contracted.
- 10.55. —Both pupils reacted to light, $33\frac{1}{2}$ minutes after return of the circulation, but there was no winking.
- 10.57.30.—Faint spontaneous winking appeared, 36 minutes after return of the circulation. The knee-jerks had become very much exaggerated. There was a general return of muscle tone.
- 11.22. —Inarticulate barking sounds were made.
- 11.40. —The muscles were generally spastic.
- 12.00. —Movements of the leg, such as occur in the early stages of anesthesia, were begun.
- 3.35. —Temperature, 37.7° C.
- 5.00. —Temperature, 38.0° C. Periods of restlessness, with moving about in the box, and respiratory cries alternating with periods of quiet. There was no response to a light moved in front of the eyes, nor to loud sounds. If touched the dog usually moved. There was no evidence of pain being felt. Even with frequent attempts the scratch reflex could not be obtained.
- 10.30. —The condition was the same, except that there was more restlessness and more spasticity. The next morning the dog was found dead and stiff. The autopsy revealed no gross lesions.

EXPERIMENT 7

Death from Asphyxiation; Resuscitation Begun 4¼ Minutes After Cessation of Circulation; Total Duration of Anemia, 5¾ Minutes

JULY, 1906.

Mongrel collie dog; weight, about 9.2 kilos. Ether was used for carrying out the operative technique in the usual way. The trachea was exposed by a small incision and clamped to produce asphyxia.

10.42.40.—The heart almost stopped beating, only to start again with a distinct pulse perceptible.

10.45. —Respiration ceased.

10.45.15.—Circulation finally ceased.

10.49.30.—Began to resuscitate, 4¼ minutes after cessation of circulation.

10.51. —The heart began to beat again, making the total cessation of circulation 5¾ minutes.

11.00. —Stopped the artificial respiration.

11.03.30.—On touching the right eye the conjunctival reflex was obtained, 12½ minutes after cessation of the circulation, and ½ minute later it was obtained in the left eye.

11.05. —In the right eye the light reflex was good, but in the left it was faint, 14½ minutes after cessation of the circulation. The right pupil was contracted, while the left was dilated. The hind legs were drawn up, but there were no knee-jerks.

11.15. —The knee-jerks were obtained, 24½ minutes after cessation of the circulation.

11.16. —An inarticulate crying began.

11.45. —For the first time spontaneous muscular movements were noted. There was no scratch reflex, and no consciousness of light or sound. Temperature, 37.9° C. by rectum.

1.00. —Temperature, 38.5°.

4.30. —Temperature, 39.6°.

5.00. —The dog was lying quietly in an extremely stupid condition, but not sleeping. The striking of a match in front of his eyes caused him to raise his head and cock an ear just a little, but the pupils did not change. He seemed to be just a little conscious of pain. There was no scratch reflex. The hind legs were rather spastic.

5.30. —Temperature, 40.1°.

10.30 P. M.—The dog was entirely unconscious. His eyeballs were turned down and half covered by the conjunctivæ. The pupils were dilated and gave but a faint light reflex. The knee-jerks were active. Only the hind legs were slightly spastic. On pinching the paw the leg was withdrawn. On warming the ear both the head and the body were moved slightly. The special senses were absent. Temperature, 39.2° . On inserting the thermometer in the rectum the legs were moved.

On the second day the dog was still in a deep stupor, and evidently very ill. No satisfactory results were obtained in making the usual examination. On the third day it was found that the dog was infected, and he was killed with chloroform.

EXPERIMENT 8

Death from Chloroform; Resuscitation Begun $3\frac{1}{2}$ Minutes After Cessation of Circulation; Total Duration of Anemia, 5 Minutes

JULY, 1906.

Male mongrel collie puppy; weight, 3.6 kilos. Experiment conducted as in Experiment 1. Total duration of anesthesia, up to cessation of respiration, about 15 minutes.

11.05.45 A. M.—Respiration ceased.

11.09. —Circulation ceased.

11.12.30.—Began to resuscitate, $3\frac{1}{2}$ minutes after cessation of circulation.

11.16. —The heart began to beat, making the total cessation of circulation 5 minutes.

11.17. —Spontaneous respiration began.

11.26. —Stopped giving artificial respiration. From the first the blood-pressure continued to be good, and the spontaneous respiration was well maintained. After stopping artificial respiration the latter was normal for 20 minutes, then began gradually to fail. Artificial respiration was resumed for a while, but without effect. Up to this time none of the reflexes had reappeared (knee-jerks, muscle, or eye), and the muscles were entirely flaccid. At about 11.50 respiration failed altogether. On rapidly opening the chest the heart was found to be still beating, and continued to beat rhythmically for 15 minutes, even after both ventricles had been incised.

The lungs appeared to be normal. The abdomen contained a slight excess of fluid. Portions of the brain were placed in alcohol about 15 minutes after opening the thorax, while there was still some circulation.

EXPERIMENT 9

Death from Chloroform; Resuscitation Begun 3½ Minutes After Cessation of Circulation; Total Duration of Anemia, 5½ Minutes

DECEMBER 22, 1906.

Mongrel dog; weight, about 8.0 kilos. Besides the usual arrangements a cannula was inserted in a femoral artery and connected with a mercury manometer, so that the blood-pressure could be recorded on a smoked drum.

12.10 P. M.—Control on drum.

12.13. —Vasomotor action elicited. Control.

12.17. —Forced the chloroform.

12.19.30.—Respiration ceased.

12.20. —The heart stopped beating, but after a few seconds began to beat again.

12.22. —Circulation ceased.

12.25.30.—Began to resuscitate, 3½ minutes after cessation of circulation. Only two thirds of a cubic centimeter of adrenalin chlorid solution was injected.

12.27.30.—The heart began to beat again, making the total duration of cessation of circulation 5½ minutes.

12.29.30.—A single respiratory gasp occurred. There was no vasomotor reaction on stimulation.

12.30.30.—There were several respiratory gasps, but no vasomotor reaction.

12.31.30.—Respiration began steadily, and immediately after a distinct vasomotor reaction was obtained.

12.38. —Control.

12.40. —There was a feeble conjunctival reaction to touching the eyeball. The knee-jerks were first obtained, and were somewhat exaggerated.

12.43. —There was faint, spontaneous winking.

12.45. —There was a faint pupillary reaction to strong light.

12.50. —There was a general spastic condition of the muscles. The respiratory movements were labored.

12.55. —Slight spontaneous movements of the hind legs occurred.

- 12.59. —On disturbing the dog he made purposeful muscular movements, and the head was raised, as if he wanted to rise. On warming the ear he showed definite signs of consciousness.
- 1.00. —There was a faint response to auditory stimuli, respiration stopped for a moment, the eyes opened, and the ears pricked up. To stimulation with light only winking was obtained.
- 1.30. —The dog tried to rise and move forward. The spasticity was distinctly less. There was no indication of conscious vision.
- 1.42. —The dog tried to walk, but was too ataxic to succeed.
- 2.00. —Condition about the same.
- 4.36. —There was the same degree of purely reflex visual action and also auditory reaction, which, as before, had the appearance of consciousness merely rather than of seeing or hearing. More spasticity was present. When first seen the appearance was more stupid than at 2.00, but, while being observed, there suddenly started a violent dyspnea, in place of the normal respiration, and several unsuccessful attempts were made to crawl forward. This lasted for about 7 minutes, gradually subsided to quiet breathing for about a minute, and then began again. The second period of dyspnea lasted for about 3 minutes, to be followed by a short period of almost complete apnea, another minute of dyspnea, half a minute of apnea, and two or three more times the forward propulsive efforts were made. This arrhythmic, Cheyne-Stokes type of respiration continued as long as this period of observation lasted, about 40 minutes. When the dog was returned to his bed he became somewhat quieter.

DECEMBER 23, 1906.

- 10.00 A. M.—On approaching the dog he raised his head toward the observer with some appearance of intelligence, but he immediately relapsed into his stupid state. It is a question if any ideation was conveyed. The flash of a match repeated in front of his eyes evoked only a faint conjunctival reflex. The signs of more conscious reaction were apparent, although not more markedly so than on the preceding day. The pupils were very much dilated, reacting to light both directly and indirectly, i.e.,

stimulation of one eye only would cause the other to react also. Appreciation of pain was very doubtful. The knee-jerks were exaggerated, although there was less plasticity than on the preceding day. When placed on his feet, he was able to stand, although on walking he was very ataxic, largely because of paralysis of the right hind leg, the result of the operative procedures. There was no patellar reflex, even after repeated tests. Petting was submitted to without any appearance of ideation, while there was absolute indifference to threatening. Water was refused when placed in his mouth. He was etherized, and a portion of the brain at once transferred to 96 per cent. alcohol.

EXPERIMENT 10

*Death from Chloroform; Resuscitation Begun 5 Minutes After
Cessation of Circulation; Total Duration of
Anemia, 10 Minutes*

DECEMBER, 1906.

Dog; weight not noted. Experiment conducted as in Experiment I.

9.55 A. M.—Began to anesthetize with ether.

10.10. —Changed to lethal dose of chloroform.

10.12. —Respiration ceased.

10.14.40.—Circulation ceased.

10.19.30.—Began to resuscitate, 5 minutes after cessation of circulation. Rather violent massage was employed, and three doses of adrenalin of two cubic centimeters each were given.

10.24.20.—The heart began to beat, making the total cessation of circulation 10 minutes.

10.29.30.—First indications of returning respiration were noted.

10.32.20.—Faint spontaneous respiration began.

10.40. —Stopped giving artificial respiration.

10.45. —Knee-jerks were obtained in the right hind leg.

10.50. —An occasional conjunctival reflex could be obtained in the right eye. The knee-jerks were exaggerated.

10.53. —The conjunctival reflex was obtained in the left eye.

11.00. —There were partially spontaneous conjunctival reflexes.

11.07. —The pupils had been contracting slowly, and were about one-half normal size. There was no pupillary reflex to

TABLE I—SERIES I

The Time of the Respiratory and Circulatory Changes

NO. OF EXPERIMENT	Time from Beginning of Administration of Chloroform to Respiratory Failure	Time from Respiratory to Cardiac Failure	Duration of Recurrence of Inefficient Heart Beats After Apparently Complete Failure ¹	Duration of Total Anemia	Results
12	4 $\frac{5}{8}$	3 $\frac{1}{6}$	0	3	Killed after 1 hour.
10	4 $\frac{1}{4}$	1 $\frac{1}{2}$	0	4 $\frac{1}{6}$	Killed after 1 hour.
17	—	3	0	4 $\frac{1}{6}$	Died, 53 minutes.
3	1 $\frac{1}{4}$	4	0	5	Recovery.
22	2	3	1 $\frac{1}{3}$	5 $\frac{1}{4}$ (6 $\frac{7}{8}$)	Recovery.
8	2 $\frac{1}{2}$	1 $\frac{1}{2}$	2	5 $\frac{1}{2}$ (7 $\frac{1}{2}$)	Killed, 24 hours.
26	2	1 $\frac{1}{4}$	0	5 $\frac{3}{4}$	Killed on 4th day; secondary infection.
13	2	6	2	6 (8)	Killed after 1 hour.
2	2 $\frac{1}{2}$	1	1 $\frac{1}{2}$	6 (6 $\frac{1}{2}$)	Recovery.
23	2 $\frac{2}{3}$	1 $\frac{3}{4}$	0	6 $\frac{1}{2}$	Died, 24 hours.
29	2 $\frac{5}{8}$	3	0	6 $\frac{1}{6}$	Recovery.
25	1 $\frac{1}{2}$	4 $\frac{1}{2}$	0	7	Died after 30-40 hours.
7	—	3 $\frac{1}{4}$	0	7	Died, 34 minutes.
11	7 $\frac{5}{8}$	1 $\frac{1}{6}$	0	7 $\frac{1}{2}$	Died, 15-20 hours.
6	3	3	0	7 $\frac{1}{2}$	Died, 12-20 hours.
27	2 $\frac{1}{2}$	22	0	7 $\frac{1}{2}$	Recovery.
20	2 $\frac{1}{3}$	1 $\frac{2}{3}$	0	8	Died, 10-20 hours.
28	3 $\frac{1}{3}$	1 $\frac{1}{6}$	0	8 $\frac{1}{6}$	Died, 12-20 hours.
18	—	2	0	8 $\frac{1}{4}$	Died, 63 minutes.
4	4	1	1 $\frac{1}{6}$	8 $\frac{1}{3}$ (8 $\frac{1}{2}$)	Died, about 12 hours.
19	2 $\frac{3}{4}$	1 $\frac{5}{8}$	0	8 $\frac{5}{8}$	Died, about 20 hours.
14	2	1	0	8 $\frac{1}{2}$	Died, 30-40 hours; disseminated bronchopneumonia.
24	4 $\frac{1}{2}$	3	0	8 $\frac{1}{2}$	Died, 23 hours.
1	—	6 $\frac{3}{4}$	0	9 $\frac{1}{4}$	Died, 11 hours.
9	2	2 $\frac{2}{3}$	0	9 $\frac{2}{3}$	Killed, 1 hour.
15	3 $\frac{1}{2}$	1 $\frac{1}{2}$	0	9 $\frac{3}{4}$	Died, about 18 hours.
16	—	—	0	10	Died, 10-18 hours.
30	1 $\frac{1}{2}$	3	0	12 $\frac{1}{6}$	Died, about 2 $\frac{1}{2}$ hours.
5	—	1 $\frac{1}{6}$	0	13 $\frac{1}{3}$	Died, 24 hours.
21	2	3	0	14	Died, 40 minutes.

¹This column refers to the spontaneous recurrence of the heart sounds in five cases from one-third to one and a half minutes after they had entirely ceased. As the extent of the circulatory recovery could not be exactly estimated, though usually it was not sufficient to produce a palpable pulse, in the next column the duration of the total period without any evidence of cardiac activity is given first, while the figures in parentheses include the partial recovery.

²Asphyxiated dog.

³Synchronous.

Note.—Time is expressed in minutes, and blood-pressure in millimeters of mercury.

light. The knee-jerks were very much exaggerated. There was only moderate resistance to passive motion of the legs—to flexion more than to extension.

- 11.12. —The fore and hind legs were held in rigid extension, with occasional tremors occurring.
- 11.15. —The right pupil was more contracted than the left, and gave no reflex.
- 11.40. —There was still no pupillary reaction to light, although the pupils were of equal size by this time. The respiration was normal, and the heart action and pulse were of good character. The cerebral cortex was exposed and stimulated by an induced current in various places around the motor area. No muscular contractions resulted. Before the heart stopped beating the brain was transferred to alcohol.

TABLE II—SERIES I

Ten Cases in Which the Total Anemia Lasted Seven and One-Half or More Minutes

NUMBER OF EXPERIMENT	Mode of Death	Total Duration of Anemia ¹	Results
28	Ether	7½ minutes	Presumptive recovery; killed after 24 hours.
19	Asphyxia	8½ minutes	Killed after 6 hours.
31	Chloroform	9½ minutes	Died after 20 hours.
37	Chloroform	9½ minutes	Died after 20 hours.
48	Asphyxia	12 minutes	Died after 3¾ hours.
39	Chloroform	13½ minutes	Died after 15 hours.
41	Chloroform	15 minutes	Died after 15 hours.
30	Ether	16⅓ minutes	Died after 3½ hours.
43	Chloroform	24 minutes	Died after 4½ hours.
49	Chloroform	32 minutes	Died after 27 minutes.

¹The figures in this column include the time spent in resuscitating.

TABLE III—SERIES I
The Course of the Blood-Pressure After Resuscitation

NUMBER OF EXPERIMENT	Duration of Anemia ¹	Time of Respiratory Recovery	Maximum Blood-Pressure after Resuscitation	Time to Reach Lowest Level	Lowest Level of Blood-Pressure	Approximate Duration of Lowest Level	Total Time to Second Rise	Height of Second Maximum Rise	Subsequent Course
28	7½	4½	240	10½	80	2	11	160	Maintained for 24 hours.
19	8½	11½	206	14½	130	3	.....	.....	Maintained for 6 hours.
31	9½	7	210	30	80	4	.....	.....	Removed from table.
37	9½	1½	230	40	80	5	40	90	Removed from table.
48	12	16	220	16	50	10	36	80	Fell after 5 minutes.
39	13½	15½	250	18	80	2	20	120	Fell in 1 hour to 70 mm.
41	15	8¾	180	28	44	15	43	88	Removed from table.
30	16⅓	15½	144	23	118	3	26	140	Fell after 10 minutes.
43	24	4	110	23	36	5	28	70	Second maximum rise held for 1 hour.
49	32	21	114	.....	.....	.....	.....	.....	Cardiac failure after 27 minutes.

¹ Includes approximate time of resuscitating.

² Immediate rising tendency.

³ Level steadily maintained.

⁴ Removed from table in 30 minutes.

⁵ In general a decline to death.

Note.—Time is expressed in minutes after restoration of circulation, and blood-pressure in millimeters of mercury.

TABLE IV—SERIES I

The Time of Return of the Reflexes After Restoration of the Circulation

No. OF EXPERIMENT	Duration of Anemia	Respira- tion	Corneal Reflex	Winking	Light Reflex	Knee-Jerk	Cutaneous Reflex (First)
12	3	2	4 ³ / ₄	5	38	16	—
10	4 ¹ / ₆	1 ² / ₃	10	10 ¹ / ₂	18 ¹ / ₂	10	13 ¹ / ₂
17	4 ¹ / ₆	2 ² / ₃	20	25	0	0	0
3	5	2 ² / ₃	2	1	10 ¹ / ₄	2	—
22	5 ¹ / ₄	1 ³ / ₄	1	15 ³ / ₄	128	17	23
8	5 ¹ / ₂	2	13 ¹ / ₂	16 ¹ / ₂	18 ¹ / ₂	12	—
26	5 ³ / ₄	—	12 ¹ / ₂	—	14 ¹ / ₂	24 ¹ / ₂	—
13	6	7 ¹ / ₂	1	19	2	35	39
2	6	3 ³ / ₄	10 ³ / ₄	13	40	8 ³ / ₄	25
23	6 ¹ / ₂	2	10 ¹ / ₂	19 ¹ / ₂	3	31 ¹ / ₂	32 ¹ / ₂
29	6 ¹ / ₆	1 ¹ / ₃	5 ¹ / ₆	7 ¹ / ₂	94	11 ¹ / ₆	17 ² / ₃
7	7	1	0	0	0	0	0
25	7	2 ¹ / ₂	1	Under 1	29	Under 15	Under 15
11	7 ¹ / ₂	4 ³ / ₄	17	23	34	17	34
6	7 ¹ / ₂	14	20 ¹ / ₂	36	33 ¹ / ₂	28 ¹ / ₂	—
27	7 ¹ / ₂	2	12 ¹ / ₂	20 ³ / ₄	53 ¹ / ₂	14 ¹ / ₂	24 ¹ / ₂
20	8	3	21	1	0	21	66
28	8 ¹ / ₆	1 ¹ / ₂	17 ⁵ / ₈	34	68	1	42
18	8 ¹ / ₄	2 ² / ₃	20	25	0	0	0
4	8 ¹ / ₃	2 ¹ / ₂	1	18 ¹ / ₂	0	23 ¹ / ₂	33 ¹ / ₂
19	8 ¹ / ₂	1	15	35	62	17	60
14	8 ¹ / ₂	1 ¹ / ₄	1	18 ¹ / ₂	0	17	—
24	8 ¹ / ₂	1 ¹ / ₂	14 ⁷ / ₈	38	3	1	53
1	9 ¹ / ₄	4 ¹ / ₄	61 ¹ / ₂	1	98 ¹ / ₂	74 ¹ / ₂	—
9	9 ² / ₃	8	25	35	2	20 ² / ₃	—
15	9 ³ / ₄	1 ¹ / ₂	16	34	0	14	49
16	10	6	28	38	3	28	—
30	12 ¹ / ₆	2 ¹ / ₄	12 ¹ / ₂	23 ³ / ₄	32	25 ³ / ₄	28 ³ / ₄
5	13 ¹ / ₃	4	16	16	60+	14	16
21	14	3	0	0	0	0	0

¹ Recurred; exact time not noted.² Insufficient time.³ Did not return under observation.

Note.—Time is expressed in minutes.

CONCLUSIONS

1. In dogs lightly anesthetized by ether and then killed quickly by chloroform the average limit of total cerebral anemia, estimated from cessation of the heart sounds to return of circulation, which admits of recovery, is between six and seven minutes. The ulterior limit appears to be under ten minutes,

hitherto stated as the most conservative figure, and any recovery after more than seven and one-half minutes of anemia would be exceptional.

2. Further experience with the resuscitation of animals killed by anesthesia and by asphyxia, embracing numerous unrecorded experiments, as well as those forming the basis of this chapter, establishes the former conclusion of the authors, viz., that the procedures detailed afford a reliable method of resuscitation within its limitations, and one uniformly successful within the limits compatible with the recovery of the central nervous system.

CHAPTER II

ANEMIA OF THE CENTRAL NERVOUS SYSTEM: CLINICAL OBSERVATIONS. CEREBRAL ANEMIA THROUGH LIGATION OF THE COMMON CAROTID ARTERIES

GENERAL CONSIDERATIONS

Although the blood supply of the brain is better safeguarded than is that of any other part of the body, experience in ligating the common carotid arteries in man has shown that harmful cerebral anemia may result.

The brain of man, being a mesial and symmetrical organ, has two sets of arteries from which its blood supply is derived, each set consisting of (1) the common carotid, (2) the vertebral, (3) the profunda cervicis, and (4) the inferior thyroid. The common carotid and the vertebral artery of either side of the head furnish the main blood supply and connect with the arteries of the opposite side through the circle of Willis. The profunda cervicis arises actually from the superior intercostal, but so close to the origin of the latter that it may practically be said to arise from the subclavian, distal to the origin of the vertebral; it connects with the princeps cervicis, and through it with the occipital, the last-named being a branch of the external carotid. The inferior thyroid arises from the thyroid axis on the subclavian (also distal to the origin of the vertebral), connects with the superior thyroid, and the latter with the external carotid at its point of origin

with the common carotid. However, as it also connects with the inferior thyroid of the opposite side, it would be less efficient than the profunda cervicis as a path of collateral circulation on account of its stream being divided.

From the anatomic relationships it necessarily follows that ligation of the innominate artery would shut off entirely *direct* circulation from the *right* side of the brain. Likewise ligation of the common carotid and of the subclavian proximal to the origin of the vertebral from the subclavian would completely shut off *direct* cerebral circulation on the side on which the ligation was done.

If the common carotids and the vertebral arteries of *both* sides are ligated the remainder of the collateral vessels must take up the burden, a burden which, for practical purposes, is beyond their capacity. It is almost incredible that an individual could live for any length of time after such ligation, but, in the "Science and Art of Surgery," Erichsen mentions a case of Davy's in which life was maintained for "a considerable time."

In ligating either common carotid artery success may depend on the patency of the circle of Willis. While its absence must be extremely rare, Derby describes a case in which hemiplegia followed ligation, and at the autopsy the circle of Willis was found actually to be absent.

Granting that the circulation through the four major arteries is alone efficient to maintain the life of the brain, and that ligation of one common carotid leaves the three other vessels open, still it by no means follows that only one-fourth of the blood supply is cut off, since the common carotids are much larger than the vertebrals. Consequently it is not strange that this interference may cause harm.

ANALYSIS FROM THE LITERATURE OF FIVE HUNDRED CASES OF LIGATION OF THE COMMON CAROTID ARTERY

In order to ascertain with reasonable accuracy how frequently injury of the brain due to anemia has followed ligation of the common carotid artery, five hundred cases were chosen at random from reliable sources in the literature of the subject. Many cases were omitted in which serious injury to the head might have complicated the results.

Among the 500 cases were 51, or 10.2 per cent, in which serious or fatal cerebral injury occurred as a result of the anemia. In securing these figures the conditions for which ligation was done were disregarded—the operation of ligation *per se* being considered alone. It is of interest to compare this result with the figures given by Keller in the table below:

AUTHOR	Number of Ligations	Number of Cases with Cerebral Symptoms	Number of Deaths
Le Fort.....	370	100 or 27.0%	71 or 21.0%
Pilz (1).....	520	165 " 32.0%	91 " 17.5%
Pilz (2).....	139	32 " 23.0%	20 " 14.0%
Sattler.....	63	4 " 6.3%	3 " 4.5%
Keller.....	47	4 " 8.5%	4 " 8.5%

From this table it is readily seen that there is a considerable variation in the number of cases in which cerebral symptoms occurred. The later the cases occurred chronologically the better the results, i. e., up to a certain extent. This is doubtless due to the general improvement in surgical methods, particularly as regards asepsis.

In analyzing the above 51 fatal cases it was found that they could be classified as follows:

1. Number of cases with hemiplegia of the *opposite* side from that on which the ligation was made (including 4 cases with cerebral abscess) 42 = 8.4% (of 500)
2. Number with hemiplegia of the *same* side.. 0 = 0.0%
3. Number with "paralysis" and inflammation of dura mater 1 = 0.4%
4. Number without paralysis but with other or not clearly stated fatal injuries of cerebral origin 8 = 1.6%

Among the 42 cases with hemiplegia (see No. 1 above) there were:

1. Fatal cases, death occurring within a comparatively short time..... 34 = 6.8% (of 500)
2. Recoveries with permanent paralysis (so far as could be determined)..... 6 = 1.2%
3. Recoveries with stated transient paralysis.... 2 = 0.4%

Not included under recoveries with transient paralysis (see No. 3 above) were certain cases in which symptoms occurred which probably could be attributed, at least in part, to cerebral anemia; such symptoms as "peculiar sensation in arm of opposite side"; "weakness in opposite arm"; opposite arm and leg somewhat weaker, with hair of head turned from black to gray and the hair of the opposite side from the ligation thought to be grayer than that of the same side, and with temporary pallor of the same side of the head; headache, unpleasant fullness in the head for three years, when the patient died; stupor for 48 hours; serous apoplexy (in a case of pulsating tumor of the orbit); convulsions immediately after tightening the ligature; pallor, cold sweat, and strabismus—all on the side on which the ligation was done.

In the fatal hemiplegia cases which came to autopsy the cerebral lesion was found invariably on the same side as that on which the ligation was done, while the opposite side of the body had been paralyzed while life lasted. In only one

case in the entire series was embolism reported to have been found, one of Siegrist's cases, and in that the middle cerebral artery was not affected. The patient was a man, 47 years of age, who had carcinoma of the tongue and secondary hemorrhage. The right common and internal carotids were tied. At the moment when the ligature was tightened the patient became pale and cyanotic, the pulse and respiration ceased, the sensoria were lost immediately (the operation was done under cocaine), both pupils were dilated, the right almost completely, the left to a lesser degree, but all these symptoms ceased after about two minutes. Later in the day he complained that he could not see with his right eye, and the typical signs of embolism of the central artery of the retina appeared. This was confirmed at the autopsy. In addition a thrombus was found in the internal carotid artery which continued into the middle cerebral artery, the artery of the corpus callosum, and the posterior communicating artery.

The mere fact that the above case was the only one of embolism found in the series strengthens the view that cerebral injury following ligation of the common carotid is due to ligation rather than to embolism, just as in ordinary cases of apoplexy the lesions are caused by anemia, and it matters little where the obstruction is as long as the blood supply is shut off.

That anemia may not always be due to ligation directly is suggested by the autopsy reports of certain cases, notably Siegrist's (see above), in which, as stated already, a thrombus was found to extend from the point of ligation for quite a distance into the common carotid, with prolongations into some of its branches, no embolism being detected. In a case of fatal hemiplegia reported by Zimmerman, in which both the common and internal carotids were ligated, there was found ascending thrombosis in the internal carotid, which extended into the middle cerebral, the anterior communicating, and the

artery of the corpus callosum. Hemiplegia had not developed until evening of the day of the operation, death taking place on the third day. In a second case of Zimmerman's the common, internal, and external carotids were tied. At the autopsy ascending thrombosis was found in the internal carotid with extension into the middle cerebral artery, the artery of the corpus callosum, the internal capsule, the corona radiata, and the temporal lobe. Acute meningitis and a double inspiration pneumonia were present, the attack of hemiplegia having come on on the day after the operation, with death occurring on the fourth day.

In regard to the local conditions in the brain itself, it may be said that the autopsy reports stated almost invariably that "cerebral softening" was present on the side on which the ligation was done. In one case of hemiplegia it was reported that the consistency of the brain was unaltered, but that there was light stippling (Punktirung) of the white matter. In most of the cases the softening seemed to be throughout the hemisphere, although in a few cases it was localized, e.g., in one it was in the temporo-occipital and parietal region, in another in the corpus striatum, and in a third around the margins of the fissure of Sylvius. In a case of Dubreuil's the under half of the frontal lobe showed extravasation of blood from two-thirds of its substance with one-half of this area apparently softened. In one case only, in which other factors were not present to account for it, was edema stated to have been present.

In considering the etiology of cerebral injury after ligation of the common carotid it may be stated at the outset that the *dangers accompanying surgical interference with the circulatory system of the aged are in direct ratio to the age of the patient*. In the 500 cases studied the age of the patient was stated 349 times. Of the 349 patients there were 301 in whom

cerebral symptoms were stated to have been absent, or not stated to have been present. The average age of the 301 patients was 33.6 years. In the 48 cases of cerebral injury in which the age was stated the average age was 41.5 years. Therefore, in so far as such a rough comparison may have weight, the older the person the greater the likelihood of cerebral injury.

Conditions for which the common carotid artery have been ligated are varied, and some of them are now of historic interest only. The following table shows the distribution in the 500 cases:

1. Hemorrhage (including traumatic aneurysms)....	206 = 41.2%
2. Tumors (almost all malignant).....	100 = 20.0%
3. Traumatic pulsating exophthalmos, spontaneous pulsating exophthalmos, and aneurysms of orbit....	91 = 18.2%
4. Spontaneous aneurysms other than of the orbit....	76 = 15.2%
5. Trifacial neuralgia	11 = 2.2%
6. Preliminary ligations for hemostasis.....	8 = 1.6%
7. Epilepsy	3 = 0.6%
8. Miscellaneous and unclassified.....	5 = 1.0%

500

Among the tumor cases it was stated in only one instance that ligation was done to starve the tumor. In fact, in most of these cases control of hemorrhage was the object sought. Consequently a truer figure to represent the hemorrhage cases would be 61.0 per cent.

No attempt has been made to arrive at the conclusions as to the bearing of the general mortality in these cases on ligation. In the first place, particularly among the traumatic cases, the injuries for which ligation was done were so severe that they overshadowed the possible effects of the ligation itself. The high mortality attributed by certain authors to

ligation should probably be attributed in great part to shock, hemorrhage, and infection. It would be manifestly illogical to classify a death in a case of traumatic pulsating exophthalmos, the result of fracture of the base of the skull, as due to cerebral injury resulting from ligation alone. The same would be true of a death the result of a head wound from a rifle ball or fragment of a shell. It is equally illogical to present cases of pulsating exophthalmos as affording evidence that the eyes may be injured by ligation of the common carotid artery. The usual cause of pulsating exophthalmos is rupture of the internal carotid in the cavernous sinus, and in cases which are not treated at all vision is frequently lost on the affected side.

There is evidence of but few cases of serious injury to any of the organs of the special senses, due to ligation alone. The pupil of the same side may be narrowed temporarily, although not in all cases; but in practically all, if not in all cases, this is followed by permanent dilatation. Various observers have noted temporary disturbances of the circulation of the eye, such as pallor of the papilla, a weakened circulation in the arterial branches, and a diminished fulness of the veins. After ligation of both common carotids Jacobi and Ehrmann observed dimming of the eyesight.

As to cerebral injury, it has been found that the time of occurrence of cerebral symptoms in relation to the time of ligation varied considerably. Some authors claim that cerebral symptoms are not manifested immediately. In this connection the case reported by Quenu is of interest in spite of the fact that no autopsy was held. The age of the patient is not stated. He had had an operation for epithelioma of the neck with severe hemorrhage from the carotid. Preparations were made to ligate the common carotid without the use of a general anesthetic. Just before the ligature was tightened

the patient replied in a normal way to a remark made to him, and, although anemic, had previously seemed to be normal mentally. To quote Quenu's own words (translation): "I tightened the ligature, and at the instant the patient passed into coma: the entire left side was struck by flaccid paralysis. The patient died in the evening or the next morning without having regained consciousness." Whether or not an autopsy was held for confirmation of the cause of death the whole occurrence was perfectly consistent with what well might happen, especially with a brain in a previously anemic condition through general loss of blood and with the consequent physical impairment of the brain cells.

In two other instances among the cases studied paralysis was said to have occurred immediately after the ligature was tightened. The first, a case of Verneuil's, was a man 30 years of age who had received a shot wound of the cheek. Hemiplegia and coma resulted immediately with death 42 hours later. At the autopsy the cerebral hemisphere on the side of the ligation was found to be profoundly altered. The second, a case of Hopmann's, was a man, 23 years of age, who also had received a shot wound in the cheek. Immediately after ligation partial paralysis of the entire opposite side of the body occurred. It was a pus case, and eventually the eyeball had to be enucleated. The patient recovered.

The table on page 64 shows the time in which cerebral symptoms were manifested in 51 cases in which they occurred.

Further studies showed also that in general the older the patient the earlier the cerebral symptoms occurred.

In the study of these 500 cases it was found that the internal jugular vein of the same side as that on which the common carotid artery was ligated was occasionally either ligated also or rendered functionless through injury. This

<i>Number of Cases</i>	<i>Time of Appearance of Cerebral Symptoms</i>
2	34 days.
1	31 "
1	26 "
1	21 "
1	19 "
1	11 "
2	10 "
1	7 "
1	6 "
3	5 "
1	4 "
6	3 "
5	2 "
1	1 day.
1	20 hours.
3	12 "
2	"immediately after".
18	Indefinitely stated or not
—	stated at all.
Total 51	

In the 33 cases in which the time was stated it is found that in 24, or 72.7 per cent., the symptoms were manifested in less than a week.

occurred in 16 cases, or 3.2 per cent. Among the 16 cases were 4 in which cerebral complications occurred—hemiplegia in each case. Whether ligation of the internal jugular had anything to do with the causation of cerebral symptoms is impossible to state. Owing to the richness of the venous anastomoses of the head it seems hardly probable that it did. In any case, if there were not free anastomosis then stoppage of a large venous trunk would tend to produce hyperemia rather than anemia.

*The Author's Cases of Temporary Simultaneous Closure of Both Common Carotid Arteries*¹

Case No.	Sex	Age	Nature of Operation	Ligation	Cerebral Symptoms	Result
1	M.	46	Fibrosarcoma of mouth.....	Clamps	None	Recovery
2	F.	21	Congenital tumor of neck.....	Clamps	None	Recovery
3	.....	48	Epithelioma of mouth.....	Clamps	None	Recovery
4	M.	58	Epithelioma of mouth.....	Clamps	None	Recovery
5	.....	.....	Epithelioma of lower jaw.....	Clamps	None	Recovery
6	.....	7 mos.	Angiosarcoma of cheek and neck, of rapid growth.....	Clamps	None	Recovery
7	.....	.....	Carcinoma of nasal septum.....	Clamps	None	Recovery
8	.....	.....	Carcinoma of tongue.....	Clamps	None	Recovery

¹ From "Problems Relating to Surgical Operations," Crile.

TECHNIQUE OF LIGATION OF THE COMMON CAROTID ARTERY AND ITS BRANCHES

Formerly ligation of the common carotid artery was sometimes done when the comparatively modern procedure of temporarily closing the vessel would have better served the interests of the patient. The author has repeatedly demonstrated that, when properly done, an artery may be closed temporarily without injury for as long a time as is ever required for an operation. Consequently certain operations on the head, for example, in which hemorrhage is troublesome, can be done with much greater ease and safety by temporary closure of the common carotid. By this procedure the local field is in better condition for the careful dissection which is so often necessary, and the danger of harmful cerebral anemia is almost completely avoided. Moreover, *as a preliminary step to permanent ligation temporary closure should be done when possible.* This point the author wishes to emphasize strongly. There are very few cases in which it cannot be done, and the occurrence of harmful immediate symptoms can be taken as a warning against making a permanent ligation.

The following observations constitute a brief résumé of the author's experimental work to determine the effect of a

temporary closure of the carotid: The immediate effect on the circulation of the temporary closing of one carotid artery was to increase the blood pressure, but usually a compensation followed, and the pressure returned to its normal level. No effect upon the respiration was observed. The simultaneous closure of both carotid arteries produced a greater rise in the blood-pressure, which also by physiologic compensation usually soon returned to the normal level. In many of the latter experiments there was a decrease in the respiratory action, although the effect was very slight. In no instances were any striking results noted. In the recovery experiments no effect upon the animal was observed beyond that attributable to the anesthesia and the operation in the cases in which the clamps were allowed to remain on the arteries. The animals seemed playful and strong. Even after 24 hours of complete closure there was but little microscopic evidence of injury to the vessel wall. Circulation through the clamped portion was readily reëstablished. However, in cases in which the animal had suffered infective inflammation of the wound during the application of clamps for a considerable length of time, say for two days, the damage to the vessel walls was marked, and in some cases the lumen was occluded. As to the after-effects, in no case was there any clotting; the aseptic cases made good recoveries; the circulation was reëstablished; and no impairment of consequence occurred. The cerebral vessels were carefully observed at autopsy, and in no case were either emboli or thrombi found, nor was there noted any gross effect on the brain.

In the course of clinical operations the author has temporarily closed the common carotid artery 136 times. The ages of the patients ranged from 7 months to 69 years. In every instance the circulation was resumed as soon as the clamps were removed. There were no appreciable late effects

on the vessel wall at the point of clamping, and none on the circulation in the closed arteries and their branches. Less anesthetic was necessary in those cases in which both common carotids were closed. The respiration might be embarrassed, but was relieved by partially releasing the pressure on one or both vessels. The operation time was much diminished as a result of the freedom from blood of the field of operation, and the amount of blood lost was much lessened, as was the difficulty of keeping blood out of the respiratory tract.

In the closure of the common carotid artery, a valuable clinical procedure is to transfer the clamp to the external carotid just as soon as the latter vessel is reached, as, for example, in a block dissection of the neck. In elderly subjects, especially those with atheromatous arteries, distinct cerebral impairment, amounting even to mild delirium, may appear after temporary closure of the common carotid artery and last for several days, but apparently no permanent damage is done to the brain. Since the adoption of this method of closing the external carotid artery from the beginning of the operation, or transferring the clamp in the course of the operation, no functional impairment of the brain has been observed.

In the author's experience closure of the common carotid artery does not arrest hemorrhage as completely as does closure of the external carotid. The reason is that when the common carotid is closed and the external is open there is a back flow of blood via the anastomoses in the circle of Willis. This explains why rather free hemorrhage may be seen when the common alone is closed. The best control of all is secured by closing both external carotids.

In his own series of cases the author has observed no instances of embolism or thrombosis as a secondary result of the temporary closure of either common or external carotids.

As a general principle it stands to reason that, other fac-

tors not interfering, the ligation of a large artery should not be done when a small branch of the same vessel can be reached, the closure of which will control the bleeding. In regard to the carotids no one has emphasized this more strongly than Wyeth. In his classical "Essays in Surgical Anatomy," published in 1878, he says: "I cannot conclude the surgical anatomy of these arteries without protesting with all the earnestness I may possess against the operation of tying the *common carotid* for lesions of the *external carotid* or its branches when this last vessel may be ligated."

While a discussion of the surgical anatomy of the vascular system of the head and neck is rather outside of the province of this book it has a direct enough bearing to make the following extracts from Wyeth pertinent:

"1. In all *intracranial* lesions involving alone the *internal carotid* or its branches this vessel should be tied. If this procedure is not successful then the *external carotid* should be secured at the crossing of the digastric. If the *facial* be given off below this point it should be secured by a separate ligature. . . . For lesions of the *internal carotid* in the neck (excepting aneurysm) it should be tied above and below the lesion in all cases. The operation on the cardiac side alone, be the *common* or *internal* trunk the seat of the ligature, is not justifiable, death having occurred in many instances through the descending current from the circle of Willis. In aneurysm of this artery the single ligature on the cardiac side will suffice.

"2. When the lesion (excepting aneurysm) exists within one-half inch of the bifurcation of the *common carotid*, involving this vessel, or the *external* or *internal*, or both, the *common* trunk must be tied on the *cardiac* side, and the other two arteries on the *distal* side of the lesion. The *superior thyroid* and any other branches of the *external carotid* be-

tween the ligature upon this vessel and the bifurcation should also be secured.

"In case of aneurysm in either of these points the single ligature on the *cardiac* side will usually suffice.

"3. In erectile or pulsating tumors of the orbit (intra-orbital aneurysm) ligature of the common carotid is to be advised. . . . Since the anastomoses between the terminal branches of the *external* and *internal* carotids, through the orbit, are more or less exaggerated in intraorbital aneurysm . . . I am of the opinion that the ligature of the *common carotid* is the surest and safest operation . . .

"4. Wounds of the *superior thyroid* artery too near its origin to permit a ligature on the cardiac side of the lesion require deligation of the *common*, *external*, and *internal carotids* and torsion of the *distal* end of the wounded vessel.

"5. In *incised*, *punctured*, *lacerated*, and *gunshot* wounds of the *external carotid* or its branches where it is deemed inexpedient to secure the vessel at the seat of injury *the external carotid of one or both sides should be secured* below the origin of the *lingual* . . . If the *lingual* or any other branch is in immediate contact with the ligature it (or they) should be also secured.

"The *common* trunk should never be tied under such circumstances *except as a last resort*.

"6. Hemorrhage of the *tonsils* and *pharynx*, if not arrested by ligature of the *external carotids* as advised, will require either the separate ligature of the *pharyngeal ascendens* or of the common and *internal* carotids.

"7. It must be assumed that when the ligature of the *external carotid* below the origin of the *lingual* does not arrest hemorrhage from the pharynx the bleeding is from the *ascending pharyngeal*, and that this branch originates from the bifurcation of the *internal carotid*. . . . (The history

gives one or two deaths from hemorrhage from the tonsils after ligature of the *common trunk alone*.)

"8. Aneurysm of the *external carotid* or its branches (excepting the *superior thyroid*) demands deligation of the *external carotid alone* when a sufficient space exists between the tumor and the bifurcation to admit the ligature with safety.

"9. Aneurysm of the *internal carotid* should be treated by ligature of *this vessel alone* when there is sound artery enough between the tumor and the bifurcation to admit the ligature with safety.

"10. Aneurysm of the *common carotid* (if digital compression shall have been abandoned) should be treated by ligature of this vessel as far from the tumor (on cardiac side) as possible.

"11. Ligature of the *common carotid* for aneurysm of the *arch of the aorta* is of doubtful propriety. . . .

"12. Ligature of the *common carotid* alone for the cure of innominate aneurysm is an exceedingly dangerous procedure; 12 of 17 cases proved fatal from the operation; only 2 were cured. . . .

"16. In epilepsy, while the danger of death as a result of the operation is comparatively slight (5 per cent.), the proportion of *cures* or *improved* cases is not great enough to commend this procedure to the profession. . . .

"17. In persistent and exhaustive *neuralgia* of the fifth nerve when all other methods have proved ineffectual ligation of the *common carotid* should be practiced.

"The *external carotid* of one or both sides should first be tied below the lingual (the point of election). If this fails the *common trunk* upon the affected side may be secured.

"The operation is contraindicated when pressure upon the *common carotid* of the affected side does not arrest the pain.

"18. In *hemiplegia or headache* the ligation of the *common carotid* is not justifiable. . . ."

Facts like the foregoing furnish an invaluable basis for the control of hemorrhage—one of the most important parts of the surgery of the head and neck. Their value in preventing surgical anemia as far as possible lies in the light they throw on how best to avoid unnecessary closure of arterial trunks—a secondary but important matter.

In addition to what has already been presented a few words may well be said in regard to ligation of the external carotid. While the weight of evidence is overwhelmingly against the probability that ligation of the external carotid may cause harmful or, in fact, any cerebral anemia that can be manifested clinically, nevertheless it may not always be a harmless surgical procedure, as is shown by the following case of Scudder.

The patient was a woman, 50 years of age, with sarcoma of the superior maxilla. The *left* external carotid artery was ligated just below the origin of the facial artery, the patient being in the sitting posture. Then the jaw was completely excised. On the next day a *right* hemiplegia developed. Death occurred six days later, the patient being partially unconscious during that time. The *left* middle cerebral artery was found at the autopsy to be occluded a short distance from its point of origin by a firm, gray-red, thrombus-like mass, which was apparently prolonged into some of the branches of the artery as a blackish red, somewhat softer material. At the site of the basal ganglia on the left side there was a pale, in places grayish-red, disorganized, more or less disintegrated soft mass of brain tissue, which extended from the posterior portion of the left frontal lobe back as far as the posterior portion of the thalamus laterally, to the left of and involving a good part of the striate body and downward

into the temporal lobe. In the left temporal lobe the condition extended over quite an area, and reached as far as the cortical portion. In this situation the brain tissue was pale, disintegrated, and mushy. Elsewhere the brain tissue was not remarkable. There was no evidence of arteriosclerosis of the circle of Willis.

SUMMARY

The histologic evidence that, even in so-called "recovered" animals, some or even many nerve cells are permanently lost and that all are temporarily damaged explains the great temporary and lesser permanent loss of power following any grave anemia of the brain.

It argues against the practice of permitting the blood pressure to fall extremely low in cases of hemorrhage before resorting to transfusion. It warns the surgeon to be cautious in ligating or temporarily closing the common carotid artery in aged subjects. It warns him not to press on the brain with retractors and packings unless the pressure is made strictly intermittent, never exceeding five minutes at a stretch. It explains the reason why in all types of brain pressure the early depression of the higher functions, such as associative memory, occurs before the depression of the lower functions, such as respiration and circulation. It emphasizes the significance of the gradual onset of dulness and stupor in increased intracranial pressure. It fixes an absolute limit to the possibility of resuscitation in cases of drowning, and therefore makes one doubt the authenticity of many reported cases of resuscitation after apparently long intervals of suspended animation.

CHAPTER III

ANEMIA OF VOLUNTARY MUSCLES: EXPERIMENTAL OBSERVATIONS. ANEMIA OF THE POSTERIOR EXTREMITY OF DOGS

*In collaboration with Dr. Lawrence Pomeroy and
Dr. A. M. Tweedie*

How long can an extremity endure total anemia and survive without consequent loss of function? Even in dogs this has not been an easy matter to determine, on account of the variety of factors which enter into the problem. One thing is very evident and that is, that while a dog's thigh may have a tourniquet applied to it so as to shut off all circulation for even as long a time as ten hours, and so that twenty-four hours later there is complete loss of function with disturbance in the electrical reactions (except the reaction of degeneration), yet no microscopical changes of a structural nature can be detected at this time. The same dog if allowed to live will show paralysis of a permanent nature, with or without the subsequent development of the reaction of degeneration, and hence the irreparable damage is done at the end of the twenty-four hours even if nothing but edema and interstitial hemorrhages be present. What will eventually become irreparable loss of function is not indicated by early structural changes.

In a rough way it may be said that permanent paralysis usually follows anemia of a dog's thigh of seven hours' dura-

tion. Recovery to the extent of apparently complete restoration of function has occurred after a longer time, but in a useful leg even grave microscopic changes may be found when the animal is killed, so that to a certain extent appearances may be very misleading.

In regard to loss of knee-jerk the findings are quite constant. The knee-jerk was always lost after the 6-hour or longer durations of anemia. The fact that it was always lost after 6 hours of anemia did not mean necessarily that it might not return and become entirely normal again. The shortest period of anemia after which it was lost was 3 hours, and in this particular case (Exp. 7) it returned after 12 days.

The same may be said in regard to the foot-drop—in fact, the time of appearance of the foot-drop was almost identical with the disappearance of the knee-jerk. The muscles controlling the foot-drop were always the first to become affected and the last to become normal.

The occurrence of sensory paralysis was the most variable of the factors accompanying muscular anemia. It was less apt to be complete than was the motor paralysis, and usually disappeared within the first few days after the experiment.

The reaction of degeneration was variable. It was observed earliest in Experiment 26, a 7-hour experiment, but in two other 7-hour experiments it was absent. In the experiments of still longer duration it was not invariably present. Possibly this was due to the variation of pressure with which the tourniquet was applied. For example, one might use much more than sufficient pressure to shut off the circulation, as no pressure gauge was connected with the tourniquet employed in the experiments.

The microscopic changes showed rather definite progression of degeneration.

In all of the following experiments, unless otherwise spe-

cifically noted in detail, anemia of an extremity was obtained by the application of an Esmarch bandage which was tightened until arterial pulsation ceased, the dog being under morphia and light ether anesthesia throughout the time of application.

Protocols of Forty-three Selected Experiments

EXPERIMENT 1

NOVEMBER 10, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. Tourniquet applied to upper third of left thigh for 1 hour. After the application no pulsation could be detected in the femoral artery. At the close of the experiment the dog was in good condition.

NOVEMBER 12.

The dog limped a little, but the muscular strength of the leg seemed to be normal. The knee-jerk was normal.

NOVEMBER 18.

Leg apparently normal.

DECEMBER 1.

Leg apparently normal. All reflexes normal. Reaction to galvanic and faradic currents normal.

EXPERIMENT 2

NOVEMBER 15, 1908.

Small mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. Tourniquet applied to upper third of left thigh for 2 hours. At the close of the experiment the condition of the dog was good.

NOVEMBER 16.

Some impairment of motion of the affected leg was present, and, while the reflexes were normal, the muscular power was slightly diminished. Reaction to galvanic and faradic currents normal.

NOVEMBER 17.

There was marked improvement.

NOVEMBER 19.

The leg seemed to be normal in every way. Reflexes and electrical reactions normal.

EXPERIMENT 3

NOVEMBER 23, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. Tourniquet applied to upper third of left thigh for $2\frac{1}{4}$ hours. At the end of the experiment the dog was in good condition.

NOVEMBER 24.

There was some impairment of the muscular power and activity. The knee-jerk was present, and sensation seemed to be normal.

NOVEMBER 25.

The leg was normal in every way.

EXPERIMENT 4

NOVEMBER 24, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. Tourniquet applied to upper third of left thigh for $2\frac{1}{2}$ hours. At the close of the experiment the condition of the dog was good.

NOVEMBER 25.

The dog limped somewhat, but the leg was not paralyzed. The reflexes were normal. The dog was observed for several days more, but no changes could be made out, the anemia apparently not being sufficient to damage the muscle fibers.

EXPERIMENT 5

DECEMBER 1, 1908.

Mongrel dog; condition, good. Ether; morphia, q. s. Tourniquet applied to right thigh for $2\frac{1}{2}$ hours. At the end of the experiment the condition of the dog was good.

DECEMBER 2.

There was marked impairment of function in the leg, but not complete paralysis. The flexor muscles of the foot were more affected than other groups. There was occasional foot-drop.

DECEMBER 3.

The impairment had disappeared, and the muscular power seemed to be normal.

EXPERIMENT 6

NOVEMBER 25, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. Tourniquet applied to upper third of left thigh for $2\frac{3}{4}$ hours. At the close of the experiment the dog was in good condition.

NOVEMBER 26.

There was slight paralysis of the flexors of the foot. The other muscles seemed to be normal.

DECEMBER 6.

The leg seemed to be normal to electrical stimulation. The reflexes were normal. The dog was killed, and sections taken.

MICROSCOPICAL EXAMINATION.—As a whole the muscle cells showed reduced stainability. The cross-striations of the cells were much reduced, and entirely absent at the periphery of the bundles. Throughout the sections there was marked fragmentation. Certain areas showed regeneration actively going on, while in others there were marked hyaline changes. The walls of the blood vessels were thickened. There was no hemorrhage into the tissues. There was but a small degree of inflammatory infiltration.

EXPERIMENT 7

NOVEMBER 18, 1908.

Black and tan bitch; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for 3 hours. At the close of the experiment the bitch was in good condition.

NOVEMBER 19.

There was partial paralysis of all the muscles below the tourniquet, and the flexors of the foot were completely paralyzed, with consequent complete foot-drop. The reflexes were absent. Sensation to pain seemed to be delayed, but the electrical reactions were normal.

NOVEMBER 25.

The condition of the leg was about the same.

DECEMBER 1.

There was slight improvement. At times the bitch flexed her foot, and there was more motion in the other partly paralyzed muscles. The reflexes could not be elicited. Sensation to pain was more acute, and the electrical reactions were still normal.

DECEMBER 15.

Slow improvement had continued, with partial return of muscular power. The electrical reactions continued to be normal.

DECEMBER 30.

The leg seemed to be normal in every way, including the reflexes.

JANUARY 7, 1909.

The bitch was killed with chloroform, and pieces of muscle taken for sectioning.

MICROSCOPICAL EXAMINATION.—On the whole the sections presented a normal appearance. In certain areas the cross-striations were a little less distinct than normal, but this may have been due to the way the sections were cut. The nuclei stained perfectly everywhere, and showed no signs of degeneration, and there was no round cell infiltration. The sarcolemma was slightly thicker than normal.

EXPERIMENT 8

NOVEMBER 27, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the right thigh at the junction of the upper and middle thirds for 3 hours. At the close of the experiment the dog was in good condition.

NOVEMBER 28.

There was but slight impairment of the function of the muscles below the tourniquet. The reflexes were normal.

DECEMBER 1.

The return to normal seemed to be complete in every way.

EXPERIMENT 9

NOVEMBER 30, 1908.

Bulldog bitch; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for 3 hours. At the close of the operation the dog was in good condition.

DECEMBER 1.

There was almost complete paralysis of the muscles of the leg below the tourniquet with foot-drop. The knee-jerk was not lost.

DECEMBER 2.

The condition was markedly better.

DECEMBER 28.

The leg was in apparently normal condition.

EXPERIMENT 10

OCTOBER 9, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the left thigh for 3 hours. At the close of the experiment the dog was in good condition.

OCTOBER 10.

There was a pronounced toe-drop, but the other muscles were not paralyzed, and the electrical reactions were normal. The leg was very sensitive to pain, and the dog howled whenever the leg was touched. The temperature and pulse rate were normal.

OCTOBER 14.

As far as could be determined the muscles were in normal condition, except that, after exertion, the dog still showed a slight toe-drop

on the affected side. The electrical reactions were normal, and there was no difference in the reactions to pain between the two legs.

OCTOBER 19.

The muscles seemed to be normal in every way.

NOVEMBER 12.

The dog was anesthetized, and the adductor magnus muscle removed and a portion of the sciatic nerve. No gross changes were apparent in either. The histologic examinations also showed no changes.

EXPERIMENT II

NOVEMBER 19, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the left thigh for 4 hours. At the close of the experiment the dog was in good condition.

NOVEMBER 20.

The affected leg showed complete foot-drop, and the peroneal muscles were completely paralyzed. The other muscles still retained some power, but it was much below normal. The dog used the leg, but walked on the dorsum of the foot instead of the plantar surface. The knee-jerk was absent. To the faradic current there was delayed reaction, but to the galvanic the reaction was normal.

NOVEMBER 30.

The condition of the leg was the same.

DECEMBER 1.

There seemed to be slight improvement, and the flexors of the foot showed signs of regaining their power. The reflexes could not be obtained.

DECEMBER 5.

The improvement was marked. The foot dropped occasionally. The knee-jerk had returned. No change could be made out in the electrical reactions.

JANUARY 4, 1909.

There was no paralysis of the flexor muscles. The dog was killed, and pieces of tissue removed for examination.

MICROSCOPICAL EXAMINATION.—In the muscle cells there was a general change involving all of the cytoplasm. The cross-striations were less plain, and, to a slight degree, fragmentation had taken place. Except for a slight increase of the granules about the nucleolus the nuclei were apparently normal. There was no inflammatory infiltra-

tion. The blood vessels showed no changes. Throughout the sections there was a general increase of connective tissue. In certain areas there was cloudy swelling, which seemed to be the result of a previous edema. When compared with fields of normal muscle it was found that there was an increase in the number of nuclei, showing that cell division had been progressing faster than normal. The sarcolemma was not thickened. No nerve endings were made out in the preparations.

EXPERIMENT 12

OCTOBER 10, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for *4 hours*. At the close of the experiment the dog was in good condition, no change in the respiratory rate having been noticed.

OCTOBER 11.

Marked toe-drop was present, and the leg seemed to be numb. The reflexes were absent, but the electrical reactions were normal. The leg was dragged, and voluntary movement was apparently lost below the tourniquet.

OCTOBER 16.

The symptoms of disturbance had practically all disappeared. The toe-drop was shown only when the dog was fatigued, and then but slightly. The electrical reactions were normal.

NOVEMBER 12.

The dog was anesthetized, and the adductor magnus muscle and part of the sciatic nerve removed. No gross or microscopic changes could be detected.

EXPERIMENT 13

DECEMBER 31, 1908.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for *5 hours*.

JANUARY 1, 1909.

Marked impairment of muscular power was present, but not complete paralysis. There was marked paralysis of the flexors of the foot, with resulting foot-drop.

JANUARY 8.

The paralysis was somewhat less. The foot-drop was still present, and the knee-jerk was diminished.

JANUARY 14.

Death occurred during the night from unknown cause, the autopsy revealing no change to which death could be attributed. Blocks of tissue were taken for examination.

MICROSCOPICAL EXAMINATION.—The sections showed considerable change. Under low power magnification infiltration of leukocytes between the muscle fibers could be seen. The fibers themselves were poorly stained, and the striæ were almost obliterated. In many areas the fibrillæ did not show at all, the entire fibers showing hyaline changes. There was a great difference in the size of the fibers, many showing an increase in the number of muscle nuclei. These nuclei were round or oval in shape, and about three times as large as normal nuclei. Marked fragmentation had occurred in all parts of the sections. The sarcolemma was greatly thickened.

EXPERIMENT 14

JANUARY 4, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the right thigh for 5 hours. At the close of the experiment the dog was in good condition.

JANUARY 5.

There was partial paralysis of the muscles below the point of constriction, and partial toe-drop.

JANUARY 8.

The condition was about the same.

JANUARY 12.

Muscular power was more nearly normal. The foot dropped less. The electrical reactions were negative.

JANUARY 17.

Marked improvement had occurred, but there was still some impairment of the muscular power of the foot.

JANUARY 18.

The dog was killed in the course of a resuscitation experiment. Blocks of tissue were removed for examination.

MICROSCOPICAL EXAMINATION.—Extensive degeneration had occurred. In some areas the muscle fibers could not be distinguished as such at all, on account of proliferation of the nuclei and infiltration of leukocytes. In an occasional area cross-striation could be seen immediately adjoining fibers completely destroyed and undergoing absorp-

tion. Fragmentation was marked, and the sarcolemma was thickened.

EXPERIMENT 15

JANUARY 23, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the right thigh for 5 hours.

JANUARY 24.

The dog died during the night. The microscopical examination showed only normal muscle.

EXPERIMENT 16

OCTOBER 14, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the right thigh for 5 hours. At the close of the experiment the condition of the dog was good.

OCTOBER 15.

There was complete paralysis of all the muscles below the point of constriction. Foot-drop was pronounced. On stimulating with the faradic current the muscles seemed to be more irritable than normal. The latent period was increased, but it required less stimulus to produce a maximal contraction than in the other leg. The period of contraction seemed to be shortened, but, as compared with that of the other leg, the relaxation phase was increased. Frequent contractions soon threw the muscles into tetanus. No reaction of degeneration could be made out. Sensitiveness to pain seemed to be diminished.

OCTOBER 18.

The paralysis had become only partial, and, with the exception of the muscles of the foot, the dog had considerable use of the leg. The foot-drop was as marked as at the time of the last observation. Sensitiveness to pain seemed to be increased. The reaction to galvanic stimulation seemed to be nearly normal. The length of the latent period was still increased, but a greater stimulus was required to produce a maximal contraction than was needed before. There was still no reaction of degeneration. The reflexes were still abolished. The foot was still somewhat edematous. The general condition of the dog was good.

OCTOBER 24.

Except for some foot-drop the paralysis had disappeared, and the dog walked with scarcely any limp. The electrical reactions showed

no degeneration, and still greater stimulation was necessary to produce a maximal contraction. The reflexes had not returned, but the sensitiveness to pain seemed to be normal.

OCTOBER 29.

The foot-drop had disappeared. A slight knee-jerk could be obtained. The leg was used without any difficulty.

NOVEMBER 12.

No trace of the previously altered functions could be detected. The dog could leap and play as well as ever. Under ether anesthesia the adductor magnus and part of the sciatic nerve were removed. No gross changes could be detected.

MICROSCOPICAL EXAMINATION.—Evidences of an old hemorrhage into the muscle tissue were found. About the upper part of the muscle some edema was present, and in this region there was slight necrosis. About the blood vessels were areas of round cell infiltration. In many places the sarcolemma had separated from the muscle fiber, apparently as a result of previous edema. No definite signs of regeneration could be made out, and there did not seem to have been any marked destruction of muscle fibers.

EXPERIMENT 17

DECEMBER 5, 1908.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for 6 hours. The dog died about 2 hours after the close of the experiment. The autopsy was negative. No changes in the muscles were detected.

EXPERIMENT 18

DECEMBER 7, 1908.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for 6 hours. At the close of the experiment the dog was in good condition.

DECEMBER 8.

There was complete paralysis of all the muscles below the point of constriction. The reflexes could not be obtained, and sensitiveness to pain seemed to be abolished. To the faradic current there was a delayed reaction, but no reaction of degeneration could be made out.

DECEMBER 15.

The conditions were about the same. The dog was accidentally killed. No sections were taken.

EXPERIMENT 19

JANUARY 5, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the thigh for 6 hours. At the close of the experiment the dog was in poor condition.

JANUARY 6.

The dog died during the night. The autopsy revealed no gross changes to which death might have been attributed. Blocks of tissue were removed for microscopical examination.

MICROSCOPICAL EXAMINATION.—The sections showed the presence of edema, but there were no structural changes present.

EXPERIMENT 20

JANUARY 18, 1909.

Mongrel bitch; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the right thigh for 6 hours. At the close of the experiment the bitch was in good condition.

JANUARY 19.

The general condition was good. Below the site of application of the tourniquet there was almost complete paralysis. The flexors of the foot were most involved, and the foot-drop was marked. The knee-jerk was absent.

JANUARY 20.

Death occurred during the night. Blocks of tissue were taken for examination.

MICROSCOPICAL EXAMINATION.—Edema alone was present.

EXPERIMENT 21

JANUARY 20, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the right thigh for 6 hours. The dog died before the tourniquet was removed. At the autopsy the cause of death was undetermined. Sections of the anemic muscles did not reveal any changes.

EXPERIMENT 22

OCTOBER 14, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the right thigh for 6 hours. At the close of the experiment the dog was in good condition.

OCTOBER 15.

There was complete paralysis of all the muscles below the point of application of the tourniquet. Foot-drop was pronounced. The reaction to the galvanic current did not seem to be much altered, although the latent period was increased and the relaxation phase somewhat prolonged. Sensitiveness to pain seemed to be much diminished.

OCTOBER 18.

The condition seemed to be about the same. The foot-drop was complete, but the sensitiveness to pain was increased. On stimulating with the galvanic current the period of shortening was greatly prolonged, and the period of relaxation irregular. The muscles soon became fatigued, and after being stimulated for several minutes would not respond at all. No reaction of degeneration could be made out. On walking the leg was dragged, and it was evident that voluntary control was completely lost. The general condition was excellent.

OCTOBER 24.

There had been marked improvement since the previous note was made. A certain amount of voluntary muscular control had returned. The knee-jerk was still absent, and the toe-drop was as pronounced as before. The period of shortening on galvanic stimulation was prolonged, but not as much as before. It took about twice as long to cause the muscle to become tetanic. There was no reaction of degeneration.

OCTOBER 29.

Improvement had been steady, and the dog was found to have good control over most of the muscles. The foot-drop was present only when the dog was tired. The electrical reactions were about the same, with the exception that the periods of both relaxation and shortening had become lessened. The latent period was still prolonged, and the reflexes decreased. There was no reaction of degeneration.

NOVEMBER 11.

All traces of paralysis had disappeared, with the exception that the knee-jerk was greatly diminished. The electrical reactions were normal. The foot-drop had disappeared.

NOVEMBER 27.

Normal responses were made to every test, the knee-jerks now being as active as in the other leg. Still no reaction of degeneration was obtained. Under ether anesthesia the dog was killed, and the

adductor magnus muscle and a portion of the sciatic nerve removed. The muscle seemed to be firmer than normal, and to contain more fibrous elements.

MICROSCOPICAL EXAMINATION.—There was no doubt but that an increase in the fibrous elements had occurred. In many areas evidence of old hemorrhages was present. The sarcolemma was thickened, and, in many places, separated from the fibers. The number of nuclei was increased, and their arrangement was irregular. There were fewer areas of necrosis in this experiment than in the last of the five-hour ones. The sciatic nerve showed no changes.

EXPERIMENT 23

DECEMBER 12, 1908.

Mongrel bitch; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for 7 hours. While the bitch was apparently in good condition at the end of the experiment, she was found dead the next morning. Blocks of tissue were removed for examination.

MICROSCOPICAL EXAMINATION.—Marked edema, with extensive interstitial hemorrhage, was found. There did not seem to be any specific change in nuclei or cytoplasm.

EXPERIMENT 24

DECEMBER 15, 1908.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left hind leg for 7 hours. During the latter part of the experiment the respirations became very rapid, but decreased in rate on giving more ether. At the end of the experiment the dog was apparently in good condition.

DECEMBER 16.

There was complete paralysis of the muscles below the point of application of the tourniquet, with complete foot-drop. The dog was unable to walk at all.

DECEMBER 18.

The electrical reactions were normal, but there was no improvement in the paralysis, and the knee-jerk could not be obtained.

DECEMBER 28.

Some improvement had appeared; the dog could walk with marked foot-drop. The knee-jerk could not be obtained.

DECEMBER 30.

There was voluntary movement in all of the muscles, although less in the flexors of the foot than in the others.

JANUARY 7, 1909.

Improvement was marked. The knee-jerk was obtained. The dog was killed in a resuscitation experiment.

MICROSCOPICAL EXAMINATION.—The sections stained poorly. In most areas the cross-striations had disappeared, and, where present, they showed very faintly. In many of the fibers Kölliker's columns showed. In some of the fibers hyaline degeneration was complete. In many places active regeneration was shown by the great increase in the number of nuclei.

EXPERIMENT 25

DECEMBER 16, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the right thigh for 7 hours. At the close of the experiment the dog was in poor condition, and died during the night.

MICROSCOPICAL EXAMINATION.—Very few changes were found. The cross-striation was not prominent, but could be seen in most places. The muscle fiber and sarcolemma nuclei were well stained. No evidence of degenerative processes was found.

EXPERIMENT 26

OCTOBER 18, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the right thigh for 7 hours. During the last hour of the experiment the respirations rose to 70 per minute, and were not affected by increasing the amount of ether. This rapid rate was maintained for three hours after the experiment, or four hours in all. Otherwise the condition of the dog at the end of the experiment was good.

OCTOBER 19.

All of the muscles below the site of application of the tourniquet were paralyzed. The knee-jerk was abolished, and there was complete insensitiveness to pain. Under electrical stimulation the muscles contracted, but the latent period was greatly prolonged. In the affected leg the period of shortening was also much longer than in the other leg. There was not the great variation in the period of relaxation that there was in the period of shortening; the muscles

were soon in tetany, so that little could be determined. There was no reaction of degeneration, and the manipulations did not seem to cause pain.

OCTOBER 24.

On this date there was some improvement. While motor paralysis seemed to be complete, sensitiveness to pain was present. The entire foot was very edematous, and was dragged on walking. There was still no knee-jerk. The electrical reactions were the same. There was no reaction of degeneration.

OCTOBER 27.

There was some control of the leg, but the foot-drop was still absent. Stimulation with the galvanic current showed that the period of relaxation had decreased since the 24th, but that it was still prolonged, and that there was the same disturbance of the phases of shortening and relaxation. Three minutes of repeated stimulation threw the muscles into tetany, from which they did not recover for several minutes.

NOVEMBER 5.

While the foot-drop was still marked the general condition of the leg had improved. The periods of shortening and relaxation were the same in both legs, but the latent period was much increased in the affected leg, even more so than at any previous time. The knee-jerk was still absent. Sensitiveness to pain seemed to be about normal. The reaction of degeneration was shown for the first time, 18 days after constricting the leg.

NOVEMBER 9.

There was no apparent improvement in the involved muscles, and motor control seemed to be completely lost. The knee-jerk was absent. The reaction of degeneration was still more marked. Edema was still present. Sensitiveness to pain was still present, although there was no evidence of any suffering from pain when the dog was not being tested.

NOVEMBER 15.

The condition of the muscles was unchanged as far as the reactions were concerned. If anything the edema was worse than before. The knee-jerk was still absent.

NOVEMBER 17.

The dog seemed to be suffering from pain. The edema was less. The other conditions were the same.

NOVEMBER 25.

The edema had about disappeared, and there seemed to be other slight improvement.

NOVEMBER 30.

Considerable use of the leg had returned. On pricking it with a pin the leg was drawn away. The greatest improvement was in the electrical reactions, there being no disturbance of the periods of shortening or relaxation, although the length of the latter was still increased over the normal.

DECEMBER 8.

The foot-drop was but slightly improved, but the control of the other groups of muscles was good. The knee-jerk was still absent, and the reaction of degeneration still persisted. The other electrical reactions were about normal. The dog whined a great deal, as if he were in pain, but this may have been due to a running sore (of trophic origin?) on the dorsum of the foot.

DECEMBER 14.

Voluntary control was diminished again. The other conditions were as before, except that the muscles were more easily thrown into tetany.

DECEMBER 27.

In general the condition was stationary, except that voluntary control was lessened still further. The reaction of degeneration was present, and the knee-jerks absent.

FEBRUARY 24.

At this date, more than 2 months after the constriction, the paralysis of the muscles below the point of application of the tourniquet was complete. The reaction of degeneration was present, and the knee-jerk had not returned. Under ether anesthesia the adductor magnus muscle and part of the sciatic nerve were removed. The muscle was paler, firmer, and smaller than normal. The nerve was congested, but otherwise seemed to be normal.

MICROSCOPICAL EXAMINATION.—A great increase in the amount of fibrous tissue had occurred, with fragmentation of the individual fibers. For the most part the cross-striations were absent. In many areas pigmentation had occurred, and about these areas there was marked necrosis. Scattered through the sections were areas of round-cell infiltration and hemorrhage into the tissues. In certain areas the normal muscle fibers seemed to have been entirely replaced by connective tissue. The sarcolemma was everywhere thickened, and it was often separated from the fibrils, apparently by the previously oc-

curring edema. Everywhere there was a great increase of the multinucleated cells, and these were arranged irregularly in reference to the long axes of the muscle fibers. To a large extent the condition was that of progressive muscular atrophy, which had undoubtedly passed beyond the stage where entire repair could have taken place.

EXPERIMENT 27

DECEMBER 26, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the right thigh for 7 hours. At the close of the experiment the dog was in good condition.

DECEMBER 27.

Partial paralysis of all of the muscles below the point of application of the tourniquet was present. Foot-drop was present, and the knee-jerk was absent. The electrical reactions showed prolongation of the latent period, but otherwise they were normal. The general condition was good.

DECEMBER 29.

The condition of the affected muscles was markedly better. The knee-jerk and foot-drop were as before, but considerable voluntary control was present. The latent period had become about normal.

JANUARY 8, 1910.

Slight foot-drop was still present. The knee-jerk had returned.

JANUARY 15.

The foot-drop had disappeared. The leg seemed to be normal in every way. Under ether anesthesia the adductor magnus muscle and a portion of the sciatic nerve were removed for examination.

MICROSCOPICAL EXAMINATION.—But few changes could be made out. The cross-striation was less apparent. The muscle nuclei had increased in number. In some areas there was slight fragmentation and pigment deposition. The sarcolemma was separated from the fibrillæ, and thickened. The nerve seemed to be normal.

EXPERIMENT 28

JANUARY 14, 1910.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the right thigh for 7 hours. At the close of the experiment the dog was in good condition.

JANUARY 15.

Complete paralysis was present, with marked foot-drop and loss of the knee-jerk. The latent period was prolonged, and the phases of shortening and relaxation were very irregular. The leg was very edematous. The sensitiveness to pain was greatly diminished and delayed. There was no reaction of degeneration.

JANUARY 26.

Marked improvement had occurred since the last observation, eleven days previously. The edema had all disappeared. The knee-jerk was present, but diminished. The electrical reactions showed improvement, the latent period being the same for both legs. The muscles could still readily be thrown into tetany by repeated shocks, it not being impossible to do this with the sound leg. There was no reaction of degeneration present. The voluntary control was good.

JANUARY 30.

There was still slight foot-drop, but the improvement was even greater. The electrical reactions were normal, and the knee-jerk active. The edema had returned during the previous two days. The voluntary control was good.

FEBRUARY 16.

The foot-drop had disappeared, and the leg seemed to be normal.

MARCH 4.

The leg seemed to be perfectly normal in every way. Under ether anesthesia the adductor magnus muscle and part of the sciatic nerve were removed.

MICROSCOPICAL EXAMINATION.—The muscle fibers stained well, but the number of cross-striations was reduced. In some areas the latter were faint, in others absent, and in still others present and normal in appearance. The nuclei were increased, both in size and in number, being distributed in varied relations to the long axes of the fibers. In certain areas there was hemorrhage into the tissues and round-cell infiltration. There had been a certain amount of regeneration of the muscular elements, but the increase of the connective tissue elements was not marked. In some areas the sarcolemma was thickened, and separated from the fibrillæ by the previously present edema. In fact, a certain amount of edema had persisted, but it was confined to an area near the point of application of the tourniquet. The nerve was edematous in places, and, on cross section, the individual fibers were somewhat shrunken.

EXPERIMENT 29

JANUARY 7, 1909.

Black and tan bitch; condition, good. Ether, morphia, q. s. A tourniquet was applied to the upper part of the right thigh for $7\frac{1}{2}$ hours. At the end of this time death occurred.

AUTOPSY.—Microscopical examination of sections showed only normal muscle as far as structural changes were concerned.

EXPERIMENT 30

JANUARY 6, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the right thigh for 8 hours. The dog died during the night, probably from the effects of the long anesthesia, as the autopsy revealed no explanation. Sections were made from the muscles, but no structural changes were made out. Evidently the blood had not circulated through the leg again after removing the tourniquet, as the tissues were pale and the blood vessels empty.

EXPERIMENT 31

OCTOBER 24, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the right thigh for 8 hours. At no time was there any variation in the respiratory rate, and the dog was in good condition at the end of the experiment.

OCTOBER 25.

The muscles were completely paralyzed. The knee-jerk was lost, and the entire leg seemed to be numb. Marked edema was present. As regards the electrical reactions the latent period was prolonged, and the shortening phase was both prolonged and incomplete. The relaxation phase was also much prolonged, and the muscles were easily thrown into tetany. No reaction of degeneration could be detected. The general condition was good.

OCTOBER 27.

The general condition of the muscles was the same, but the edema had increased. Apparently there was no pain.

NOVEMBER 5.

Some improvement had occurred, as there was partial voluntary control of most of the muscles, the foot-drop still being complete. The knee-jerk was absent, and the edema still present. There was no reaction of degeneration. The latent period was still prolonged, but the periods of shortening and relaxation were nearly normal.

NOVEMBER 9.

Steady improvement had occurred.

NOVEMBER 15.

The knee-jerk was present for the first time. The foot-drop was present for the first time, but only when the dog was made tired by walking or running. The edema had practically disappeared.

NOVEMBER 25.

So far as could be determined the leg was normal in every way.

DECEMBER 25.

The condition was still normal, the use of the leg being perfect. Under ether anesthesia the adductor magnus muscle and part of the sciatic nerve were removed. While the tissues were vascular the muscle was much smaller than the corresponding one in the sound leg. No gross changes could be made out in the nerve, and there were no adhesions.

MICROSCOPICAL EXAMINATION.—Many areas were present in the muscle, which took the stain faintly, and in these the cross-striations had disappeared; there was much fragmentation, and the connective tissue was much increased. The sarcolemma was thickened and separated in many places by the generalized edema which had previously occurred. Everywhere there was a great increase in the number of nuclei, and they were often arranged irregularly and at an angle with the long axes of the fibers. The new nuclei were irregular and often vacuolated. In some places the muscle fibers were granular, and in others round-cell infiltration and interstitial hemorrhages had occurred. Everywhere evidences of cell proliferation and regeneration were present. The nerve fibers showed less marked changes, although in cross section they seemed shrunken, and the connective tissue seemed to be increased in the nerve sheaths.

As a whole the changes produced in this experiment were much milder than those caused in Experiment 28, a seven-hour experiment.

EXPERIMENT 32

FEBRUARY 14, 1910.

Mongrel bitch; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for 8 hours. Before the close of the experiment the dorsalis pedis artery was opened in the foot, and it was proved by the absence of circulation that the blood was shut off from the entire leg. On removing the tourniquet the blood began slowly to flow. The artery was then

ligated, and the experiment terminated. The bitch was in good condition.

FEBRUARY 15.

Complete paralysis was present with foot-drop and loss of knee-jerk. The latent period was prolonged, and the phases of shortening and relaxation were irregular. There was no reaction of degeneration. Edema was very marked, and the leg seemed to be numb. Very few electrical impulses sufficed to throw the leg into tetany. The strength of current that would produce a maximal contraction in the sound leg failed to produce any contraction whatsoever of the affected leg. In the latter the reaction to the faradic was better than to the galvanic current.

FEBRUARY 18.

Very slight improvement had occurred, the condition being practically the same as before.

FEBRUARY 23.

The general condition was the same. For the first time the reaction of degeneration was obtained. The latent period was shorter, and the periods of shortening and relaxation were more normal. Edema was still very marked. The knee-jerk had not returned.

FEBRUARY 27.

Except that the reaction of degeneration was more marked the condition was about the same.

MARCH 14.

The reaction of degeneration was still more marked. Voluntary control was about the same, but sensation seemed to be returning. A strength of current sufficient to cause a maximal contraction in the sound leg caused the same in the affected leg. The edema was less.

MARCH 27.

There had been some improvement in the voluntary control, but the foot-drop was as marked as ever. The reaction of degeneration was still present, the other reactions now being normal.

APRIL 7.

The improvement, if any, had been slight, and the voluntary control was poor. The reaction of degeneration had persisted, as well as the foot-drop, and absence of knee-jerk

MAY 14.

At this date, three months after the application of the tourniquet, there was still but little change in the muscles of the affected leg. The reaction of degeneration had been present since its first appearance. The practically complete loss of voluntary control was the same, the foot-drop still being present and the knee-jerk absent. The amount of edema had varied from time to time, and the temporarily lost sensibility had returned, at least in part. Under ether anesthesia the adductor magnus muscle and part of the sciatic nerve were removed. The gross appearance of the muscle was strikingly altered, as it was only about one-third of the size of the normal adductor magnus muscle of the sound leg. It was also much darker in color than normal, from marked interstitial hemorrhage, and was more fibrous. The nerve was injected and thickened.

MICROSCOPICAL EXAMINATION.—The muscle was profoundly changed. The cross-striations could not be made out at all, and, in fact, in many areas it was impossible to recognize any muscle tissue; what had been muscle tissue had become a broken-down mass. Extensive hemorrhages were everywhere, as was also edema. The tissues, as a whole, stained faintly. Many irregular, indefinitely arranged nuclei were present. The sarcolemma was everywhere thickened, and separated by the still-present edema. Round-cell infiltration was marked, and generally present. The condition seemed to be one of atrophy rather than of attempted regeneration. The sciatic nerve showed marked thickening of the neurilemma, with some hemorrhage into the sheath. Inside of the sheath many vacant spaces were present, which seemed to indicate absorption of portions of the fibers.

EXPERIMENT 33

JANUARY 22, 1909.

Mongrel bitch; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the left thigh for $8\frac{3}{4}$ hours. The bitch died during the night, probably from the effects of the long anesthesia. The autopsy was negative. Microscopically no structural changes were found.

EXPERIMENT 34

JANUARY 22, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for $8\frac{3}{4}$ hours. The dog died during the night, probably from the effects of the ether,

as the autopsy revealed no explanation. The sections showed no structural changes, only anemia.

EXPERIMENT 35

JANUARY 9, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the right thigh for 9 hours. At the end of that time the dog was in good condition.

JANUARY 10.

The muscles below the point of application of the tourniquet were completely paralyzed. The knee jerk was absent, foot-drop was present in marked degree, and the sensitiveness to pain was delayed as well as diminished. The electrical reactions were normal, although there was less response to the faradic current on the paralyzed than on the normal side.

JANUARY 11.

The dog died during the night from undetermined cause. The sections failed to reveal any structural microscopic changes beyond edema and interstitial hemorrhages.

EXPERIMENT 36

NOVEMBER 5, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the right thigh for 9 hours. During the last part of the experiment the respiratory rate rose to 60 per minute, but at the end the dog was in good condition. That there was no circulation in the leg was proved by opening the dorsalis pedis artery.

NOVEMBER 6.

Complete paralysis and universal edema were present. Foot-drop was complete, the knee-jerk was lost, and sensitiveness to pain was greatly diminished, if not entirely absent. The response to a galvanic current was very slow, and was still slower to a faradic current. A much greater impulse was required to produce a maximal contraction in the affected than in the sound leg. The latent period of contraction was much prolonged, the phase of shortening was both prolonged and incomplete, and the phase of relaxation prolonged and irregular. Tetany was quickly caused by a few rapidly repeated impulses. No reaction of degeneration was present.

NOVEMBER 9.

Except that sensitiveness to pain had returned the condition was practically the same as it was three days previous.

NOVEMBER 15.

There had been some improvement. While the foot-drop was as marked as before there was some power in the other voluntary muscles. The knee-jerk was absent, and the edema less. The reaction of degeneration was present.

NOVEMBER 17.

The reaction of degeneration was more marked. The knee-jerk was absent. Sensitiveness to pain was increased. The voluntary control was better.

NOVEMBER 26.

As a whole the condition had been about stationary. The reaction of degeneration was very marked, but the other electrical reactions were nearly normal. The knee-jerk had not returned.

DECEMBER 5.

There had been no appreciable change, except, perhaps, less voluntary control than before. Sensitiveness to pain was about normal.

JANUARY 14, 1910.

The condition was about the same, being clearly one of progressive muscular atrophy. The leg was paralyzed. The knee-jerk was absent, and the reaction of degeneration marked. Under ether anesthesia the adductor magnus muscle and part of the sciatic nerve were removed. The muscular tissue seemed to be very fibrous and harder than normal. The nerve showed no gross changes.

MICROSCOPICAL EXAMINATION.—The fibrous tissue was greatly increased in all parts of the sections. Fragmentation of the muscle fibers was marked, the cross-striations, to a large extent, being absent, and, when present, being very indistinct. The sarcolemma was thickened and separated from the fibrillæ in many places by edema. In various areas hemorrhage into the tissues had occurred, particularly along the course of the blood vessels themselves. The blood vessels were much altered. The nerve trunk showed marked breaking-up of the bundles and shrinkage of the fibers. Vacuolated areas were numerous.

EXPERIMENT 37

APRIL 24, 1910.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for 9 hours.

At the close of the experiment the dorsalis pedis artery was exposed and opened. A slight continuous flow of blood resulted, which showed that the circulation had not been entirely shut off. At this time the dog was in good condition.

APRIL 25.

All of the muscles of the affected leg were completely paralyzed, with foot-drop and loss of knee-jerk. The leg was very edematous and very numb. The electrical reactions showed marked prolongation of the latent period, and delayed and irregular phases of shortening and relaxation. There was no reaction of degeneration.

APRIL 29.

The extensor muscles were completely paralyzed, but the voluntary control of the others was present to a certain extent. Considerable tenderness was present, as the dog snapped at anybody who tried to touch him. The knee-jerk was absent. It was impossible to determine the electrical reactions, on account of the pain that the attempt caused.

MAY 12.

Paralysis was almost entirely absent, the foot-drop showing only after the dog was fatigued by running around the room. The knee-jerk was still absent, no reaction of degeneration could be obtained. The latent period was the same in both legs. Much of the edema had disappeared.

MAY 17.

The leg was normal in every way.

MAY 26.

The leg was still completely normal as far as function was concerned. Under ether anesthesia the adductor magnus muscle and part of the sciatic nerve were removed. The muscle was somewhat smaller than normal, and firmer.

MICROSCOPICAL EXAMINATION.—The muscle bundles stained rather faintly with less prominence of the cross-striations than normal. In one small area there was marked fragmentation, while interstitial hemorrhages were numerous. In some places there was round-cell infiltration. The blood vessels had much thickened walls. About some of them amyloid changes had taken place. No areas suggesting infarction were found. On the whole the changes were irregularly distributed, in marked contrast to those found in some of the preceding experiments. This was probably because the circulation had

not been entirely cut off. On account of the microscopic changes it was difficult to account for the rapid return of voluntary control of the leg.

EXPERIMENT 38

APRIL 2, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the right hind leg for 10 hours. At the close of the experiment the condition of the dog was good.

APRIL 3.

The muscles below the point of application of the tourniquet were completely paralyzed. Sensitiveness to pain was both diminished and delayed. The reflexes were abolished. Reaction to the faradic current was somewhat sluggish, but was normal to the galvanic current.

APRIL 8.

Slight improvement of function had occurred. Sensation was more acute. The response to the faradic current was more active.

APRIL 16.

There had been slight continued improvement, the flexor muscles of the paw showing the least. Sensation was acute.

MAY 7.

The condition was apparently unchanged.

MAY 16.

Little or no improvement had occurred during the previous nine days. While voluntary movement was present in all of the involved muscles it was much less than in the normal leg. The electrical reactions were normal. The knee-jerk was present but diminished. Under ether anesthesia the dog was killed, and the adductor magnus muscle and part of the sciatic nerve were removed.

MICROSCOPICAL EXAMINATION.—Everywhere through the sections there was marked atrophy of the muscle fibers, with evidence of formation of new muscle cells. In the old fibers the cross-striations were very indistinct, while in the new they were very distinct. In certain areas numerous, large, irregularly shaped, more or less vesiculated and granular nuclei were present. General fragmentation was absent, such as there was being confined to a few small areas. The muscle cell proliferation seemed to have been most active around the larger blood vessels. The sarcolemma was everywhere much thickened. In some areas extensive hemorrhage and pigmentation had occurred.

EXPERIMENT 39

NOVEMBER 5, 1909.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for *10 hours*. During the latter part of the experiment the respiratory rate was greatly increased up to 76 per minute, and remained at this rate for three hours afterward. Otherwise the condition was good. Just before the tourniquet was removed, opening the dorsalis pedis artery showed that the cessation of circulation had been complete. Ten minutes after removing the tourniquet the circulation seemed to be as vigorous as ever.

NOVEMBER 6.

All of the muscles below the point of application of the tourniquet were completely paralyzed. The leg was edematous, with marked swelling, and numb. The latent period of contraction was greatly prolonged, while the periods of shortening and relaxation were irregular. Fatigue soon followed the stimulation.

NOVEMBER 7.

The dog was found dead this morning, having been dead for several hours. The autopsy showed the presence of pneumonia. The muscles were very edematous, and there had been interstitial hemorrhages. The sciatic nerve was also edematous, and hemorrhages had occurred along its course.

EXPERIMENT 40

APRIL 24, 1910.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for *10 hours*. At the close of the experiment opening the dorsalis pedis artery showed that there was no circulation present. Toward the latter part of the time the respiratory rate rose from 33 to 95 per minute. The respiration was very labored, and neither rate nor character seemed to be dependent on the depth of anesthesia. This condition persisted for about four hours after the experiment.

APRIL 25.

As usual there was complete paralysis, with marked foot-drop and loss of knee-jerk. The leg was very edematous, and sensitiveness to pain seemed to have been completely lost. The electrical reactions showed a marked increase in the latent period of contraction, as well as irregular and delayed phases of shortening and relaxation. No

reaction of degeneration was present. The muscles were soon fatigued and then thrown into tetany by continued stimulation.

APRIL 28.

The conditions were the same except for an increase in the amount of edema.

MAY 2.

There had been a slight return of voluntary control. The edema was less. The foot-drop was still complete, and the knee-jerk absent. There was no reaction of degeneration. A much greater stimulus was required to produce the minimal contraction on the affected side than the maximal contraction on the sound side. No reaction of degeneration was present.

MAY 8.

The reaction of degeneration was present.

MAY 14.

The condition seemed to be stationary in regard to voluntary muscular control. The reaction of degeneration was much more marked. The edema had almost disappeared, and sensitiveness to pain was very acute.

MAY 27.

The reaction of degeneration was still more marked. The knee-jerk had not returned.

JUNE 15.

The leg had become much smaller in size. On making a urinary examination glucose was found to be present, but how long it had been present was not known, as this was the first time that the test had been made.

JUNE 16.

By the polariscope 0.4 per cent. of sugar was present in the urine.

JUNE 18.

Condition the same locally, with the dog in very poor general condition.

JUNE 24.

The dog died during the night. The autopsy failed to show any suggestive lesions. The glycosuria had been present continually since it was first detected, the percentage of sugar varying much from day to day. The last examination of the muscles was made on the 21st inst., and there was then no apparent change. The reaction of

degeneration was very marked, the knee-jerk had not returned, the size was reduced two-thirds, there had been extensive interstitial hemorrhage, and the muscles were hard. The sciatic nerve was hemorrhagically injected.

MICROSCOPICAL EXAMINATION.—Many profound changes had occurred, and in places it was difficult to tell that the tissue had ever been muscle. The cross-striations were often completely obliterated, and were nowhere distinct. Fragmentation was almost universally present. The nuclei were greatly increased in size and number, and bore no definite relation to the axes of the fibers. The sarcolemma was greatly thickened and very edematous. Round-cell infiltration was everywhere present. The hemorrhages in evidence macroscopically were still more so microscopically. The nerve showed fibrous degeneration. The neurilemma was much thickened and edematous. On cross-section the individual fibers were seen to be atrophied, and often entirely absent, as shown by the vacant space which they had previously occupied.

EXPERIMENT 41

APRIL 27, 1910.

Mongrel dog; condition, good. Ether, morphia, q. s. A tourniquet was applied to the upper third of the right thigh for *10 hours*. Absence of circulation was proved by opening the dorsalis pedis artery. At the close of the experiment the condition of the dog was good.

APRIL 28.

The dog died during the night from aspiration pneumonia. In the gross the muscles showed edema without interstitial hemorrhage, but the microscopical examination showed no structural changes.

EXPERIMENT 42

APRIL 25, 1910.

Mongrel dog; condition, good. Ether; morphia, q. s. A tourniquet was applied to the upper third of the left thigh for *10 hours*. Absence of circulation was proved by opening the dorsalis pedis artery. At the close of the experiment the dog was in good condition.

APRIL 26.

Complete paralysis was present, with foot-drop and loss of knee-jerk. The leg was very edematous and numb. The latent period of contraction was increased, and the phases of shortening and relaxation were irregular. The muscles were easily fatigued, and soon passed into tetany. No reaction of degeneration could be made out.

APRIL 28.

Sensitiveness to pain had returned.

MAY 2.

Some improvement had occurred. The dog could walk without much trouble. The foot-drop was still present and the knee-jerk absent. There was no reaction of degeneration.

MAY 25.

As far as could be determined no trace of the effects of the anemia was left. The electrical reactions were normal.

MAY 27.

Condition the same. Under ether anesthesia the adductor magnus muscle and part of the sciatic nerve were removed. The gross examination failed to show any changes.

MICROSCOPICAL EXAMINATION.—There was considerable interstitial hemorrhage and round-cell infiltration. In places the cross-striations did not show plainly, while in others they were distinct. Variable degrees of fragmentation were present. There was a great increase in the number of nuclei, and their position was without relation to the long axes of the fibers. The blood vessels were greatly thickened, and some of them were almost occluded. No infarcts were found. The sciatic nerve had a thickened neurilemma. The individual fibers were less distinct than normal. As a whole the condition was that of recovery from a degree of anemia which had not been severe enough to cause permanent changes. Why this should be so, when such marked changes followed lesser intervals of anemia, is difficult to explain.

EXPERIMENT 43

APRIL 25, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A tourniquet was applied to the upper third of the right thigh for 16 hours. At the end of this time the dog was in good condition.

APRIL 26.

All of the muscles below the point of application of the tourniquet were paralyzed. The reflexes could not be obtained, sensitiveness to pain was delayed, if not entirely absent, and the reaction to the faradic current was less than in the normal leg. The reaction to the galvanic current was nominal.

APRIL 27.

The condition was about the same in the leg. The general condition was excellent.

MAY 3.

There was slight improvement. The response to the faradic current was greater, as well as sensitiveness to pain.

MAY 5.

Slight voluntary muscular movement was present. The knee-jerk could not be elicited.

MAY 8.

Voluntary control had continued to return, the flexors of the paw showing the least improvement.

MAY 15.

The knee-jerk had partially returned. The electrical reactions were normal. On walking the dog dragged the limb.

MAY 25.

Since the last note there had not been much improvement in the paralysis, the condition seeming to be at a standstill.

JUNE 1.

Very slight improvement had occurred.

JUNE 10.

There was still marked paralysis present. The knee jerk was present, but it was very sluggish. The electrical reactions were normal. The dog was chloroformed, and the adductor magnus muscle and part of the sciatic nerve removed.

MICROSCOPICAL EXAMINATION.—The muscles were generally atrophied with almost complete loss of the cross-striation. Fragmentation was extreme, and the fibrillæ were all but destroyed. Throughout the section there were many cells containing large granular nuclei. The latter were indefinitely arranged. In many places the infiltration of leukocytes had been very great, and in some areas there was pigmentation, resulting from interstitial hemorrhages. In other areas numerous infarcts were found, with necrosis surrounding them. There did not seem to be the proliferation of the fixed cells that would be expected. The sarcolemma was everywhere thickened, and, in some areas, so much so that the muscle fibers were practically obliterated. As a whole the sections seemed to show that regeneration had not had time to start, and that general atrophy alone had taken place.

The Results Obtained by Causing Anemia of the Hind Leg of Dogs for Varied Durations of Time

Exp. No.	Duration of Anemia	Foot-drop	Knee-Jerk	Reaction of Degeneration.	Sensory Paral.	Late Results
1	1 hours	No	Yes	No	No	Recovery
2	2 hours	No	Yes	No	No	Recovery
3	2 1/4 hours	No	Yes	No	No	Recovery
4	2 1/2 hours	No	Yes	No	No	Recovery
5	2 1/2 hours	Occasional	Yes	No	No	Recovery
6	2 3/4 hours	Slight	Yes	No	No	Recovery
7	3 hours	Complete	No	No	Slight	Recovery
8	3 hours	No	Yes	No	No	Recovery
9	3 hours	Yes	Yes	No	No	Recovery
10	3 hours	Marked	Yes	No	No	Recovery
11	4 hours	Complete	No	No	No	Recovery
12	4 hours	Marked	No	No	Yes	Recovery
13	5 hours	Marked	Diminished	No	.....	Death after 2 weeks from unknown cause
14	5 hours	Partial	.....	No	.....	Nearly well after 2 weeks, then killed
15	5 hours	.....	.....	.....	.....	Died during night—no microscopic changes
16	5 hours	Marked	No	No	Slight	Recovery
17	6 hours	.....	.....	.....	.....	Died during night—no microscopic changes
18	6 hours	Marked	No	No	Yes	Condition same after 8 days, dog killed
19	6 hours	.....	.....	.....	.....	Died during night; edema alone present
20	6 hours	Marked	No	No	.....	Death on 2nd day. Edema only change
21	6 hours	.....	.....	.....	.....	Death before tourniquet was removed. No microscopic changes
22	6 hours	Marked	No	No	Partial	Recovery of function
23	7 hours	.....	.....	.....	.....	Died during night—no microscopic changes
24	7 hours	Complete	No	No	.....	Almost complete recovery, 22 days, dog then killed
25	7 hours	.....	.....	.....	.....	Died during night—no microscopic changes

The Results Obtained by Causing Anemia of the Hind Leg of Dogs for Varied Durations of Time—(Continued)

Exp. No	Duration of Anemia	Foot-drop	Knee-jerk	Reaction of Degeneration	Sensory Paral.	Late Results
26	7 hours	Marked	No	Yes	Yes	Paralysis after 2 months—dog then killed
27	7 hours	Moderate	No	No	.....	Recovery, 20 days. Microscopic changes found
28	7 hours	Marked	No	No	Partial	Recovery after 1 month. Microscopic changes found
29	7½ hours	.....	.....	.....	.....	Death at 7½ hours. No microscopic changes
30	8 hours	.....	.....	.....	.....	Death at 8 hours. No microscopic changes
31	8 hours	Marked	No	No	Yes	Recovery after 1 month. Microscopic changes found
32	8 hours	Marked	No	Yes	Yes	Paralysis after 3 months
33	8¾ hours	.....	.....	.....	.....	Death at 8¾ hours. No microscopic changes found
34	8¾ hours	.....	.....	.....	.....	Death at about 18 hours. No microscopic changes found
35	9 hours	Marked	No	No	Partial	Death at about 48 hours. No microscopic changes
36	9 hours	Complete	No	Yes	Partial	Permanent paralysis
37	9 hours	Complete	No	No	Yes	Recovery with microscopic changes at 1 month
38	10 hours	Complete	No	No	Partial	Partial paralysis after 1½ months
39	10 hours	Complete	No	.....	Yes	Death at about 48 hours. Edema and hemorrhages in muscle
40	10 hours	Marked	No	Yes	Complete	Death at 2 months. Glycosuria for some days preceding. Paralysis complete
41	10 hours	.....	.....	.....	.....	Death at about 18 hours from pneumonia. No changes
42	10 hours	Marked	No	No	Yes	Apparent functional recovery at 1 month. Microscopic changes found
43	16 hours	Marked	No	No	Yes	Permanent paralysis

CONCLUSIONS.

1. Complete arrest of the circulation of an extremity for more than two hours is not wholly safe.

2. The longer the anemia beyond two hours the greater is the degree of temporary or permanent paralysis, and anemia of seven hours or more results in permanent paralysis.

3. Good functional recovery occurs sometimes, even though there may be a certain amount of destruction of muscle fibers. It has not been definitely ascertained whether paralysis followed by apparent functional recovery might not in the course of months be followed by further and permanent impairment of function.

CHAPTER IV

ANEMIA OF VOLUNTARY MUSCLES: CLINICAL OBSERVATIONS. OCCLUSION OF THE ABDOMINAL AORTA IN MAN

CLINICAL experience has shown that in the human being the abdominal aorta may be partly or wholly occluded by embolism, by thrombosis, by pressure, or, in case of operative necessity, by ligation, but whatever its cause, the occurrence of this condition is rare. It is of interest, however, on account of the interference with the blood supply of the lower extremities and the variety of tissues affected and the difficulty of establishing collateral circulation which can efficiently take the place of the largest blood vessel in the body.

In the absence of personal clinical experience, and in order to base this study as directly as possible on observed facts, fifty cases of obstruction of the abdominal aorta were collected at random from the literature of the subject. No attempt was made to include every reported case; Welch alone had collected 59 up to the year 1899. The list includes only cases reported after 1850. There were 36 of probable embolism, 5 of thrombosis, and 9 of ligation. (For the technical problems of ligation the reader is referred particularly to the article by W. W. Keen.) In the following pages, unless it is specifically mentioned that the 9 cases of ligation were included, reference is made only to the cases of embolism and thrombosis.

In regard to the influence of sex and age upon the occurrence of obstruction of the abdominal aorta by embolism or

by thrombosis, it was found that in 40 cases there were 21 females and 19 males, and that most of the cases fell between the ages of 20 and 60 years, the minimum age being 19 and the maximum 64 years. The exact age distribution by decades is shown in the following table :

Age Grouping by Decades

10-19 years	1 case.
20-29 years	8 cases.
30-39 years	8 cases.
40-49 years	10 cases.
50-59 years	8 cases.
60-69 years	2 cases.
Age not stated	3 cases.
<hr/>	
	40 cases.

Infection of one kind or another is the primary cause of almost all cases of embolism or thrombosis of the abdominal aorta—acute articular rheumatism and erysipelas being the principal definite causes, next to arteriosclerosis, and the rather indefinite infections following childbirth. As would be expected the secondary cause—almost without exception—is found in the effect of these infections upon the endothelium of the heart and of the aorta itself. In one of Duncan's cases death occurred between 3 and 4 days after the onset of embolism, which began 5 days after a childbirth. At the autopsy the heart was found to be "perfectly normal" (from Hervieux). If no abnormality were overlooked, and infection may be ruled out, it is difficult to understand just how embolism resulting in gangrene of both legs could be brought about. The capillaries in the pulmonic circulation would prevent any coagulum from the venous sinuses of the uterus from

passing into the left side of the heart. With a normal heart it is very improbable that even a very acute infectious process would cause thrombosis in so short a time except possibly in the pulmonary veins—an occurrence which might have been overlooked by Duncan.

The only exception which was found to the general rule that obstruction of the abdominal aorta is of endovascular origin was in one of Bristowe's cases. In this case the aorta was completely obstructed at the level of the celiac axis by the pressure of a thoracic aneurysm which forced it against the vertebræ. Even here one would naturally conjecture whether the aortic stream might not have been first slowed by partial obstruction resulting from pressure by coagulum formation in the aneurysm, and the subsequent release of an embolism; the resultant backing-up of pressure forcing the aneurysm against the aorta with still more force to complete the pathologic circle.

Including the 5 cases of thrombosis there were 37 cases in which the endovascular obstruction had evidently occurred primarily at the bifurcation of the aorta. In some of these the coagulum extended a considerable distance above and below this point, filling the aorta as high even as the diaphragm above and extending for a greater or less distance into its ramifications below. In Pozzi's thrombosis case the artery was said to have been filled throughout its entire extent even down to the feet in the lower branches.

In 2 cases the point of obstruction was at the level of the celiac axis. One was the above-mentioned case of Bristowe's. In the other, also one of Bristowe's cases, and one in which a thoracic aneurysm was present, it was not stated whether the obstruction was localized or whether a coagulum had extended up from the bifurcation as a sequence to the lodgment of an embolism from the aneurysmal sac. Finally, in a third case of

Bristowe's, there was obstruction at the level of the superior mesenteric artery, an aneurysm of the thoracic aorta being present, and also a second aneurysm, the size of a filbert, at the opening of the superior mesenteric artery. The latter may have been caused by the backing-up of pressure after obstruction of the aorta rather than have been simultaneously present with the other aneurysm.

In the 40 cases of obstruction not included in the 9 ligation cases and the above cases of Bristowe's, the associated conditions were as follows: cardiac disease, 30; aortitis, 4; aneurysm, 3; syphilis (no more definite statement made), 1; postoperative volvulus (thrombosis case), 1; subsequent to childbirth, heart normal, 1.

Among the 30 cardiac cases the distribution according to the most important lesion was as follows: endocarditis with mitral stenosis, 13; endocarditis without mitral stenosis, 14; cardiac cases with indefinite diagnosis, 3. According to these figures mitral stenosis apparently has not played as important a part as has been ascribed to it by other observers, although this lesion is present frequently.

In regard to the 13 cases of *endocarditis with mitral stenosis* the underlying infectious process was not stated in so many cases that the details of the exceptions are not worth recording. Among the 14 cases of *endocarditis without mitral stenosis* there were 5 postpuerperal cases, 3 with acute articular rheumatism, 2 with erysipelas, 1 with pneumonia, 1 with typhus, and 2 in which the associated condition was not stated.

In the great majority of the cardiac cases the observation that emboli have started from some portion of the left heart is confirmed by finding on the auricular or ventricular wall (much more commonly the former) a portion of an old thrombus, or the place from which a thrombus has become detached.

Doubtless in the cases of mitral stenosis the partial obstruction of the flow through the mitral valve favors clotting in the left auricle. In some cases the presence of a thrombus on the wall of the auricle led to the formation of a cup-shaped pocket into which it was possible in a few instances to fit the embolus taken post mortem from its lodging place at the bifurcation in the aorta. In other cases microscopic comparison of the embolus and of the coagulum remaining in the left side of the heart has shown identity of structure.

It is of considerable significance that embolism of the abdominal aorta may be associated with multiple emboli of other vessels, particularly those of the kidneys and spleen (see Meynard, Tutschek, Barić and du Castel, and others). In one case the splenic artery was obliterated by an embolus, in another three of the lumbar arteries, while Lauenstein in one of his cases found areas of softening in the cerebrum. From the standpoint of operative interference the occurrence of such emboli might in itself be prohibitive.

The cardinal symptoms of embolism of the abdominal aorta are as follows: (1) sudden severe pain in the legs, (2) sudden paraplegia, and (3) general collapse. From the clinical histories of the above-mentioned cases it seems improbable that embolism ever occurs without pain, and it is certainly difficult to believe that it could occur in a stream of the size and force of that in the aorta without immediate symptoms indicating its onset. In partial confirmation of this is the fact that out of 41 cases studied the onset of symptoms in 29 was sudden, while in 8 only was it late, and in 4 cases no statement regarding the time of onset is made. Included among the 8 cases with slow onset were 5 cases of thrombosis; a case diagnosed as embolism, although there was reasonable doubt as to whether it might not have been thrombosis with final sudden obstruction; and another in which the abdominal

pain was sudden but the leg symptoms were slow in developing, thus suggesting embolism with only partial obstruction at first; and, finally, a case in which the symptoms of gangrene were delayed considerably in their appearance. It seems probable that where the onset of symptoms is delayed in cases which are clearly not thrombotic in character there is incomplete obstruction, even if it be temporary only. It stands to reason that the force of the heart-beat would tend to hammer an embolus farther and farther into the inadequate path—at least until development of the collateral circulation could relieve part of the pressure.

In thrombosis the symptoms most frequently follow arteriosclerotic changes in the aortic wall. They may start so slowly that it is impossible to say at exactly what time they began; they may develop more or less slowly, and yet, at the critical moment, the completion of the obstruction may cause onset to seem to be sudden after all. In either embolism or thrombosis the relation of the obstruction to the openings of the renal arteries is important. These are more likely to be occluded in the latter than in the former.

In regard to the character of the pain, it may be agonizing, may cause the patient to fall to the ground as from a knife thrust, and, while usually in the legs, may be in the lumbar region or the abdomen. The pain, as with all the other symptoms of this affliction, doubtless varies considerably with the completeness of the obstruction of the aorta. If the obstruction be limited to the immediate vicinity of the bifurcation it hardly seems as if it could be connected with anemia of the spinal cord, but rather as if it were caused by local hyperemia and pressure in the extremities, such as is produced when a tourniquet is applied too tightly. With a high obstruction the spinal arteries would be involved in proportion to its extent. With incomplete obstruction paresthesias of different

varieties may be the forerunners of pain, or would probably be present later in case the collateral circulation should be partially established. Occasionally the pain may be spasmodic in nature. Pain was stated to have been present at some time in the course of the affliction in 32 out of 50 cases studied (ligation cases included), and no statement either way was made about the remaining 18 cases.

In regard to paralytic changes in the legs the problem rests on the fundamental law of anemia that the disturbance varies directly with the degree of anemia and its duration. All degrees of disturbance may be found at some time or other, from moderate paresthesia up to complete sensory and motor paralysis. Including the ligation cases, out of the 39 cases in which statements were made as to motor paralysis of greater or less degree, in 36 it was present and in 3 absent. In 37 cases sensory paralysis of greater or less degree was present and in 3 absent. Coldness of the legs was present in 34 cases and absent in one. Various observers took the temperature of the legs, finding in some cases as low a temperature as 20.0° C. In 29 cases pallor of the legs was present, and in no case was it stated to have been absent. In 17 cases mottling was present, no statement being made as to the remainder.

The presence of gangrene was noted in one or both legs in 31 cases, was stated to have been absent in 13, and was not recorded in 6. Out of the 31 cases it was present in both legs in 26 and in only one in 5. When present in both legs usually the extent was different in each. No attempt was made to record the exact variation in this regard. Occasionally the gangrene progressed above the legs before death occurred. For example, in Price's case by the eleventh day the right leg was cold, by the 13th mottling was present, by the 15th the left leg was affected in the same way and later the gangrene spread up the abdomen to the umbilicus, and the left

forearm also was gangrenous, probably from embolism. At the autopsy the wall of the bladder was found to be black and gangrenous looking, and the uterine cavity was black. In another case there was gangrene up to the gluteal region.

The following summary is drawn from the few cases in which statements were made regarding the appearance of definite signs of gangrene (the final outcome of anemia) in its relation to the onset of the symptoms; the time from the onset of the symptoms to death, and the time from the onset of the gangrene to death:

TIME ELAPSING BETWEEN			
A. Onset of Symptoms and		B. Onset of Gangrene	
(1) Gangrene;	(2) Death.	and Death.	
1. 23 days.	27 days.	4 days.	
2. 16 "	48 "	32 "	
3. 14 "	30 "	16 "	
4. 13 "	15 "	2 "	
5. 8 "	39 "	31 "	
6. 7 "	11 "	4 "	
7. 6 "	19 "	13 "	
8. 6 "	46 "	40 "	
9. 5 "	22 "	17 "	
10. 5 "	9 "	4 "	
11. 3 "	43 "	40 "	
12. ¹ 1½ "	1½ "	—	
13. ¹ 1½ "	1½ "	—	
14. ¹ 1½ "	1½ "	—	

These figures are too few to average, but it will be noted that in 10 out of 14 cases gangrene developed in 8 days or less.

Observations of the pulsation of the femoral arteries showed that in 32 out of 33 cases pulsation was absent. In

¹ These figures are included because the gangrene developed in this length of time or less. In Case 12 it was stated that "both legs were black for some hours before the fatal result" so that apparently well-marked gangrene developed in a very short time after the onset.

the case which was the apparent exception the pulsation was very feeble, and the patient died in 12 hours. As in other cases in which there was a feeble pulsation at first, which soon ceased, it is probable that in this case the pulsation would have ceased altogether if the patient had lived longer. In 11 cases in which a statement was made the dorsalis pedis arteries were pulseless.

In regard to edema of the legs, it was said to have been present in 5 cases, absent in 2, while no statement was made in 43. The knee-jerks were said to have been absent in 6 cases, and in no case present, no statement regarding knee-jerk being made in the remainder of the cases studied. In 2 cases the cremasteric reflex was said to have been absent.

As to the third general cardinal symptom of collapse, a great variation in manifestations was found. Usually there were extreme prostration, with or without fever, dyspnea, rapid, weak, irregular pulse, with finally delirium, coma, and death. In 10 cases statements regarding incontinence of urine and feces were positive in 9 and negative in 1. It is unfortunate that more observations were not made on this point. Quite often serious bedsores developed. In 6 cases sweating was present, this being not only characteristic of profound collapse, but probably indicative also of the temporarily greatly increased blood-pressure in the upper part of the body. In 8 cases mention is made of the presence of red blood corpuscles in the urine, and in 5 more of their absence. On account of the often-associated cardiovascular conditions, the albumin also present in the urine was of little consequence. Hiccough was present in 3 cases, but little significance can be attached to it. With the presence of gangrene, particularly when moist, the terminal symptoms of profound toxemia or sapremia were characteristic of gangrene of the extremities due to any cause.

In regard to the diagnosis of obstruction of the abdominal aorta little need be said. A typical case should be recognized quickly, and a large majority of cases will be of embolic origin. As Blumer states in Osler's "Modern Medicine," some of the more chronic cases at some stages might suggest Raynaud's disease, but careful consideration of the symptoms should enable the latter to be ruled out. The same may be said of acute myelitis. Cases of asymmetrical gangrene can usually be traced so readily to their individual etiologic origin, and gangrene of one extremity so rarely occurs in obstruction of the aorta, that here again it would be unusual to meet with difficulties in diagnosis.

The prognosis in cases of obstruction of the abdominal aorta is practically hopeless. Primarily it rests on the establishment of collateral circulation. There have been enough cases to indicate that a collateral circulation consistent with life can be established. Keen had a remarkable case in which the patient lived for 48 days after ligation. No gangrene developed, and at the autopsy a large amount of blood was found in the abdomen, the ligature around the aorta having cut through. Before 1850 Monteiro had a case in which the patient survived ten days and twenty hours, death in this case also occurring from the cutting through of the ligature. A patient of Tillaux's survived 39 days, but it was found that the aorta was not completely occluded.

While the following remarkable case of Sir William Gull's did not come to autopsy the lack of doubt as to the diagnosis of obstruction makes it well worth recording in detail in the observer's own words:

"J. B., æt. 34, employed as a shipwright in the dockyard at Woolwich. Habits temperate. Accustomed to take part in carrying heavy loads; and, being over six feet in height, the greatest share of the weight often falls to him. At the beginning of March, 1855, being

then, as he supposed, in good health, he was *suddenly seized* (author's italics), while at work in a stooping posture, with pain round the loins. This went off after he had rested a few minutes. With the pain he had a desire to go to stool, but without effect. As he resumed his work the pain returned, and extended down the legs, with a sense of numbness, soon followed by entire paralysis, both of sensation and motion, from the loins downward. The sphincters were paralyzed. After a few days sensation returned, and he was able to take a few steps unsupported. He gradually improved, but the gait remained unsteady, and the use of the legs soon brought on increased weakness and numbness. For these paraplegic symptoms he was admitted, under my care, into Guy's Hospital, in June of the same year. On examining the spine no tenderness nor irregularity could be detected, but on auscultation a soft, bellows murmur was audible down the back, but most distinctly at the lower angle of the scapula, on the left side. There was no pain or tenderness at the part, nor any pain in the course of the intercostal nerves. Percussion elicited slight dulness where the murmur was most audible. Anteriorly, under the ensiform cartilage and lower third of the sternum, there was a prolonged bellows murmur, not heard so distinctly upward in the course of the aorta, or toward the left axilla. There was no pulsation in the abdominal aorta, nor in the arteries of the lower extremities. The legs were cold, the muscles wasted; no edema nor any venous turgescence in them. The superior epigastric artery, on the right side, was enlarged, and could be distinctly seen pulsating for two inches of its length, the blood running from above downward. From that date until the present time (August, 1857) the case has remained under notice. The superficial arteries of the back and abdomen have gradually enlarged. A few of the principal branches seen by the artist, as the patient sat before him, are shown in the sketches * * * These give, however, but a feeble idea of the extent of the arterial anastomosis as it can be traced by the finger under the integuments. At the posterior boundary of the axilla, on either side, the small arteries are so numerous as to form a soft pulsating mass, reminding one of the rich arterial plexuses in the intercostal spaces of the cetacea. The enlarged arteries on the back emerge at the fourth and fifth intercostal spaces, and dip again at the ninth. The anastomosis is much more extensive on the back and sides of the trunk than on the abdominal walls. From time to time he has slight returns of weakness and numbness in the legs. *No pulsation is yet discoverable in the aorta or femoral arteries, nor in any of their branches* (author's italics). The systolic murmur at the lower third

of the sternum remains. The chief part of the murmur now heard in the back is apparently referable to the rush of blood along the numerous subcutaneous channels of anastomosis. The patient has regained power to walk tolerably well, but his muscles are thin and his gait languid. Feet cold and damp. His general health is good, and he is able to do the lighter parts of his work. The pulsation of the arteries of the upper extremities is full and throbbing, and the heart's impulse increased. There is no sign of venous obstruction."

The typical symptoms of obstruction of the abdominal aorta were present in this case, and that the obstruction was complete seems probable from the fact that no pulsation was discoverable in the aorta itself or in the femoral arteries or their branches after as long a period as two years and four months, the later history being unknown. There is no doubt but that the collateral circulation was sufficiently established to maintain life. Whether it was a case of embolism or of thrombosis is of little consequence, although from the sudden onset the former is suggested, the source being probably an aneurysm.

In the 50 cases used in the author's study the mortality was 100 per cent. As a general rule, it may be stated that patients with thrombosis survive much longer than those with embolism. It should be remembered in connection with the former, however, that the onset is insidious, and that symptoms sufficiently pronounced to suggest the diagnosis may appear and persist for a long time when only partial obstruction is present. The duration from onset to death in all the 50 cases was as follows:

<i>Duration from Onset to Death</i>	<i>Number of Patients</i>
210 days.	1 ¹
180 "	1 ²
75 "	1 ³
60 "	1 ⁴
48 "	2 ⁵
46 "	1 ⁶

NOTE.—See footnotes on following page.

<i>Duration from Onset to Death</i>	<i>Number of Patients</i>
45 days.	1 ¹
39 "	1 ⁸
33 "	1 ⁹
30 "	2 ¹⁰
27 "	1 ¹¹
22 "	1 ¹²
21 "	1
19 "	1
15 "	1
11 "	1
9 "	1
7 "	2
4 "	1
3½ "	1
3 "	4
2¾ "	1
2 "	1
1½ "	3
1⅛ "	1
1⅙ "	1
1 ⅓ "	1
1 day.	3
12 hours.	6 ¹³
10 "	1
Not stated.	5
	<hr/> 50

¹Thrombosis.—One leg only was gangrenous. ²Thrombosis.—Both legs gangrenous, one after the other. ³Embolism, but with one leg affected temporarily only. ⁴The case was probably one of primary embolism, with complete obstruction, followed by thrombosis. Gangrene was present, but whether both legs were affected was not stated. ⁵One of these was a ligation case, with establishment of the collateral circulation (Keen), the other an unusual case as regards duration with both legs amputated for gangrene. ⁶One leg only gangrenous. ⁷Embolism, both legs. ⁸Embolism, both legs gangrenous. Was very extensive, gluteal region affected. ⁹No gangrene. Collateral circulation established. Autopsy. ¹⁰Embolism, with beginning gangrene of left leg. ¹¹Embolism, gangrene did not begin until twenty-third day. ¹²Embolism. ¹³Two of the cases of thrombosis are included among these 5 cases.

The duration from onset to death in the ligation cases only is given in the following table:

<i>Author</i>	<i>Duration from Ligation to Death</i>
1. Keen.	48 days.
2. Morris (ligation for 27 hours).	3 "
3. Watson.	2 $\frac{3}{4}$ "
4. South.	2 "
5. Czerny.	1 $\frac{1}{8}$ "
6. Milton.	1 "
7. Stokes.	12 hours.
8. McGuire.	12 "
9. Czerny.	10 "

It is seen from the above table that death usually occurred soon after ligation. The operative factors would doubtless greatly augment the seriousness of the procedure, to say nothing of the underlying conditions for which the ligation was performed.

The only possible treatment for obstruction of the abdominal aorta must be through surgical intervention immediately after the sudden onset of definite symptoms, but aside from general considerations, the technical details furnish insuperable obstacles in many ways. In the absence of harmful multiple emboli it might be conceived that the operation could be carried through by temporary closure of the aorta just below the level of the inferior mesenteric artery, by then opening the vessel and gently withdrawing the embolus. If the embolus were found to extend up above the level of temporary ligation the clamp could be temporarily partially released in the hope that the blood stream would wash it down, care being taken to prevent it from getting below the bifurcation. This would be possible only under absolute control of the hemostasis, and with a much calcified aorta such control would probably be

impossible. On the other hand, if it were doubtful whether all clot below the bifurcation had been removed there might be a possibility of removing it all, or most of it, by introducing a tube of suitable size into the lower part of the aorta and aspirating vigorously with or without the preliminary introduction of a small stream of normal saline solution to assist in dislodging the clot. An ordinary aspirating set with a glass tube of suitable size with tapered end, could be easily procured for such an attempt. After removal of the clot one of the most difficult parts of the technique would remain—sewing up the aorta with sufficient accuracy to prevent leakage, and with sufficient strength to prevent tearing out of the sutures. The author would attempt to introduce very closely placed fine sutures, according to Carrel's method of closing such a blood vessel, and would then reinforce them with much larger sutures not passing through the intima. In the meantime the blood-pressure should be held at as low an ebb as possible by means of sodium nitrite in maximum dosage. By a most happy combination of fortunate circumstances, it is conceivable that life could be saved by this method.

CHAPTER V

ANEMIA OF VOLUNTARY MUSCLES: CLINICAL OBSERVATIONS. ANEMIA OF THE LOWER EXTREMITIES IN MAN THROUGH LIGATION OF THE MAIN ARTERIAL TRUNKS

In making an extensive study of ligation of the main arterial trunks of the lower extremities it was rather surprising to note how little of consequence was to be found in the literature of the subject in regard to the changes due to anemia which fall short of gangrene—for example, muscular atrophy and nerve degenerations, with accompanying disturbances of locomotion and sensation. Apparently the patients either had gangrene or entirely recovered, no middle ground ever being recorded. This may be interpreted in one of two ways: either the observations were not made with sufficient care, or else such changes did not occur. In certain cases in which recovery took place the usual temporary coldness and pallor of the extremity were reported, but no more disturbance was seen than might commonly be found. Opinion, therefore, must incline toward the view that final functional restoration was complete. Depriving parenchymatous organs, for instance the thyroid gland, of part of their blood supply leads to permanent diminution in the functional capacity without gangrene, but with increase in the connective tissue elements, but no similar condition seems to occur when the same thing is done to the extremities.

Many factors may complicate the problem of ligation of the iliac or femoral arteries besides that of the establishment of collateral circulation. The age of the patient

may have an important influence, the generally lowered resistance to shock and infection which accompanies arteriosclerosis, or the relative anemia of lowered blood-pressure from different causes, may predispose to gangrene. Then again an extremely important part is played by the condition for which the ligation is done. In a majority of all cases hemorrhage is present and not only endangers life directly, but indirectly, through diminishing the nutrition of the tissues and thereby predisposing them to gangrene. Moreover, with incised, punctured, or gunshot wounds, and with compound fracture there is usually infection of varying degree. Among the non-traumatic complications aneurysms, neoplasms, carious bone, and elephantiasis may be mentioned. The structure-obscuring swelling of infection or of traumatic aneurysm may add greatly to the difficulty of locating the arteries to be ligated, and cases are on record in which religation has been necessary, still more of the blood supply being thus cut off since the proper vessel could not be distinguished. Abnormalities of the vessels themselves may lead to ineffectual ligation, to unexpected hemorrhage, or to the shutting off of valuable collateral trunks. Finally, unless both ends of a severed artery can be secured, tying the central end alone may give temporary cessation of hemorrhage, but subsequent serious hemorrhage may occur through the collateral vessels with the sacrifice of still more of the blood supply if the peripheral end cannot be reached.

Factors Entering into Ligation of the Femoral Artery and Its Branches

- I. Age of the Patient.
 - A. Arteriosclerosis.
 - B. Weakened heart action.
 - a. Slowing of the blood stream.
 - b. Relative anemia.
 - C. General lowered resistance to shock, infection, etc.

2. Nature of the Reason for Ligating.
 - A. Traumatism.
 - a. Incised wounds.
 - b. Punctured wounds.
 - c. Gunshot wounds.
 - d. Fractures.
 - (1) Compound.
 - (2) Simple.
 - B. Non-traumatic cases.
 - a. Aneurysm.
 - b. Neoplasm.
 - c. Removal of carious bone.
 - d. Elephantiasis.
3. Infection (One of the Most Important Complicating Factors).
 - A. Difficulty in ascertaining landmarks on account of swelling, pus-formation.
 - B. Difficulty in tying off vessels.
 - C. Necrosis of vessel wall after ligation, necessitating re-ligation.
4. Abnormal Variations in the Arteries.

From the foregoing alone it is easily seen how difficult it is to predict what will happen when a given artery is ligated. In the following pages, in using cases from different sources in the literature, it has seemed best to confine the attention almost wholly to the frequency of occurrence of gangrene and the time of its appearance in relation to the operation. Only cases later than 1850 have been used.

I. LIGATION OF THE COMMON ILIAC ARTERY

Dreist has published the most complete compilation of cases of ligation of the common iliac artery, his series amounting to 78 in all. Among these cases there were 13 in which gangrene developed. Gillette adds two cases to those gathered by Dreist, one from the *British Medical Journal*, and the other a case of his own. In the 80 cases, as

analyzed by Gillette, gangrene occurred altogether 14 times, or in 17.5 per cent. Before the antiseptic era the mortality was 77 per cent. Since 1880 the mortality has fallen to 33 per cent. The occurrence of gangrene, therefore, is not necessarily an index of the death rate. Fortunately, the necessity for performing this dangerous operation does not often arise.

II. LIGATION OF THE EXTERNAL ILIAC ARTERY

One hundred and thirty-five cases of ligation of the external iliac artery were tabulated at random from the literature. Among these gangrene was stated to have occurred 16 times, or in 11 per cent. In 4 of the 16 cases the external iliac was not the only artery ligated, so that there was additional interference with the blood supply. Gangrene was associated with ligation for spontaneous aneurysm 6 times, for gunshot injuries 5 times, for traumatic aneurysm 3 times, and in the remaining 2 cases the associated condition was not stated.

In only a few cases were definite statements made as to the duration of time between the ligation and the appearance of gangrene. In the cases in which the external iliac artery alone was ligated gangrene appeared as follows:

In case 1—after 25 days.

In case 2—after 11 days.

In case 3—after 3 days.

In case 4—after 1 day.

In the 4 cases in which more than the external iliac was ligated gangrene appeared in all four on the third day after ligation. In 3 other cases in which gangrene was stated to have occurred, but in which no statement was made as to the exact time of its appearance, death occurred on the 7th, 5th,

and 4th days respectively. In these cases, therefore, gangrene had developed in less than a week.

Death terminated all but one of the 16 cases with gangrene. The patient that survived had his leg amputated. While gangrene must have played a serious part among the lethal elements, too much stress should not be laid on it in the presence of hemorrhage, sepsis, and shock.

As showing the possibilities of ligation of this vessel the following remarkable case is of interest:

Moschowitz reports what he considers to be the only case on record in which *simultaneous* ligation of both external iliac arteries has ever even been attempted. The double ligation was done for hemorrhage following bilateral ureterolithotomy in a man 36 years of age. All pulsation ceased below the points of ligation, both lower extremities becoming blanched. On the evening of the same day "the toes were warm, of a delicate pink hue, and capable of slight active motion. On the following day slight femoral pulsation was to be felt, and on the third day an occasional flutter was noted in the dorsalis pedis artery." In spite of the critical nature of all of the surgical procedures and the formidable loss of blood, complete recovery took place.

III. LIGATION OF THE COMMON FEMORAL ARTERY

One hundred and fifty cases of ligation of the common femoral artery were tabulated. In regard to etiology, the ratio of males to females was as 7 to 2, doubtless because women are more protected than men from traumatic injury; the youngest patient was 10 years old and the oldest 78 years; grouping the cases by decades clearly showed that most cases occurred in the most active periods of life. Traumatism and resulting hemorrhage were in almost all cases the direct causative factors necessitating ligation.

In 29 cases, practically 20 per cent, gangrene of the leg of greater or less extent was present. In 11 out of the 150 cases the continuity of the femoral vein was interrupted either by traumatism or by simultaneous ligation with the artery. In only 2 of these 11 cases did gangrene develop definitely, while in a third it showed signs of developing, but recovery took place. Therefore, as would be expected from the presence of the free venous anastomoses of the leg, it is not apparent that ligation of the femoral vein in addition to ligation of the femoral artery makes the development of gangrene more imminent.

Among the 29 cases in which gangrene occurred there were 25 of traumatic and 4 of non-traumatic origin. Among the former the associated conditions were: gunshot injury, 10 times; hemorrhage after operation for malignancy, 5 times; traumatic aneurysm, 3 times; fracture of femur, 1 time; and cases with the nature of the traumatism not stated, 6 times. Among the 4 non-traumatic cases 3 were associated with spontaneous aneurysm, and 1 with elephantiasis.

When it comes to statements of the exact time of appearance of gangrene after ligation the figures, as a whole, are disappointing. Some assistance is obtained from the fact that gangrene was said to have been present and that death occurred at such and such a time after ligation, so that we know at least the time before which gangrene must have occurred. The definite and the inclusive figures are shown in the following tables:

Definite Statements

<i>Case No.</i>	<i>Time of Appearance of Gangrene</i>
1.	77 days.
2.	14 days.
3.	12 days.

<i>Case No.</i>	<i>Time of Appearance of Gangrene</i>
4.	6 days.
5.	5 days.
6.	2 days.
7.	2 days.
8.	2 days.

Inclusive Statements

<i>Case No.</i>	<i>Time Before Which Gangrene Occurred</i>
1.	25 days, death.
2.	19 days, death.
3.	17 days, recovery after amputation.
4.	7 days, death.
5.	4 days, death.
6.	4 days, death.
7.	4 days, death.
8.	3 days, death.
9.	3 days, death.
10.	3 days, death.
11.	2 days, death.

From both of the foregoing tables it is seen readily that gangrene occurred in 13 out of 19 cases in a week or less, the average being 3.6 days. Between 2 and 3 days would probably be a more correct figure when the inexactness of the second table is considered. In the 77-day case in Table I the question arises as to how much part was played by other changes besides the ligation, as the patient was 64 years old and had a spontaneous aneurysm.

The mortality among the 29 cases in which gangrene occurred was very high, all but 2 of the patients dying. In the 2 recovery cases amputation was done. While a few of the

fatal cases were complicated by amputation, it is probable that this hastened the termination but little. In many of the cases the loss of blood was great.

IV. LIGATION OF THE EXTERNAL FEMORAL ARTERY

In the 289 cases of ligation of the external femoral artery studied by the author due acknowledgment is made to Rabe for many cases borrowed from his compilation.

Among the 289 cases there were 44 in which gangrene occurred, or practically 15 per cent. Of the 44 cases 25 were of traumatic origin. Among these the associated conditions were: gunshot injury, 8; post-operative hemorrhage, 6; traumatic aneurysm, 4; fractures (1 compound, 1 nature not stated), 2; and cases in which the nature of the traumatism was not stated, 5. On comparing this list with the one given under ligation of the common femoral artery it will be noted that the sequence is identical from gunshot injury, as the most frequent associated traumatic condition, to fractures, as the least frequent. Among the 19 non-traumatic cases the associated condition was spontaneous aneurysm, 16; false aneurysm, 2; and elephantiasis, 1.

In regard to the duration of time between ligation and the appearance of gangrene it must again be said that the figures are disappointing, although the time is given more often than in other groups of cases. As before, the definite and the inclusive figures are shown in the following tables:

Definite Statements

<i>Case No.</i>	<i>Time of Appearance of Gangrene</i>
1.	21 days.
2.	21 days.
3.	18 days.

<i>Case No.</i>	<i>Time of Appearance of Gangrene</i>
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4.	13 days.
5.	9 days.
6.	5 days.
7.	3 days.
8.	3 days.
9.	3 days.
10.	3 days.
11.	2 days.
12.	2 days.

Inclusive Statements

<i>Case No.</i>	<i>Time Before Which Gangrene Occurred</i>
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1.	20 days, death.
2.	20 days, death.
3.	19 days, death.
4.	14 days, death.
5.	11 days, death.
6.	11 days, death.
7.	9 days, death.
8.	8 days, death.
9.	1 day, death.

It is seen from both of the foregoing tables that in 8 out of 21 cases gangrene occurred in a week or less, the average time being 2.7 days. Here, too, the relative indefiniteness of the second table makes the average more or less inaccurate; at best it is but approximate.

After ligation of the external femoral, amputation played a greater part in reducing the mortality than after ligation of the common femoral. In all, there were 30 deaths and 14 recoveries. In 10 of the fatal cases the statement was made

that amputation was performed, while in the remaining 20 fatal cases no statement is made to the contrary. In 13 of the 14 recoveries it was stated that amputation was performed, while in the 14th case, in which gangrene of the toes was present, no statement regarding amputation was made.

V. GENERAL RECAPITULATION

From these studies the following table has been constructed:

<i>Vessel Ligated</i>	<i>Number of Cases</i>	<i>Percentage with Gangrene</i>
Common iliac artery.....	80 (Dreist, Gillette)	17.3
External iliac artery.....	135	11
Common femoral artery..	150	20
External femoral artery ..	289	15

Bearing in mind the limitations of the method followed in compiling these statistics it is seen that the occurrence of gangrene does not really depend in any great degree upon the vessel ligated. There is little doubt that cases operated on within the last decade would show a smaller percentage with gangrene, but even at the present time (through the very nature of the conditions for which ligation has to be done) certain dangers have not been eliminated and cannot be eliminated. The great hope of to-day lies not in the ability to prevent the occurrence of gangrene, but in its earlier recognition, in earlier amputation, in a better handling of the technical part of amputation, and in a greater understanding of the problem as a whole.

CHAPTER VI

ANEMIA OF VOLUNTARY MUSCLES: CLINICAL OBSERVATIONS. ISCHEMIC PARALYSIS

The comparative rarity of ischemic paralysis and of the paralysis of the legs following embolism of the abdominal aorta necessitates drawing on the literature of both of these subjects for adequate material.

The condition known as ischemic paralysis, or more commonly as Volkmann's, or the Volkmann-Leser contracture, is both practically and theoretically of considerable interest from the standpoint of surgical anemia. That there is practically unanimity of opinion that anemia is the primary cause of ischemic paralysis is apparent from reading the various accounts in the literature of the subject, but it is equally apparent that there is considerable difference of opinion as to whether secondary causes should be sought in case of injury to muscle or to nerve elements. It is impossible to say how much weight should be assigned to each etiologic factor, but in the following carefully selected cases it is shown that certain individual factors, which may or may not be combined in any given case, may have great influence in causing the paralysis.

1. Case in Which Pressure on the Muscles Apparently Played an Important Part

In this case, reported by H. L. Barnard, the patient was 3 years old, and had had both bones of the forearm broken.

In the previous treatment of the case anterior and posterior splints had been applied for an unstated length of time. The fact that sores were found on the forearm when the splints were adjusted three weeks after the accident would tend to show that undue pressure was used. No note was made as to whether the patient could or could not move her fingers at this time, but contracture began about one month after the accident. A typical case developed, which was improved by operation six months after the injury, tendon lengthening being done. The muscles exposed were "pale, firm, fibrous, and dry and very unlike the normal succulent vascular muscles of children," and, as no mention is made of particular involvement of nerve trunks by fibrous contractions, it is to be presumed that such involvement was absent and that the pressure on the muscles, and hence anemia, was the essential causative factor.

Many other cases of this sort are reported in which undue pressure on the muscles seemed pretty clearly to play a rôle in the cause of the physical changes. It seems probable, however, in certain of these cases, particularly in the older patients, that tight splints or other restraining apparatus were blamed unjustly. This point will be considered more fully under cases illustrating the effects produced by the injury of nerve trunks.

The consideration of the preceding typical case at once gives rise to the question as to whether or not anemia alone can cause muscular contracture. It is a well-known fact that ligation of a main artery of a limb causes either gangrene or recovery with restoration of function, and usually the latter. As has been said elsewhere in these pages, search through the literature gives little or no evidence of any conditions between the two extremes, apart from the class of cases now under consideration. If the case reports of ligation fail to show the

occurrence of contracture in any cases in which pressure, at least through bandaging, may not have been causative, it is necessary to look elsewhere for evidence. Fortunately such evidence seems to be present in very exceptional cases, in which embolism was followed by more or less muscular contracture. That these cases are very exceptional¹ is shown by the fact that many cases of embolism occur in which, as in the cases of ligation, there seems to be no middle ground—either restoration of function or gangrene occurs. Here again, however, lack of accurately detailed observation may be at fault. Experimental work by Lapinsky on rabbits in which he ligated arteries resulted only in flaccid paralysis without contractures.

2. *Case in Which Embolism of the Brachial Artery Was the Only Etiologic Factor*

This case of Langer's concerned a woman, 50 years of age, who had mitral stenosis and slight aortic insufficiency, and who had had a right-sided hemiplegia three years previously. She had entered the hospital for fever and cough which she had had for two weeks. On the second day after being admitted, and *immediately* after taking a warm bath, paresthesia of her left forearm occurred suddenly, *followed very shortly by paralysis, completely flaccid in character, rigor, and increasing cyanosis*. After seven hours, flexion of the hand and finger joints was noticed, which had increased after five hours more, with the development of flexion at the elbow joint. This muscular rigidity, similar to rigor mortis, disappeared in the course of the next few hours, and it was only in the following days that permanent flexion returned again

¹ Desplats and Baillet (Paralysie et névrite d'origine ischémique, *Arch. des mal. du cœur*, 1911, IV, 481-544) have recently reported a number of cases of this kind.

in consequence of reactive changes in the muscles. These reactive processes could be recognized clinically by hard swelling, spontaneous pain, and sensitiveness to pressure, subsequent atrophy, shrinking of the muscles, and permanent contracture. *No splints or other restraining apparatus causing pressure were used.* The muscles of the upper arm were much less affected than were those of the forearm and hand. About two and one-half months after the onset the muscles of the forearm were found to be diminished in volume, and felt thickened and tendonlike. In the elbow joint there was slight flexion, while the hand was bent at almost right angles to the arm, and a little toward the ulnar side. The fingers were slightly extended at the metacarpophalangeal joint. The thumb was pulled over into the palm. The balls of the thumb and little finger were hard and considerably reduced in size. The skin of the forearm was normal, that of the hand thinned, and that of the fingers shiny. On the palm of the hand, the ball of the thumb, and the dorsal surface of the thumb were numerous tender cicatrices. On the thumb and middle finger the nails had disappeared, on the small and index fingers rudiments of the nails were present, while the nail of the ring finger was better preserved. Active movements were very much restricted. Sensory disturbance was marked. The previously present edema had disappeared. A month and a half later there was some improvement in the sensory disturbance, but otherwise the condition was essentially the same.

Langer considers that the above case shows clearly that muscular contracture may follow anemia alone, and in a comparatively short time. As would be expected, there was a preliminary stage of contraction, probably functional in character, followed by a final stage in which permanent organic changes occurred. In the preliminary stage the contraction of course could not be attributed to traumatic injury of nerve

trunks or of individual fibers. On the other hand, the anemia was not complete or the ultimate destruction of the arm would have occurred, so that irritative or other changes in nerve endings at least could not have been caused by *complete* anemia. Therefore it would seem to be entirely possible that increased local pressure, or improperly aerated blood, might cause local nerve irritation, and hence tonic contracture—it not being necessary to have the nerve irritation go as far as the production of pain. Later there was time for “coagulation” of the muscle proteids to take place with loss of fluid, and resultant contracture, as many, if not all animal substances containing water in considerable amounts contract more or less forcibly on losing it, as gelatin, for example. Still later the increase in the connective tissue elements would add still more to the contraction, and eventually would make it permanent and irreparable. It seems hardly credible that anemia could cause *immediate* contracture of muscle cells without interference with the nerve supply. Whether the above explanation holds good for the very rare reported cases in which immediate contraction does occur can be determined only by further study, and it is already known from experimental study that nothing more than flaccid paralysis has been observed to follow shutting off the blood supply—spastic paralysis has not been observed. In Langer’s case it is very evident that the process did not stop so very short of gangrene—why, it is impossible to say. Why contracture should apparently happen so rarely may be due to the possibility that in certain cases of embolism there is actually present a preliminary stage of contracture, which may be slight and hence not noticed, and no advanced stage, either on account of complete establishment of the collateral circulation on the one hand, or of gangrene on the other. The mere fact that so many reported cases were due,

or were thought to have been due, to previous malpractice explains partly why comparatively little is known about the early happenings.

From the foregoing cases it is apparently shown that generalized pressure on the muscles may lead to contracture, and that anemia alone may do the same, even without the factor of existence of gross injury of the nerve trunks. This leads to the question as to whether peripheral nerve trunk injury alone can lead to contracture. To elucidate this point the following illustrations are given.

3A. A Case in Which Marked Muscular Contracture Followed Contusion of the Leg; Spontaneous Recovery

This case of Barbier's was not a case of ischemic paralysis. The patient was a male with an alcoholic history who was run over by a cab, the wheels of which passed over both his legs, the left leg in particular being affected. He was severely enough injured to be unable to return home unaided. That night he noticed that his left foot was drawn around into a position which did not change, and which, on his entering the hospital the next day, was found to be that of a talipes equinovarus. Whether this position came on immediately after the injury could not be ascertained. The extension and rotation of the foot were so pronounced that the astragalus was subluxated, its head making a marked projection in the side of the foot. The plantar arch was more concave than normal, and the toes were strongly extended on the body of the foot. The malposition was not absolutely fixed—from time to time the foot seemed to relax spontaneously or after excitation, returning immediately to its previous position by a series of jerks. Every attempt to replace the foot forcibly resulted only in intolerable pain. When the patient attempted to walk the

weight of the body rested on the point and outer side of the foot. There were no ecchymoses or traces of contusion under the skin of the leg, but over the head of the fibula sharp pain could be elicited on pressure, and there was a zone of anesthesia on the outer aspect of the leg. No evidence of fracture could be found. Under the tightly stretched skin over the head of the astragalus the presence of an irritated musculo-cutaneous nerve was proved. *The least contact with this nerve caused very sharp pain, and the contracture seemed to be more intense after each application.* The tibiotarsal articulation also seemed to be tender. It was then found that *electrical stimulation of the peroneal muscles caused the foot to rotate back practically to its normal position* but did not reduce the extension, the foot immediately returning to its malposition on stopping the stimulation. *Electrical stimulation with either galvanic or faradic current applied to the soleus and the anterior muscles of the lower leg failed to cause any reaction.* After the contracture had persisted for three weeks the patient was given chloroform. "À peine la période de résolution commence-t-elle que le pied, jusqu' à là maintenu en rigidité presque absolu, retombe inerte. La contracture a cessé brusquement, d'un seul coup. Les mouvements provoqués se font sans raideur aucune." At this time no evidence could be detected of fracture of the fibula. Restraining apparatus was tried twice—the first time for 18 days, and the second for about a month—and failed to relieve. The patient left the hospital and about two weeks later the contracture suddenly disappeared, two and one-half months after the accident.

There is no doubt that the contracture in the above case was due to functional disturbance, and not to permanent organic changes in muscles or nerves, because of (1) its disappearance immediately under general anesthesia, and (2) its eventual disappearance.

3B. *Case of Ischemic Contracture in Which Pressure Was Probably an Important Etiologic Factor but in Which Marked Relief Followed Freeing of Nerve Trunks from Pressure by Cicatricial Tissue*

In this case of Leonard Freeman's the patient was a female, 10 years of age, who had had both bones of her forearm broken. Splints had been applied for four weeks and a plaster of Paris cast for several weeks longer. Freeman found several pressure necrosis scars, and that the skin, which was cyanotic, drawn, and glazed, "was almost completely anesthetic." The fingers were strongly contracted, the muscles of the forearm indurated and paralyzed, and the hand useless. On operating the median nerve was found to be pinched by the cicatrized pronator radii teres, the ulnar nerve less so by the flexor carpi ulnaris, and the radial nerve slightly, if at all, involved. Above the points of compression the nerves were normal, below they were hardened and small. They were freed with the result that "steady improvement followed until, at the end of three months, during which time massage was employed, sensation and motion in the hand were almost complete and the circulatory and trophic disturbance had disappeared. . . . Three years after the operation the hand and arm were in nearly perfect condition, with no atrophy or induration of the muscles, with full motion of the fingers, and normal nerve function."

In the above case, in spite of the fact that undue pressure doubtless played an important part in causing the condition, there can be little doubt that part of the deformity, and probably a large part, was played by the compression of the nerve trunks. This is indicated by the very definite compression and by the persistence of the contracture until the compression was

removed and by the subsequent disappearance of the symptoms. The good ultimate results are in contrast with the comparatively poor ultimate results in two other cases reported by the same author, in both of which there was definite pinching of important nerve trunks. An explanation is readily found, however, in the fact that in these two cases operation was deferred until one and two and one-half years, respectively, after the injury, while in the above case it was done after "four weeks plus several weeks longer." As would be expected, the earlier the operation the less the permanent injury in such a case. J. J. Thomas, of Boston, in his compilation of 107 cases, reports 60 per cent. with nerve injury, and doubtless there was a larger percentage than that even on account of cases in which no report of nerve injury was made.

That a certain number of cases of ischemic paralysis and contracture give direct evidence that they do not stop far short of actual gangrene is shown by a certain number of the clinical reports. Thomas found 37 out of 107 cases in which "various trophic changes, such as coldness, cyanosis, shiny skin, ulcers on the fingers, or blebs, were present." That gangrene may actually occur following tight bandaging without contracture is shown by the following cases:

4A. Case in Which Bandaging for Uncomplicated Pott's Fracture Was Followed by Gangrene, Necessitating Amputation

The details of this case were kindly furnished in a personal communication from Dr. E. H. Season. The patient, a man about 40 years of age, was thrown from his horse while riding in the mountains of West Virginia and sustained a simple Pott's fracture. It was put up in the usual way, and the following night a great deal of pain occurred, the bandages

clearly being too tight. The bandages were not removed for forty-eight hours, when it was found that gangrene had begun to develop, which later necessitated amputation at the knee.

4B. Case in Which Beginning Gangrene of the Hand Followed Prolonged Application of a Tight Sleeve

This case, reported by Nevitt, concerned a boy, 3½ years of age, who had been restless and cross for several days, and complained of his hand, which had become swollen and painful. When first seen by Nevitt he found the "hand and forearm greatly swollen and of a mottled purplish color; the swollen parts felt quite cold; there was a spot about the size of a twenty-five-cent piece on the palm opposite the roots of the middle and ring fingers which had become quite gangrenous. On examination it was found that constriction was caused above the elbow by a rather tight sleeve, which, there is every reason to believe, had not been removed since the child had first complained of pain . . ." With the idea of relieving tension an incision was made in the palm. There was scarcely any bleeding, but a considerable quantity of blood-stained serum escaped. Hot linseed poultices were applied, and after nine days complete recovery of sensation had occurred and free movement of the fingers was possible.

Either one of the above two cases could conceivably have ended in contracture. The important question is, how many such cases have occurred, and, because they have gone as far as gangrene, have masked the condition of contracture, and, hence, have never been reported as such.

CONCLUSIONS

Clinically it is evident that ischemic contracture is most often due to the too tight application of splints or bandages; that anemia results from the pressure so induced; that what,

until we have a clearer understanding, we may call coagulation of the muscle proteids takes place; and that degeneration of the muscle elements occurs along with proliferation of the connective tissue elements. As has been shown in the cases cited above, anemia alone, nerve injury alone, or both in combination may cause muscular contractures, so that pressure is not an *essential factor, although usually present*. As in anemia of any part of the body, there is a certain time limit within which muscle and nerve elements may undergo *complete* anemia with complete recovery. There is a longer time during which these elements may undergo *partial* anemia with complete recovery. According to the observations of Stewart and others, the endings of the motor nerves are the first to succumb to any given degree of anemia, while the muscle fibers are more resistant.

As a corollary of the above statements it is evident that the less the degree of anemia the less the permanent injury to muscles and nerves; that causes of contracture and impairment of nerve function generally should not be necessarily ascribed to anemia alone (in fracture cases particularly nerve injuries should be sought for early and also late—they may be caused by trauma at first and by compression later), and that operative interference should be as early as possible. In children particularly the greatest care should be used to avoid undue pressure in treating fractures or any other injuries of the extremities.

CHAPTER VII

CLINICAL APPLICATIONS FROM THE FOUR PREVIOUS CHAPTERS. LOCAL GANGRENE FROM ANEMIA OF THE EXTERNAL SOFT PARTS OF THE BODY

Anemia from direct pressure occurs most commonly in the course of the treatment of fractures, in anesthetic parts following hemiplegia, in prolonged wasting illnesses of any kind (bedsores), in skin flaps under too great tension; as a result of cross lesions of the spinal cord, occasionally as a result of too long-continued saline infusion in unconscious patients (as, for example, in typhoid fever), of forgotten bandages or of tight-fitting rings, and of sutures too tightly tied. Again, local anemia may be due to interference with the arterial blood supply by the direct pressure of neoplasms on the vessels as well as by embolism, thrombosis, obliterating arteritis, and by nervous vascular contraction.

ERRORS IN THE TREATMENT OF FRACTURES

In the immediate treatment of simple fractures before swelling has taken place, despite almost universal warning against the practice, one still sees the application of padded splints over a bandage which is directly over the skin. In such a case if the patient is fortunate in reaching his physician before total gangrene of the soft parts has occurred, or if he has courage enough to remove the dressings himself, all will be well; but, on the other hand, after a period of intense pain may come the comforting anesthesia of gangrene, and when

next the limb is examined both patient and physician realize the disaster which has occurred.

As already indicated, the skin, the muscles, the tendons, and the bones vary in their resistance to anemia. Total anemia may be so timed that the muscles may die and the skin and the bones live. The bones, however, are in a position of advantage, as that part of their blood supply which is delivered through the medulla may escape the direct pressure of the constricting bandage. In other instances anemia kills all of the soft parts down to the bones and the patient is compelled to accept amputation as the only way out of his unmerited misfortune. Even if no bandage is applied directly over the skin, splints inadequately padded, or, if adequately padded, applied too tightly and for too long a time, may cause local death of tissue from anemia. Perhaps one group of muscles or only the prominent bony points may be involved. The points most commonly suffering from this cause are the heel, the malleoli, and the condyles. Of these minor points the heel causes the most trouble, the soft tissues usually sloughing down to the bone with sometimes death of the superficial part of the bone also. Repair in this dense tissue may be extremely tardy, especially when the bone is involved.

It is evident, therefore, that under no circumstances should a bandage be applied directly over the skin in the treatment of fractures; that all splints or restraining apparatus should be protected with an abundance of elastic cotton or wool; and that the bandage pressure should be applied cautiously. The patient should be especially requested to give notice of undue pain, and, finally, such warnings should invariably lead to an investigation by the attending physician. It may not be amiss to restate here the well-known fact that the key to the successful treatment of fractures is proper reduction in the first instance, not omitting in the great majority of

cases the advantage of reduction under anesthesia, so that correct position may be retained with a minimum of splint restraint, pain, and swelling. The time is past when it was considered good practice to try to overcome the deformity by a feeble attempt at direct pressure with apparatus; that correction should be made in the first instance under anesthesia. If the reduction cannot be made in such a manner that proper mechanical aids will maintain a good position, then immediate fixation with plates should be considered.

A great factor in the death of tissue from mechanical pressure is the fact that, on account of the injury and the swelling, and sometimes, too, because of the lowered general blood-pressure from shock, the circulation is especially apt to be arrested locally.

ANEMIA IN LESIONS OF THE SPINAL CORD

There is probably no higher testimony to the state of efficiency of a surgical service than the degree of success obtained in the care of patients with complete cross lesions of the spinal cord. The very difficulty of preventing bedsores is a reminder of the beneficent effect of the pain which is a constant protection against local death from anemia. While the loss of the warning of pain is the principal cause of bedsores, there is another factor that enters strongly into their formation, viz., the cross lesion of the spinal cord not only breaks the motor and sensory connections with the brain and the periphery, but breaks also the vasomotor connection. The break in the vasomotor connection at once removes nerve control from the blood vessels of the parts beyond the broken point, and, hence, these vessels lose their tone. In consequence there is a large fall in the general blood-pressure. That this fall is not temporary is shown by the record of a clinical case

two and one-half months after the cord was severed, the low pressure having persisted until that time.

The general low blood-pressure due to a cross lesion plays an important rôle in the formation of bedsores, for, if the blood-pressure has fallen to one-half its normal height, it is found by experience that even a very soft bed may not be a sufficient protection. Under some conditions a bedsore may form even when the patient is on a water-bed.

Just what is the mechanism of the formation of the bedsore? Why is there almost always a period of redness of the skin that precedes the bedsore itself? Why does it usually extend down to the bone, and why does it stop just at the high bony points and not extend between these points? The sequence of change could not well be otherwise, because the skin endures total anemia longer than the subcutaneous tissue, and the various types of subcutaneous tissue found in the region endure anemia about equally well. The pressure on the bony points is just the same as that on the skin, hence all of the soft parts between the bone and the skin are subjected to an equal pressure, and are about equally susceptible to anemia, and all the parts between the skin and the bone succumb. There is first aseptic necrosis, but soon, most likely through the skin, there is infection to which the impaired tissue readily succumbs. The sequence of events following infection is obvious.

The frequent application of alcohol apparently is of value in preventing the formation of bedsores. If alcohol were applied by strict rule every four hours it would be a specific preventative. So, too, would turning the patient over once every four hours be a specific preventative without the use of alcohol. The mere relief from pressure at such intervals, especially if accompanied by local rubbing to renew the circulation, would in itself be sufficient. But the application of alcohol has another good effect, viz., it may and probably does

assist in keeping down infection especially in the deeper parts of the skin.

The most important point to bear in mind is that when there is uninterrupted total anemia of six hours, for example, certain tissues are then and for all time dead, and as the duration of total anemia is increased still other types of tissue die. A patient may progress favorably for as long as a month and then the price of one error may be the much dreaded bed-sore. The absolute protection of such patients would be further guaranteed by the use of an automatic signal that would continue an annoying warning until turned off by the nurse only at the bedside of the patient, thus insuring exact periodic attendance on the patient.

SALINE INFUSIONS

In three instances the author has seen the long-continued use of saline infusions under the breast cause gangrene, twice in unconscious typhoid patients who had had hemorrhages, and in another instance in a patient unconscious from shock and hemorrhage. In these cases the sequence of events was just the same as that seen in bedsores. Some time after the saline solution was introduced there were local swelling, tenderness, redness, and heat. Later an abscess developed which ended in the breaking down of a zone of tissue as wide and as deep as the area from which the blood supply had been driven out by the force of the pressure from the infusion bottle. In these cases it must be borne in mind that a low general blood-pressure renders it all the more easy to force the normal blood supply out of any tissue. Because the urgent need for saline infusion usually occurs in just such a condition of the circulation as renders the tissues susceptible it is essential that it be given with great care. Continuous

or interrupted massage as a part of the process of subcutaneous infusion is not only a protection against the total exclusion of blood from the part but materially increases the rate of absorption and lessens the local pain and discomfort.

FLAP TENSION AND SUTURE TENSION

Among the most common errors of the rougher surgery in vogue in the past, and, unhappily, an error which is occasionally seen still, was that of tight tying of stitches. This was especially true in wounds in which there was a scanty or an ill-fashioned flap. Under these circumstances stitches were expected to do what finesse had failed to do. The results were sudden pain, infection, anemia of the area with necrosis, failure of union, a gaping wound, disappointment for the patient and well-earned humiliation for the surgeon. In many instances conditions require a stitch to carry an unusual amount of strain, e. g., in the wall of a distended or an unusually large abdomen, and in the perineum. Whenever a stitch is thus taxed with more than the ordinary tension it should be shielded with rubber tubing (Stiles), gauze, or other material.

In perineal stitches the author has found that such protection of the stay sutures not only prevents cutting, but also prevents much of the discomfort that so frequently attends this operation. Then, too, it is a point well worth remembering when stay sutures are used and the circumstances demand a mattress stitch, that the mattress grasp should be placed on a line vertical to the wound and not parallel to it, as it is obvious that the parallel pressure might lead to anemia of the adjacent skin. When tension sutures are demanded, a buried catgut suture is less liable to cause suppuration by causing anemia in bits of subcutaneous tissue than it would in bits of skin. There is also less discomfort resulting from subcutaneous tension than from skin tension.

CHAPTER VIII

ANEMIA OF THE SMALL INTESTINE: EXPERIMENTAL OBSERVATIONS. INTERFERENCE WITH THE CIRCULATION OF LOOPS OF SMALL INTESTINE OF DOGS FOR DIFFERENT LENGTHS OF TIME UNDER DIFFERENT CONDITIONS

In Collaboration with Dr. A. M. Tweedie and Dr. H. G. Sloan

All of the following experiments were performed under as rigid asepsis as possible. Ether was used for anesthesia, and morphia usually with it, or as indicated after the operation. The experiments were divided into eight groups as follows:

I. Those in which a loop of small intestine with its blood vessels was ligated *en masse* with tape, the tape being removed before the abdomen was closed.

II. Those in which a loop of intestine was ligated as before, a lateral anastomosis having previously been made to isolate the loop, and the tape removed before closing the abdomen. This eliminated intestinal obstruction except in the loop, and in the obstructed loop constriction existed only while the tape was allowed to remain in place.

III. Those in which the lateral anastomosis was made, the loop ligated, and the tape left in place when the abdomen was closed. The object of leaving the tape in place was to see whether or not the toxic material could be kept out of the circulation.

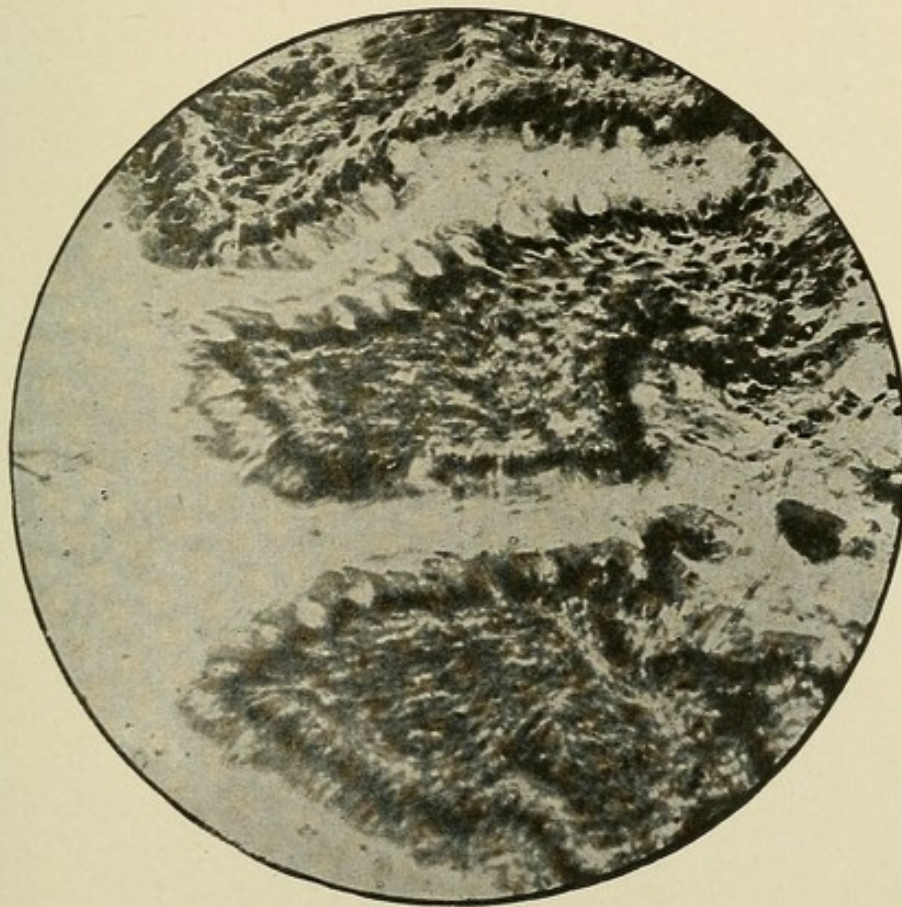


FIG. I.—NORMAL SMALL INTESTINE OF A DOG.
 Note the clearly defined villi, the goblet cells, and the generally normal appearance (high magnification).

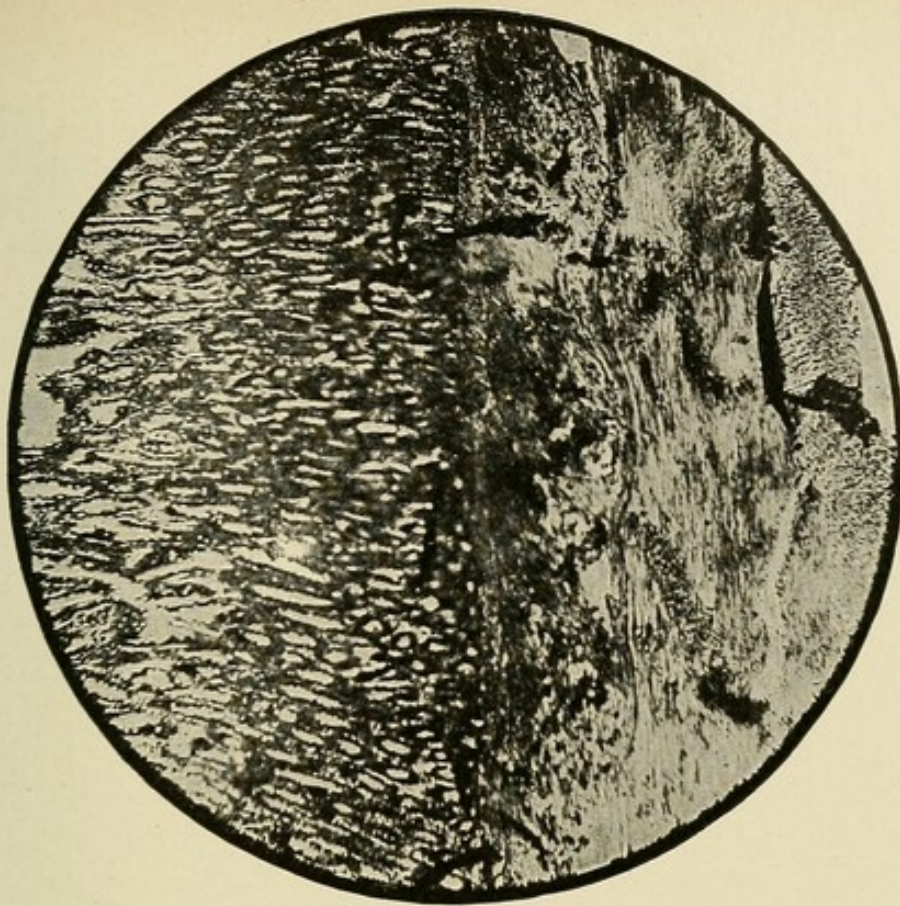


FIG. II.—NORMAL SMALL INTESTINE OF A DOG
 (Low magnification)

IV. Those in which the lateral anastomosis was made, the loop ligated, and the loop excised at the end of the period of anemia before closing the abdomen.

V. Those in which the lateral anastomosis was made, the loop ligated, a drainage tube inserted into the loop, and the abdomen closed.

VI. Those in which the lateral anastomosis was made, the loop ligated, and the loop allowed to project through the abdominal wound. The object was to allow the loop to slough away outside of the abdomen.

VII. Those in which there was partial occlusion of the blood supply of a loop by ligating mesenteric arteries and veins.

VIII. Those in which control animals were operated on without ligating the intestine.

Group I

Experiments in Which a Loop of Small Intestine with Its Blood Vessels Was Ligated en Masse with Tape, the Tape Being Removed Before the Abdomen Was Closed

EXPERIMENT 1

NOVEMBER 9, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A 15 cm. loop of small intestine, with its mesentery, was ligated *en masse* with tape. At the end of 1 hour the tape was removed and the abdomen closed. At this time the circulation could be seen to return to the loop. The dog died fifteen hours after stopping the anesthesia. The cause of death was not determined. There was marked congestion of the portions of the intestine handled in carrying out the technique but the loop showed no gross changes.

EXPERIMENT 2

NOVEMBER 10, 1908.

Mongrel bitch; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A 15 cm. loop of intestine was ligated, as before, at a point about 30 cm.

from the cecum. At the end of *1 hour* the tape was removed, and the abdomen closed.

NOVEMBER 12.

The bitch appeared to be well. Nothing abnormal was apparent, except a slight discharge from the wound.

NOVEMBER 23.

Condition, normal.

JANUARY 4, 1909.

The bitch was chloroformed. No gross changes were found in the loop.

EXPERIMENT 3

NOVEMBER 13, 1908.

Pug bitch; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A 30 cm. loop, about 90 cm. from the pylorus, was ligated. At the end of *1 hour* the tape was removed, and the abdomen closed. Recovery from the operation was good.

NOVEMBER 17.

The bitch was in good condition.

JANUARY 1, 1909.

Condition, the same.

JANUARY 7.

The bitch was killed in a resuscitation experiment, and sections of the intestine were taken for staining. Many adhesions were present around the loop, but otherwise no gross changes were present. The histologic examination was negative.

EXPERIMENT 4

JANUARY 16, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 15 cm. loop near the cecum was ligated. After *1 hour* the tape was removed, and the abdomen closed.

FEBRUARY 13.

Complete recovery.

EXPERIMENT 5

NOVEMBER 12, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 17 cm. loop was ligated at a point about 30 cm. from the cecum. At the end of *2 hours* the tape was removed, and the abdomen closed. Recovery from the operation was good.

NOVEMBER 13.

The dog was sick, but did not vomit. The bowels had not moved since the operation.

NOVEMBER 16.

The dog was still sick, but still had not vomited. There was some discharge from the abdominal incision. The wound was cleared, and a moist bichlorid of mercury dressing applied. Rectal temperature, 38.9° C.

NOVEMBER 17.

The dog was very sick. Temperature, 38.9°. Heart action rapid. The abdomen was tender, there was a foul discharge from the wound, and the dog vomited occasionally.

NOVEMBER 18.

Death occurred during the night. At the autopsy acute peritonitis was found, and a perforation at the point of ligation. The loop was markedly congested, but how much from the ligation, and how much from the peritonitis, could not be determined.

EXPERIMENT 6

NOVEMBER 13, 1908.

Mongrel bitch; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 15 cm. loop, about 120 cm. from the pylorus, was ligated. At the end of 2 hours the tape was removed, and the abdomen closed. Recovery from the operation was good.

NOVEMBER 15.

The general condition was good. There had been no vomiting, and the bowels had not moved since the operation.

NOVEMBER 17.

General condition, good. The wound was clean. The bowels moved. Temperature normal.

JANUARY 6, 1909.

The bitch was chloroformed. The autopsy revealed many adhesions about the loop. The microscopical examination of the section from the loop showed an old adhesion of the tunica serosa, but there were no signs of change other than this.

EXPERIMENT 7

NOVEMBER 28, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 20 cm. loop, midway between the jejunum and the cecum, was ligated. After

2¾ *hours* the tape was removed, and the abdomen closed. The dog recovered from the operation well, but died during the night. The autopsy showed deep congestion of all the parts that were handled during the operation. The loop showed evidence of return of circulation.

EXPERIMENT 8

DECEMBER 5, 1908.

Mongrel bitch; condition, good. Ether; morphia, gr. ½. A 25 cm. loop of small intestine was ligated. After 3 *hours* the tape was removed, and the abdomen was closed. At this time a slight return of the circulation could be seen.

DECEMBER 6.

Condition, good. Wound, clean. No vomiting. Refused to eat.

DECEMBER 7.

Condition, good. Appetite, good. The bowels had not moved.

DECEMBER 8.

Condition, good. The bowels moved during the night.

DECEMBER 10.

Condition, good. The wound was clean.

DECEMBER 24.

Death occurred during the night, cause undetermined. The autopsy findings were negative except for the fact that adhesions were present around the loop. The loop itself was normal.

EXPERIMENT 9

FEBRUARY 8, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. ½. A 10 cm. loop near the jejunum was ligated. At the end of 4 *hours* the tape was removed, and the abdomen closed. Shortly after this the dog died from the effects of the anesthetics. The autopsy was negative.

EXPERIMENT 10

DECEMBER 11, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. ½. A 15 cm. loop, 30 cm. from the pylorus, was ligated. After 4 *hours* the tape was removed, and the abdomen closed. The recovery from operation was good.

DECEMBER 12.

The wound was clean, and the general condition good. There was no vomiting. The bowels had not moved.

DECEMBER 15.

General condition, good. The bowels moved during the night.

DECEMBER 20.

The dog was found dead. At autopsy about 90 cm. of the small intestine were found to be deeply congested, looking as if arterial thrombosis had occurred. There were some adhesions about the loop, but the loop itself showed every evidence of return of circulation.

MICROSCOPICAL EXAMINATION.—But few changes were found in the sections studied. There was some desquamation of the epithelium in the gland crypts, and the tunica serosa showed numerous adhesions. Otherwise a normal appearance was presented. (See Figs. III and IV.)

EXPERIMENT 11

JANUARY 23, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 30 cm. loop, just below the jejunum, was ligated. At the end of 5 hours the tape was removed, and the abdomen closed. The dog was in good condition when removed from the table.

JANUARY 24.

Death occurred during the night. At the autopsy the loop was found to be gangrenous. Otherwise the autopsy was negative.

EXPERIMENT 12

JANUARY 24, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A 15 cm. loop, about 90 cm. from the pylorus, was ligated. After 5 hours the tape was removed, and the abdomen closed.

JANUARY 5.

General condition, good. The bowels had not moved, but there was no vomiting or abdominal distention.

JANUARY 6.

The bowels had moved during the night. In the stool there was some blood-streaked mucus. General condition, good.

JANUARY 7.

The dog appeared to be normal in every way.

JANUARY 11.

The dog was chloroformed. At the autopsy the loop appeared to be normal except for a few adhesions.

MICROSCOPICAL EXAMINATION.—Extensive desquamation of the epithelium lining the follicles and hemorrhage into the mucosa were

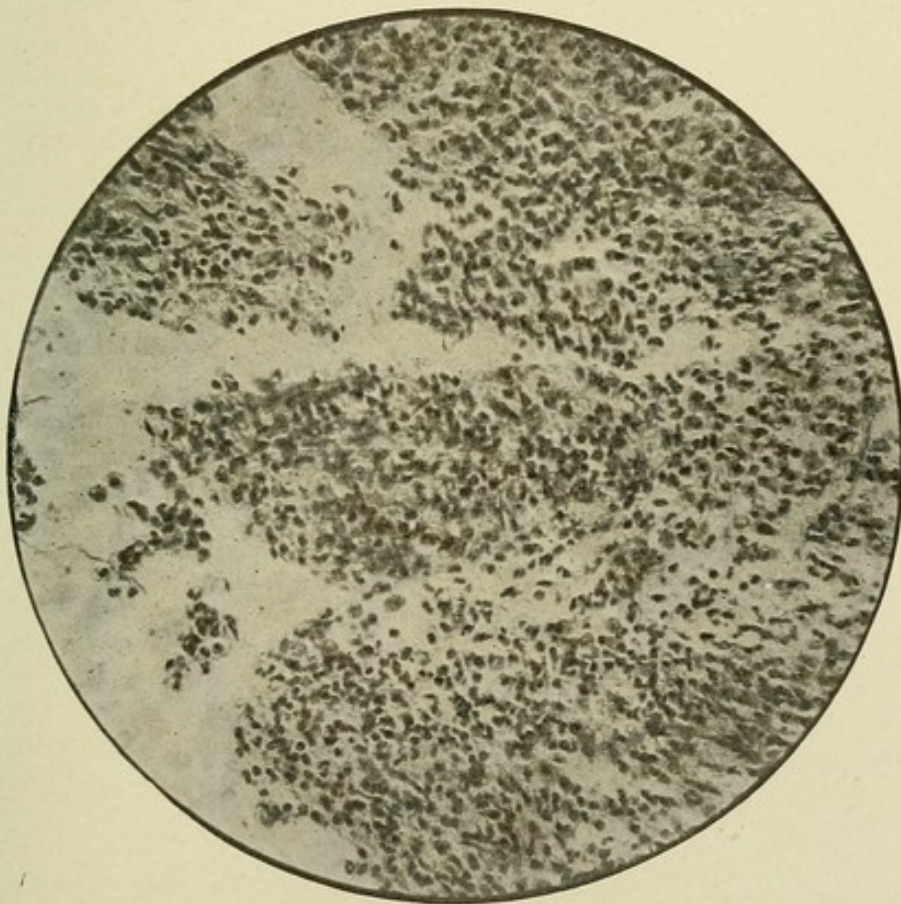


FIG. III.—ANEMIA OF THE INTESTINE

Duration of anemia four hours. The epithelium has all desquamated, there is marked invasion of polymorphonuclear leucocytes and the outlines of the villi are indistinct. This represents a condition from which recovery is impossible, at least with resumption of function on the part of the intestine. (High magnification.)

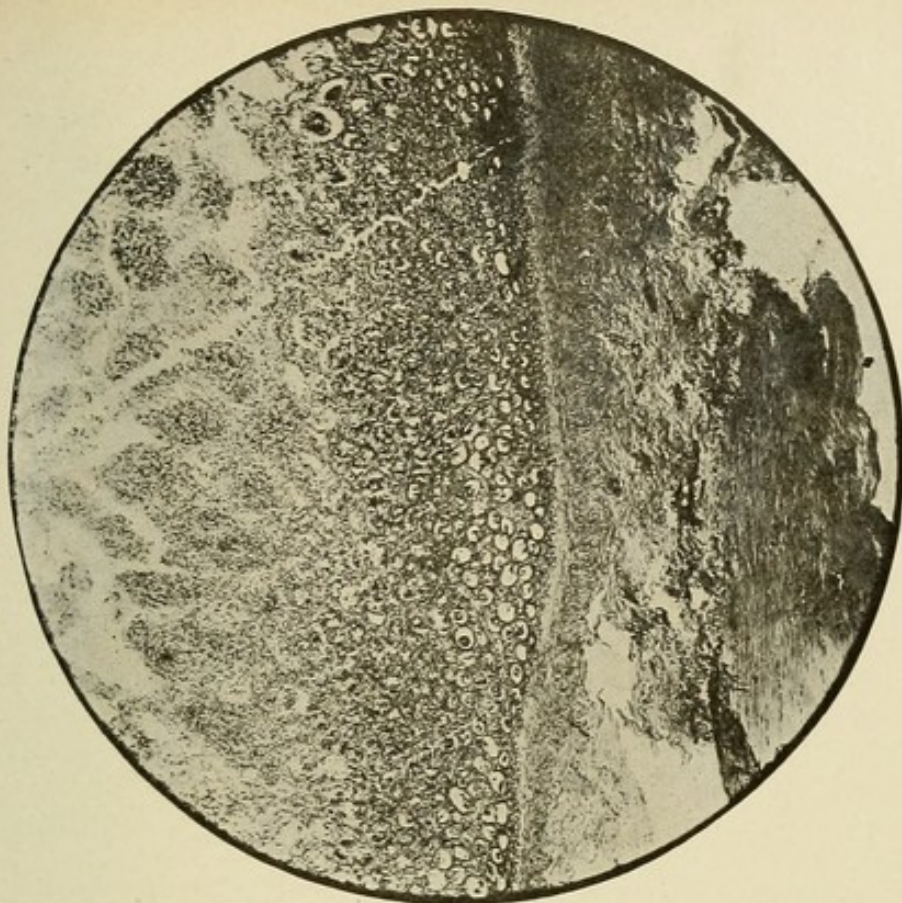


FIG. IV.—ANEMIA OF THE INTESTINE

Duration of anemia four hours. Note the blurred outlines of the villi, the marked infiltration of polymorphonuclear leucocytes (the small black dots), and the separation of the muscular coats due to edema. (Low magnification.)

found. Throughout the sections there were interstitial hemorrhages and round-cell infiltration. There was no tissue necrosis, however.

EXPERIMENT 13

JANUARY 5, 1909.

Bulldog bitch; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A 20 cm. loop, about 90 cm. from the jejunum, was ligated. At the end of 6 hours the tape was removed, and the abdomen closed. The recovery from the operation was good.

JANUARY 6.

General condition, very poor. The heart sounds were scarcely perceptible. There was no abdominal distention, or vomiting, and the wound was clean. The condition seemed to be one of rapidly progressing extreme exhaustion. Pulse, 180. Rectal temperature, subnormal. Death occurred at 9:30 A. M., about twenty-four hours after the operation. At the autopsy the peritoneum was found to be slightly congested. There was no free fluid in the abdominal cavity. The loop was gangrenous.

EXPERIMENT 14

JANUARY 16, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A 20 cm. loop near the jejunum was ligated. After 6 hours the tape was removed, and the abdomen closed.

JANUARY 17.

The dog was found dead. At autopsy the peritoneum was found to be congested, and part of the ligated loop was gangrenous. There was no free fluid in the abdominal cavity.

EXPERIMENT 15

DECEMBER 1, 1908.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 15 cm. loop, about 60 cm. from the jejunum, was ligated. At the end of 6 hours the tape was removed, and the abdomen closed. During the time that it was constricted the loop became very dark, and there was no evidence that the circulation was restored when the tape was removed.

DECEMBER 2.

Death occurred during the night, and at the autopsy the loop was found to be gangrenous. The peritoneum was somewhat congested. Sections were not made.

EXPERIMENT 16

JANUARY 17, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 15 cm. loop, 90 cm. from the cecum, was ligated. At the end of 6 hours the tape was removed, and the abdomen closed.

JANUARY 18.

General condition, poor, there being extreme exhaustion. Rectal temperature, 36.7° . Pulse, 150. Heart action, very weak. The bowels had not moved, but there was no abdominal distention.

JANUARY 20.

Death occurred during the night. The autopsy revealed some congestion of the peritoneum, and of the intestines, which had been handled. The loop showed some evidence of returning circulation, as it was less gangrenous than in the experiments in which circulation was obstructed for a longer time.

EXPERIMENT 17

JANUARY 20, 1909.

Mongrel bitch; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 30 cm. loop, about 15 cm. from the jejunum, was ligated. After 6 hours the tape was removed, and the abdomen closed. One-half hour after the operation was over death occurred. The autopsy showed that there had been no return of circulation in the loop. (See Figs. V and VI.)

EXPERIMENT 18

JANUARY 6, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 25 cm. loop, about 30 cm. from the cecum, was ligated. After 8 hours the tape was removed, and the abdomen closed.

JANUARY 7.

The dog was in a state of collapse, and vomited. The pulse rate was about 170, the heart action being scarcely perceptible to palpation. Rectal temperature, 36.1° C. During the afternoon death occurred. Just before death there was a slight convulsion. At the autopsy the loop was found to be gangrenous. Otherwise the findings were negative.

EXPERIMENT 19

JANUARY 7, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 15 cm. loop, midway between the jejunum and the cecum, was ligated. After

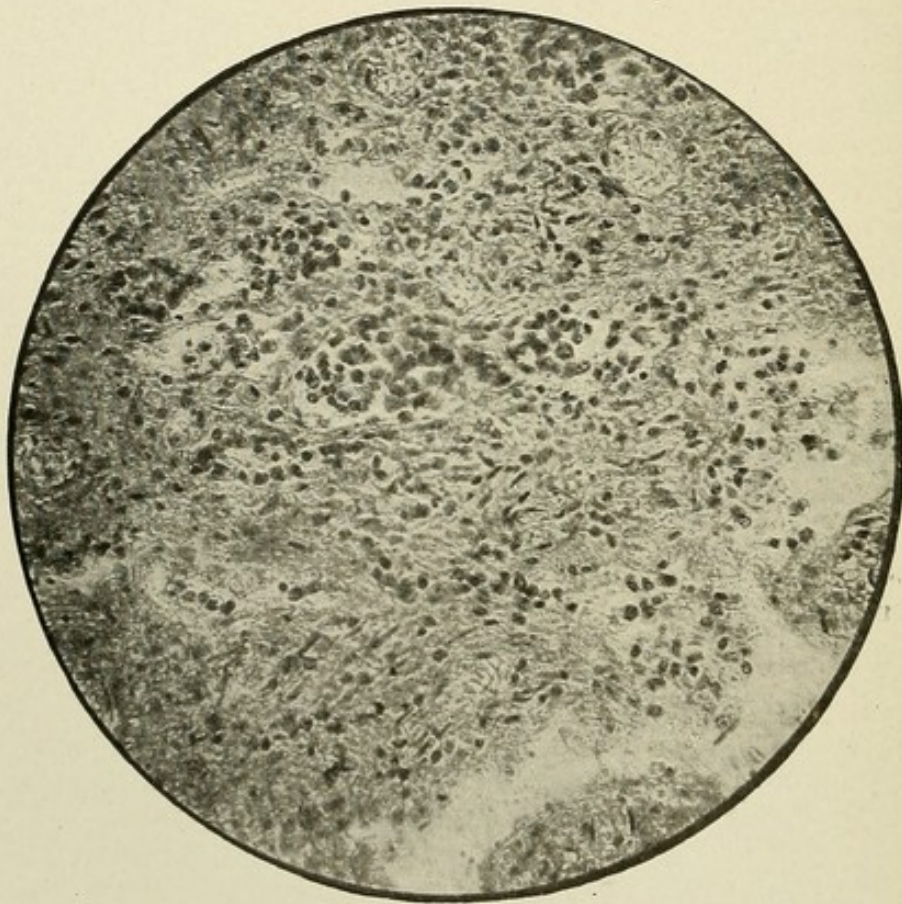


FIG. V.—ANEMIA OF THE INTESTINE

Duration of anemia six hours. The normal structure has entirely disappeared. There has been marked proliferation of connective tissue with invasion of a rich network of new capillaries. There are fewer polymorphonuclear leucocytes. (High magnification.)

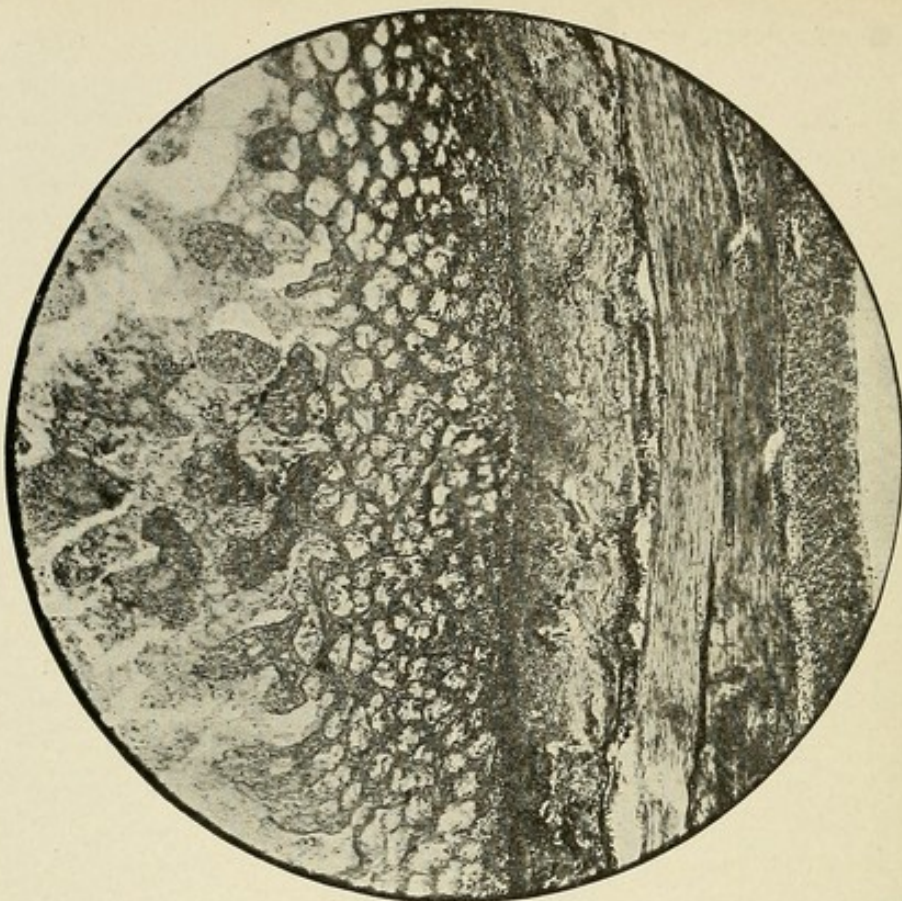


FIG. VI.—ANEMIA OF THE INTESTINE

Duration of anemia six hours. The changes have proceeded farther than in the four-hour specimen, but chief difference being the marked formation of connective tissue (better shown in the higher magnification). (Low magnification.)

8 hours the tape was removed, and the abdomen closed. The animal made a good recovery from the operation.

JANUARY 8.

The dog was found dead. At the autopsy the loop was found to be gangrenous. The other organs were negative.

EXPERIMENT 20

JANUARY 8, 1909.

Black and tan bitch; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A 15 cm. loop near the cecum was ligated. At the end of 8 hours the tape was removed, and the abdomen closed. The bitch was in good condition when taken from the operating table.

JANUARY 9.

Death occurred during the night. The autopsy showed no changes further than gangrene of the loop.

EXPERIMENT 21

JANUARY 11, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 7 cm. loop, about 30 cm. from the jejunum, was ligated. After 8 hours the tape was removed, and the abdomen closed. The operative recovery was good.

JANUARY 12.

The dog was in a state of great prostration, with abdominal distention and vomiting. The bowels had not moved. The temperature was subnormal, 36.4°C ., and the heart action very weak.

JANUARY 13.

Death occurred during the night. The autopsy revealed nothing but gangrene of the loop.

EXPERIMENT 22

JANUARY 22, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 15 cm. loop, about 90 cm. from the pylorus, was ligated. After 8 hours and 15 minutes the tape was removed, and the abdomen closed. The dog was in good condition when taken from the table.

JANUARY 23.

Death occurred. The autopsy revealed that the loop was gangrenous. The other organs were normal.

EXPERIMENT 23

JANUARY 22, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 15 cm. loop, midway between the pylorus and cecum, was ligated. At the end of 8 hours and 40 minutes the tape was removed, and the abdomen closed. The dog was taken from the table in good condition.

JANUARY 23.

Death occurred during the night. Autopsy showed the loop to be gangrenous. The other organs were negative.

EXPERIMENT 24

JANUARY 14, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{2}$. A 15 cm. loop, about 60 cm. from the cecum, was ligated. At the end of 9 hours the tape was removed, and the abdomen closed.

JANUARY 15.

The dog was found dead. At autopsy the loop was found to be gangrenous, but the other organs were normal.

Group II

Experiments in Which a Loop of Small Intestine Was Ligated, a Lateral Anastomosis Having Been Previously Made to Isolate the Loop, and the Tape Removed Before Closing the Abdomen

EXPERIMENT 25

FEBRUARY 2, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral anastomosis was made about 30 cm. from the pylorus. A 15 cm. loop external to the anastomosis was ligated. At the end of 7 hours the tape was removed, and the abdomen closed. The dog died in a short time after this. The autopsy showed the loop to be gangrenous.

EXPERIMENT 26

FEBRUARY 1, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral intestinal anastomosis was made about 60 cm. from the cecum. A loop of intestine (length not stated) external to the anastomosis was ligated. At the end of 8 hours the tape was removed, and the

abdomen closed. The dog was in good condition at the end of the operation.

FEBRUARY 2.

The dog was still alive, but very weak. The bowels moved, and there was no vomiting. Temperature, 40.8° C.; pulse, 150, and very weak. Death occurred during the afternoon. At the autopsy free fluid was found in the peritoneal cavity. There was some sloughing around the sutures in the abdominal wall. The loop was in a condition bordering on gangrene.

EXPERIMENT 27

JANUARY 27, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral intestinal anastomosis was made about 60 cm. from the jejunum. A 15 cm. loop, external to the anastomosis, was ligated *en masse*, as in the experiments in Group I. At the end of 8 hours the tape was removed, and the abdomen closed. The color of the loop showed at this time that the circulation had not been entirely shut off. The dog was in good condition at the end of the operation.

JANUARY 28.

The dog was very weak, with a subnormal temperature, and pulse rate of 180 per minute. The bowels moved.

JANUARY 29.

Death occurred during the evening, under appearances of extreme exhaustion. For the last forty-eight hours the pulse had continued to be abnormal. At the otherwise negative autopsy the loop was found to be gangrenous.

EXPERIMENT 28

FEBRUARY 3, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral intestinal anastomosis was made about 30 cm. from the pylorus. A 20 cm. loop, external to the anastomosis, was ligated. At the end of 8 hours the tape was removed, and the abdomen closed.

FEBRUARY 4.

The dog was greatly prostrated. The temperature was subnormal, and the pulse could not be counted. Death occurred at about noon. Except for the fact that no return of circulation was shown in the loop the autopsy was negative.

EXPERIMENT 29

FEBRUARY 4, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral intestinal anastomosis was made about 90 cm. from the jejunum. A 20 cm. loop, external to the anastomosis, was ligated. At the end of 8 hours the tape was removed and the abdomen closed. The dog was in good condition when taken from the table.

FEBRUARY 5.

Death occurred during the night. The loop was gangrenous, but otherwise the autopsy was negative.

Group III

Experiments in Which a Lateral Anastomosis Was Made, a Loop of Intestine Ligated, and the Tape Left in Place After the Abdomen Was Closed

EXPERIMENT 30

FEBRUARY 16, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral anastomosis was made about 30 cm. from the jejunum. A 20 cm. loop, external to the anastomosis, was ligated with tape, in the usual way, and the *tape left in place* when the abdomen was closed.

FEBRUARY 17.

Death occurred during the night, about 18 hours after the operation. Except for gangrene of the loop the autopsy was negative.

EXPERIMENT 31

FEBRUARY 22, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral anastomosis was made about 90 cm. from the cecum. A 15 cm. loop, external to the anastomosis, was ligated, and the *tape left in place* when the abdomen was closed. The dog made a good recovery from the anesthetic, but in the afternoon his temperature ran up to 38.3° . He became progressively weaker, and died during the night, about 18 hours after the operation. The autopsy revealed gangrene of the loop, but was otherwise negative.

EXPERIMENT 32

MARCH 8, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral anastomosis was made, about 90 cm. from the pylorus, leaving a loop external to it of 30 cm. Twenty-five centimeters of this loop were ligated, the *tape allowed to remain in place*, and the abdomen closed. The temperature immediately after the operation was 37.8° , while four hours later it had fallen to 36.1° C. The dog grew progressively weaker, and died during the night, about 18 hours after the operation. The autopsy was negative except for revealing that the loop was gangrenous.

EXPERIMENT 33

MARCH 10, 1909.

Mongrel bitch; condition, good. Ether; morphia, gr. $\frac{1}{4}$. Temperature before the operation, 37.8° C.; pulse, 80 per minute. A lateral anastomosis was made, about 90 cm. from the jejunum, leaving a 30 cm. loop external to it. Fifteen centimeters of this loop were ligated, the *tape allowed to remain in place*, and the abdomen closed. Progressive weakness followed the operation, the temperature falling to 36.2° , while the pulse grew weaker and more and more rapid.

MARCH 11.

Death occurred during the night, about 18 hours after the operation. The loop was gangrenous. Otherwise the autopsy was negative.

EXPERIMENT 34

MARCH 5, 1909.

Hound bitch; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral anastomosis was made, about 60 cm. from the pylorus, leaving a loop outside of the anastomosis which was 30 cm. long. Fifteen centimeters of this loop were ligated, the *tape being left in place* when the abdomen was closed. Throughout the afternoon the bitch was in a state of profound prostration, the temperature gradually falling to 36.1° , and the pulse becoming weaker and weaker. There was no vomiting. The bowels moved in a normal way.

MARCH 6.

Death occurred at 5:00 P.M., about 30 hours after the operation. Except for the loop being gangrenous the autopsy was negative.

Group IV

*Experiments in Which a Lateral Anastomosis Was Made, a
Loop of Intestine Ligated, and the Loop Excised at
the End of the Period of Anemia Before
Closing the Abdomen*

EXPERIMENT 35

DECEMBER 12, 1910.

Mongrel dog; weight, 11 kilos; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral anastomosis was made, isolating a loop of small intestine near the ileocecal valve. Fifteen centimeters of this loop were ligated, and the abdomen closed. At the end of 7 hours the abdomen was reopened, and the *anemic loop excised*, the open ends of ileum being inverted with a purse-string suture. The loop removed was dark purple. The recovery was good.

DECEMBER 13.

Temperature, 41.1° C. The dog was very stupid.

DECEMBER 14.

Temperature, 38.9°; pulse, 132; respiration, 24. The dog moved about and ate.

DECEMBER 15.

Temperature, 38.9°; pulse, 112; respiration, 22.

DECEMBER 16.

Temperature, 38.9°; pulse, 128; respiration, 22. The dog was very sick; had diarrhea, and urinated on his bandages.

DECEMBER 20.

Steady improvement up to this date. Priapism was constantly present.

DECEMBER 30.

Complete recovery.

EXPERIMENT 36

DECEMBER 13, 1910.

Mongrel bitch; weight, 12 kilos; condition, good. Ether; morphia, gr. $\frac{1}{4}$. The details of this experiment were the same as in the two preceding experiments in this group, 30 cm. of ileum being ligated, replaced in the abdomen, and removed at the end of 7 hours. The operative recovery was good, and the bitch progressed favorably

until the sixth day, when she was found dead and stiff in the morning.

AUTOPSY.—General peritonitis was present. The intestinal anastomosis was patent, and in good condition. An abscess in the pelvis had ruptured. Death was due to infection from this cause.

EXPERIMENT 37

DECEMBER 23, 1910.

Mongrel dog; weight, 14 kilos; condition, good. This was a recovery dog from one of the intestinal injection experiments. Ether; morphia, gr. $\frac{1}{4}$. Twenty centimeters of the loop isolated by the enteroenterostomy were ligated, replaced in the abdomen, and left there for $7\frac{1}{2}$ hours. At the end of this time the *loop was excised*; the operative recovery was good.

DECEMBER 30.

The dog had never been seriously ill up to this date. The wound in the abdomen was almost closed, and recovery was practically complete.

EXPERIMENT 38

MARCH 8, 1909.

Mongrel dog; condition, good. Ether; morphia, gr. $\frac{1}{4}$. A lateral anastomosis was made about 120 cm. from the jejunum, leaving a 30 cm. loop external to it. Twenty centimeters of this loop were ligated in the usual way, and the tape left in place for 8 hours. At the end of this time all of the *ischemic tissue was excised*, the ends of the intestine being closed with purse-string sutures, and inverted. The dog was in good condition when removed from the table.

MARCH 9.

Death occurred during the night. The autopsy was negative.

EXPERIMENT 39

DECEMBER 14, 1910.

Mongrel dog; weight, 9.5 kilos; condition, good. Ether; morphia, gr. $\frac{1}{4}$. On the first day the enteroenterostomy was performed at 10:00 P. M., and the loop of ileum ligated, 30 cm. being occluded. The next morning, *at the end of 10 hours*, the dog was etherized again, in order to open the abdomen and remove the loop, and died from the anesthetic. The loop was gray, the abdomen filled with very foul free fluid, and above the loop the intestine was ballooned.

Group V

*Experiments in Which a Lateral Anastomosis Was Made, a
Loop of Intestine Ligated, a Drainage Tube
Inserted Into the Loop, and the
Abdomen Closed*

EXPERIMENT 40

MARCH 4, 1910.

Mongrel dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. A lateral anastomosis was made in the usual way. A 25 cm. loop of jejunum, external to the anastomosis, was ligated. Into the loop *a rubber drainage tube was inserted*, and the operative field dammed as much as possible with omentum. The abdomen was then closed, except for the place through which the tube passed, the tape being left in place.

MARCH 5.

Death occurred during the night, about 18 hours after the operation. At the autopsy it was found that the tape had slipped, and that general peritonitis had set in. The loop was gangrenous, and there must have been absorption of toxic material from it.

EXPERIMENT 41

MARCH 31, 1910.

Mongrel dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. An anastomosis was made, which isolated 90 cm. of jejunum. The entire loop was ligated, and *drained with a rubber tube*. The abdomen was closed, leaving a gauze dam and the tape in place. At the close of the operation the dog was in good condition. During the afternoon the dog became very much prostrated. The temperature at 6:00 P. M. was 35.8° C.; the pulse, 180.

APRIL 1.

The dog was found dead about 18 hours after the operation. The autopsy showed gangrene of the loop, but otherwise was negative.

EXPERIMENT 42

APRIL 11, 1910.

Mongrel dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. An anastomosis was made,

which isolated 90 cm. of jejunum. The entire loop was ligated, *the drainage tube inserted* into it, and the field dammed with gauze. The abdomen was closed. At the close of the operation the dog was in good condition. At 6:00 P. M. the dog was much prostrated, with a temperature of 35.8° C. and pulse of 160.

APRIL 12.

The dog was very sick. Profound toxemia was evidently present. Death occurred at 12:00 M., almost 27 hours after the operation. Just before death the temperature was 35.0° and the pulse 190. The dog had been vomiting for some time. At the autopsy the only change found was the gangrenous loop.

EXPERIMENT 43

APRIL 6, 1910.

Mongrel dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. An anastomosis was made, which isolated about 90 cm. of the jejunum. This loop was ligated, and *the rubber drainage tube* inserted in the usual way, a gauze dam being placed around the field of operation. The abdomen was then closed. At 6:00 P. M. the dog was greatly prostrated, and vomited freely, although he had been in good condition at the close of the operation. Temperature, 38.9°; pulse, 190.

APRIL 7.

The dog was still greatly prostrated, vomited freely, and seemed to be dying. The wound was opened, and as much of the gangrenous bowel removed as could be done without disturbing the dam. Temperature, 36.1°; pulse, 180. Death occurred during the afternoon, about 30 hours after the operation. At the autopsy nothing abnormal was found but the gangrenous loop. There was no peritonitis.

EXPERIMENT 44

MARCH 8, 1910.

Mongrel dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. Operative procedures exactly as in Experiment 40, a 25 cm. loop external to the anastomosis being ligated and *drained with the rubber tube*. At the close of the operation the dog was in good condition.

MARCH 8.

The dog was vomiting, and very sick. The prostration was extreme. The bowels had not moved. Temperature, 36.3° C.; pulse, 160. There was considerable discharge from the drainage tube.

Later in the day the general temperature seemed to be somewhat improved, although the temperature was still subnormal, and the pulse rapid and feeble.

MARCH 9.

General condition, about the same. Temperature, 35.8° .

MARCH 10.

There was less vomiting, and the bowels had moved during the night. The degree of prostration was about the same. There was no abdominal distention. The discharge from the tube was very foul. This discharge, when collected and injected into another dog, produced about the same symptoms that were later obtained from injecting intestinal extract, but the dose was too small to cause death.

MARCH 11.

General condition somewhat improved, but the prostration was still extreme. Temperature, 36.3° ; pulse, 145. The vomiting had ceased, but profuse diarrhea had begun. Large amounts of water had been drunk, but no food taken since the beginning of the experiment. The discharge from the loop was still very profuse and foul.

MARCH 12.

General condition much improved, and prostration much less marked. Food was still refused. The diarrhea persisted. Temperature, 38.9° ; pulse, 120. Nose dry. Eyes glazed.

MARCH 13.

The dog was found dead in the morning, about 5 days after the operation. The autopsy showed that the entire ischemic loop had sloughed away. About the site of the operation general peritonitis had developed. The anastomosis had separated, but whether this was a result of imperfection of technique, and, hence, the cause of the peritonitis, could not be made out. The spleen was large and soft. The liver was abscessed, and in general showed the effects of toxemia. Sections from the kidneys showed acute nephritis. The intestines showed the presence of enteritis.

EXPERIMENT 45

MARCH 14, 1910.

Mongrel dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. An anastomosis was made, which isolated a loop of intestine 90 cm. long, the portion selected being part of the jejunum. A 30 cm. loop, external to the anas-

tomosis, was ligated. Into the loop a *rubber tube* was inserted for drainage, and the operative field dammed off as much as possible with gauze. The abdomen was then closed, the tape and gauze being left in place. At the close of the operation the dog was in good condition.

MARCH 15.

The dog was greatly prostrated, with a temperature of 36.1° and pulse of 160. There had been no vomiting or diarrhea. All nourishment and water were refused. The discharge from the drainage tube was very foul and profuse.

MARCH 16.

General condition about the same, except that the dog had vomited throughout the night, and had profuse diarrhea. Some water was taken, but food was refused. Temperature, 37.5° ; pulse, 150.

MARCH 17.

The prostration was less marked, but the vomiting and diarrhea were profuse. The discharge from the tube was still profuse and very foul. Large quantities of water were drunk, but all food was refused.

MARCH 19.

The dog seemed to be much better. Temperature, 38.3° ; pulse, 120. For the first time since the operation a little food was eaten. The vomiting and diarrhea had about ceased. From the drainage tube and from the gauze around it there was still considerable discharge.

MARCH 21.

Condition much improved. Food was well taken. The rubber drainage tube came out in the morning, and with it a large amount of pus and necrotic material, but the gauze stayed in place. Temperature, 37.8° ; pulse, 105.

MARCH 24.

Food was taken with evident relish. The discharge was very profuse. The gauze was removed. Temperature, 37.8° ; pulse, 95.

MARCH 28.

For a week the dog had seemed to be free from all complications. The discharge still persisted, but for the last three days the temperature had been normal. The dog was chloroformed (10 days after the operation), and at the autopsy there was found to be perito-

nit is localized about the site of the operation. It was well walled off with adhesions. The entire ischemic loop had sloughed away. One end of the loop was like a fibrous cord, while the other was simply closed. There did not seem to be any other changes in the abdominal organs. Sections were taken from the liver, spleen, and intestines, but these did not show any microscopic changes of consequence.

Group VI

Experiments in Which a Lateral Anastomosis Was Made, a Loop of Intestine Ligated, and the Loop Allowed to Project Through the Abdominal Wound.

EXPERIMENT 46

APRIL 23, 1910.

Mongrel dog; condition, good. A laxative was given twenty-four hours before the operation. Ether. An anastomosis was made, isolating about 60 cm. of the ileum. Part of the loop thus made was ligated and the bowel opened. Then, instead of putting in a drainage tube, and leaving the ischemic portion inside of the abdomen, it was withdrawn, and the abdomen closed around it. The dressings were applied around it. At the close of the operation the dog was in good condition. At 6:00 P. M. there had been no symptoms of toxemia.

APRIL 24.

On the whole the condition of the dog was good and in marked contrast to that of the dogs in other experiments in which the ischemic loop was left in the abdomen. Temperature, 36.7°C. ; pulse, 108. The wound was very foul, and the intestine had almost completely sloughed away 24 hours after the operation. There was considerable diarrhea, and there had been some vomiting during the night.

APRIL 25.

General condition very good. Most of the loop had sloughed off, and there was some localized infection. The edges of the wound were separated a little, and the pus allowed to escape. Temperature, 38.9° ; pulse, 120. There was still profuse diarrhea, but no vomiting. Large quantities of water were taken, but no food.

APRIL 26.

The diarrhea still persisted, and the amount of discharge from the wound had increased. Temperature and pulse the same.

APRIL 27.

Condition about the same. Temperature, 38.9° ; pulse, 115.

MAY 2.

The dog seemed to be in good condition, running around the kennel and eating well. Temperature, normal. There was still some discharge from the incision, but the intestine had sloughed entirely away.

MAY 10.

The dog was chloroformed. At the autopsy a localized abscess and peritonitis were found near the wound, but otherwise the autopsy was negative. There had been no involvement of kidneys, liver, or spleen.

EXPERIMENT 47

DECEMBER 21, 1910.

Mongrel dog; weight, 16 kilos; condition, good. Ether. Thirty centimeters of small intestine were ligated and left outside the abdomen, an enteroenterostomy having been previously made to isolate the loop. The operative recovery was good.

DECEMBER 22.

The loop was black and mushy. It was cut away level with the wound in the abdominal wall 24 hours after the ligation. At 9:00 A. M. the temperature was 40.0° C., the pulse 160, and the respirations 28. At 4:30 P. M. the temperature was 38.9° , the pulse 108, and the respiration 20. Respiration was carried on with difficulty.

DECEMBER 22, 23, AND 24.

The temperature averaged 41.1° , and the dog was very ill.

DECEMBER 30.

A fecal fistula was present. The appetite was good, the dog drank freely. Weight as at beginning of experiment, 10 kilos. The dog was killed with chloroform.

AUTOPSY.—There was no evidence of peritonitis. The enteroenterostomy was patent, and feces were in the cecum.

Group VII

*Experiments in Which There Was Partial Occlusion of the
Blood Supply of a Loop of Intestine by Ligation
of the Corresponding Arteries and Veins
in the Mesentery*

EXPERIMENT 48

MAY 16, 1910.

Mongrel dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. The blood-vessels supplying 90 cm. of intestine were ligated, and the abdomen closed.

MAY 17.

The dog was found dead, death having occurred about 18 hours after the ligation. The autopsy revealed that the entire portion of the intestine, the vessels of which were ligated, was gangrenous. Otherwise the autopsy was negative.

EXPERIMENT 49

DECEMBER 19, 1910.

Mongrel dog; weight, 5 kilos; condition, good. Ether. Three main branches of arteries and veins supplying the terminal portion of the ileum were ligated, shutting off the blood supply of 15 centimeters of gut. The isolated portion at once became anemic and contracted. After a few hours fever developed, which persisted.

DECEMBER 22.

Death occurred at 1:30 P. M., about 31 hours after the ligation. Three centimeters of the anemic gut were gangrenous and perforated. General peritonitis was present. Above the anemic area the gut was constricted.

EXPERIMENT 50

DECEMBER 17, 1910.

Mongrel dog; weight, 10 kilos; condition, good. Ether. Four main branches of arteries and veins supplying 20 cm. of the terminal portion of the ileum were ligated.

DECEMBER 18.

Temperature, 39.4° C.; respiration, 20; pulse, 160. General condition, poor.

DECEMBER 19.

Death occurred at 6:00 A. M., about 44 hours after the ligation. The autopsy revealed the presence of free bloody fluid in the abdominal cavity, general peritonitis, gangrene of the loop of ileum, and distention of the intestines above the latter. The duodenum was more distended than the rest of the small intestine. Eight centimeters above the place where the gangrene began the small intestine was intussuscepted for 6 cm.

EXPERIMENT 51

APRIL 19, 1910.

Mongrel dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. Blood vessels were ligated in the same way, and the abdomen closed. The affected 25 cm. of the intestine was bloodless at the end of the operation.

APRIL 20.

The dog had a good appetite, and seemed to be in good condition. In his food was placed a large amount of lampblack, the mixture being given by means of a stomach tube.

APRIL 21.

Except for profuse diarrhea and vomiting the condition was good. Under ether anesthesia the abdomen was reopened, two days after the ligation, and a portion of the normal as well as of the ischemic intestine removed. It was found that the normal lacteals had taken up the lampblack, while the ischemic lacteals had not. Staining the sections for bacteria showed that the latter had been made more vulnerable to taking up bacteria, that they had passed through the tunica serosa, and that around the intestine there was localized peritonitis. There had also been extensive epithelial desquamation. The blood vessels showed extensive sclerosis, and the tissues generally were very edematous. The lumina of the glands were filled with desquamated cells. The dog recovered.

EXPERIMENT 52

APRIL 18, 1910.

Black and tan dog; condition, good. A cathartic was given twenty-four hours before the operation. Ether. At the junction of the duodenum and jejunum several blood vessels were ligated in the mesentery. By this means a 25 cm. loop of intestine was apparently deprived of its blood supply. The abdomen was closed in the usual way, and the dog allowed to recover.

APRIL 19.

The dog was in good condition, and showed no symptoms attributable to the ligation.

APRIL 28.

All the time during the past ten days the dog had been in good condition, and had shown no symptoms of any sort. Under ether anesthesia the abdomen was reopened, and a portion of the ischemic loop resected. Sections made from this portion showed that certain areas were necrotic. Throughout there had been great desquamation of the epithelium of the lumen of the intestine, accompanied by some hemorrhage into the tissues. For the greater part the sections stained poorly, and, in some areas, amyloid changes could be demonstrated. The tissue, as a whole, was very edematous, and structural details could not be made out clearly.

Group VIII

Control Experiment

EXPERIMENT 53

FEBRUARY 24, 1909.

Fox terrier dog; condition, fair. Ether; morphia, gr. $\frac{1}{4}$. As a control for the other experiments the abdomen was opened and a lateral anastomosis made. No loop of intestine was ligated. The abdomen was closed in the usual way. The dog made an uninterrupted recovery.

Note.—No more control experiments were done at this time, because a wide experience in doing even more serious operations on the intestines of dogs has shown that, when properly done under aseptic precautions, the operative side alone is an almost negligible factor in affecting the results.

Tabulation of the Experiments on Intestinal Anemia

NUMBER	Length of Loop	Duration of Ligation	Changes in Loop	Duration of Life
GROUP I:				
1	15 cm.	1 hour	No gross changes	15 hours, cause of death not determined
2	15 cm.	1 hour	No gross changes	54 days, chloroformed
3	30 cm.	1 hour	None, adhesions	55 days, chloroformed
4	15 cm.	1 hour	.....	Complete recovery
5	17 cm.	2 hours	Congestion, perforation near ligation, acute peritonitis	6 days, death from acute peritonitis
6	15 cm.	2 hours	None	54 days, chloroformed
7	20 cm.	2 3/4 hours	Congestion	About 18 hours
8	25 cm.	3 hours	None, adhesions	10 days
9	10 cm.	4 hours	No gross changes	Short time, death from ether
10	15 cm.	4 hours	No gross changes, adhesions	8 days
11	30 cm.	5 hours	Gangrene	About 18 hours
12	15 cm.	5 hours	None, adhesions	7 days, chloroformed
13	20 cm.	6 hours	Gangrene	24 hours
14	20 cm.	6 hours	Partly gangrenous	About 18 hours
15	15 cm.	6 hours	Gangrene	About 18 hours
16	15 cm.	6 hours	Partly gangrenous	2 1/2 days
17	30 cm.	6 hours	Anemic	1/2 hour after operation
18	25 cm.	8 hours	Gangrene	About 30 hours
19	15 cm.	8 hours	Gangrene	About 18 hours
20	15 cm.	8 hours	Gangrene	About 18 hours
21	7 cm.	8 hours	Gangrene	About 36 hours
22	15 cm.	8 1/4 hours	Gangrene	About 18 hours
23	15 cm.	8 hours, 40 mins.	Gangrene	About 18 hours
24	15 cm.	9 hours	Gangrene	About 18 hours
GROUP II:				
25	15 cm.	7 hours	Gangrene	Short time after operation
26	.....	8 hours	Almost gangrenous	About 30 hours
27	15 cm.	8 hours	Gangrene	About 2 1/2 days
28	20 cm.	8 hours	No return of circulation	Short time after operation
29	20 cm.	8 hours	Gangrene	About 18 hours
GROUP III:				
30	20 cm.	(About 18 hours)	Gangrene	About 18 hours
31	15 cm.	(About 18 hours)	Gangrene	About 18 hours
32	25 cm.	(About 18 hours)	Gangrene	About 18 hours
33	15 cm.	(About 18 hours)	Gangrene	About 18 hours
34	15 cm.	(About 30 hours)	Gangrene	About 30 hours
GROUP IV:				
35	15 cm.	7 hours	(loop excised)	Recovery
36	20 cm.	7 hours	(loop excised)	Death on 6th day, due to faulty technique
37	20 cm.	7 1/2 hours	(loop excised)	Recovery
38	20 cm.	8 hours	(loop excised)	About 18 hours
39	30 cm.	10 hours	(loop excised)	Lived 10 hours, when death was caused by second etherization for removal of the loop
GROUP V:				
40	25 cm.	About 18 hours	Gangrene	About 18 hours
41	90 cm.	About 18 hours	Gangrene	About 18 hours
42	90 cm.	About 27 hours	Gangrene	About 27 hours
43	90 cm.	About 30 hours	Gangrene	About 30 hours
44	25 cm.	4 days	Gangrene	9 days
45	30 cm.	14 days	Gangrene, sloughing	Recovery
GROUP VI:				
46	60 cm.	1 day	Sloughed away	Recovery
47	30 cm.	1 day	Gangrene, cut away	Recovery

Tabulation of the Experiments on Intestinal Anemia—(Continued)

NUMBER	Length of Loop	Duration of Ligation	Changes in Loop	Duration of Life
GROUP VII:				
48	Vessels ligated in 90 cm. loop	About 18 hours	Gangrene	About 18 hours
49	Vessels ligated in 15 cm. loop	About 31 hours	Gangrene	About 31 hours
50	Vessels ligated in 20 cm. loop	About 44 hours	Gangrene	About 44 hours
51	Vessels ligated in 25 cm. loop	10 days	Gangrene	Recovery after removal of loop
52	Vessels ligated in 25 cm. loop	10 days	Gangrene	Recovery after removal of loop
GROUP VIII:				
53	.....	.....	.....	Control experiment, recovery

Summary of Experiments on Intestinal Anemia

GROUP I.—Intestine ligation, removal of ligature before closing the abdomen.

Number of experiments.....	24
Duration of ligation.....	1 to 9 hours
Recoveries—dog lived one week or longer	7
Deaths	17 (70.8%)

GROUP II.—Lateral anastomosis, ligation, removal of ligature before closing abdomen.

Number of experiments.....	5
Duration of ligation.....	7 to 8 hours
Recoveries—dog lived one week or longer	0
Deaths	5 (100%)

GROUP III.—Lateral anastomosis, ligation, ligature left in place.

Number of experiments.....	5
Duration of ligation.....	18 to 30 hours
Recoveries—dog lived one week or longer	0
Deaths	5 (100%)

GROUP IV.—Lateral anastomosis, ligation, excision of loop before closing abdomen.

Number of experiments.....	5
Duration of ligation.....	7 to 10 hours
Recoveries—dog lived one week or longer	2
Deaths from faulty technique.....	2 (40%)

GROUP V.—Lateral anastomosis, ligation, insertion of drainage tube into loop, abdomen closed.

Number of experiments.....	6
Duration of ligation.....	18 hrs. to 14 days
Recoveries—dog lived one week or longer	2
Deaths	4 (66 2/3%)

GROUP VI.—Lateral anastomosis, ligation with loop made to project from abdomen until it sloughed off.

Number of experiments.....	2
Duration of ligation.....	1 to 2 days
Recoveries—dog lived one week or longer	2
Deaths	0 (0%)

GROUP VII.—Ligation of blood-vessels supplying a loop of intestine.

Number of experiments.....	5
Duration of cessation of blood supply	18 hrs. to 10 days
Recoveries—dog lived one week or longer	2 ¹
Deaths	3 (60%)

¹ Part of the gangrenous loop was removed for microscopical examination.

THE INJECTION INTO THE INTESTINAL TRACT AND PERITONEAL CAVITY OF DOGS OF JUICE FROM LOOPS OF SMALL INTESTINE PREVIOUSLY RENDERED ISCHEMIC FOR VARYING PERIODS OF TIME

In this series of experiments, the natural corollary of the preceding series, loops of the small intestine of dogs were deprived of their circulation, usually for eight hours, by the usual method of ligation. The loops were then removed, care-

fully washed, and placed in a mild antiseptic solution to kill bacteria in the intestinal tract, washed again in normal saline solution, ground up with sterile sand, filtered, the filtrate diluted if necessary with sterile normal saline solution, and the resulting fluid injected as stated in the following experiments.

The point was to ascertain the effect of absorption into the peritoneal cavity of wholly or partially gangrenous intestine with its bacteria and their toxins.

Group I

Injection into the Peritoneal Cavity

EXPERIMENT 1

FEBRUARY 4, 1909.

Bulldog bitch; condition, good. Before the injection her temperature was 37.8°C. , and pulse 90 per minute. At 9:00 A. M. 10 c. c. of intestinal extract, prepared as stated above, were injected into the peritoneal cavity under aseptic precautions. By noon the bitch was very sick, her temperature having risen to 39.4°C. , and her pulse to 140. The prostration was extreme. Death occurred at 3:00 P. M., 6 hours after the injection was given. Just before death the temperature had fallen to subnormal. At the autopsy the peritoneum was found to be congested. Otherwise the findings were negative.

EXPERIMENT 2

MARCH 9, 1909.

Mongrel dog; condition, good. Under ether anesthesia 10 c. c. of intestinal extract were injected into the peritoneal cavity. Pulse and temperature previous to this were normal. At 9:00 A. M. the temperature was 38.3°C. At 3:30 P. M. the dog was very weak, with a temperature of 39.4°C. There was some vomiting, but the prostration was the most prominent symptom. Death occurred at 5:30 P. M. The autopsy revealed nothing but intense congestion at the site of the injection.

EXPERIMENT 3

OCTOBER 27, 1909.

Mongrel dog; weight, 4.9 kilos; condition, good. Under light ether anesthesia 10 c. c. of intestinal extract were injected into the

abdominal cavity at 5:00 P. M. At this time, without apparent cause, the temperature was 38.3°C . Two hours later it had fallen to 37.4°C . Twelve hours after the injection the dog was found dead, having vomited clear, greenish fluid several times during the night, and also having had diarrhea.

EXPERIMENT 4

OCTOBER 29, 1909.

Mongrel dog; weight, 4.2 kilos; condition, poor. The thyroid gland was enlarged. At 10:50 A. M. 8 c. c. of intestinal extract were injected into the abdominal cavity. Temperature, 37.2°C . At 2:00 P. M. the temperature had fallen to 35.1°C ., the pulse being 76 and the respiration 16. The dog was very sick and cold, and constantly shivered. At 9:50 P. M. the temperature was the same, the pulse 96, and the respiration 32. The dog died at 3:20 A. M., $16\frac{1}{2}$ hours after the injection.

EXPERIMENT 5

NOVEMBER 5, 1909.

Mongrel dog; condition, poor. Ether for 5 minutes. Temperature, 38.6°C .; pulse, 196; respiration, 22. At 9:00 P. M. 10 c. c. of intestinal extract were injected intraperitoneally. The injection had no effect, and recovery followed.

EXPERIMENT 6

DECEMBER 14, 1910.

Mongrel dog; weight, 11 kilos; condition, good. At 10:30 A. M. 20 c. c. of intestinal extract were injected intraperitoneally. A slight fall in temperature followed, the dog's feet became cold, and he was constantly sick, but complete recovery followed, the last note being made 15 days later.

EXPERIMENT 7

DECEMBER 15, 1910.

Beagle dog; weight, 9 kilos; condition, good. Prolonged etherization. At 9:00 A. M. 10 c. c. of intestinal extract were injected intraperitoneally. At 10:30 the temperature was 36.0°C ., the pulse 72, and the respiration 28. At 6:15 P. M. the temperature had risen to about 38.3°C . and the respiration to 40. The dog was very thirsty, drinking $1\frac{1}{2}$ quarts of water at one time, vomited, and had constant priapism. The pulse was very weak and uncountably rapid. Death occurred at about 12:00 midnight, 15 hours after the injection.

AUTOPSY.—Rigor mortis was well developed 10 hours post mortem. There was free bloody peritoneal fluid, no adhesions of the intestines, although the surfaces of the coils were dead and lusterless

in appearance; the kidneys showed punctate ecchymoses, with parenchymatous degeneration, the liver the same, and the heart had stopped in systole. The brain was softer than normal, and showed punctate hemorrhages.

EXPERIMENT 8

DECEMBER 15, 1910.

Mongrel dog; weight, 14 kilos; condition, good. Ether. Twenty c. c. of intestinal extract were injected intraperitoneally at 11:00 A. M. While the dog was more or less prostrated temporarily recovery was complete at the end of 9 days.

EXPERIMENT 9

DECEMBER 15, 1910.

Mongrel dog; weight, 7 kilos; condition, good. Ether. At 9:30 A. M. 10 c. c. of intestinal extract were injected intraperitoneally. There was a rise of temperature, pulse, and respiration. The dog became ill, with cold extremities, great thirst, and sudden starting on being touched, but there was no diarrhea or vomiting.

DECEMBER 16.

Death probably occurred at about 4:00 A. M., as the dog was found dead, and the body was still warm at 10:00 A. M.

AUTOPSY.—Rigor mortis present. The intestines were matted together. The brain was injected, reddened from punctate hemorrhages, and softer than normal. The heart had stopped in systole, the lungs were clear, the kidneys showed parenchymatous degeneration and were swollen, the liver showed fatty degeneration, the spleen was unaffected, and there was free fluid in the peritoneal cavity.

EXPERIMENT 10

DECEMBER 15, 1910.

Mongrel dog; weight, 7.5 kilos; condition, good. Prolonged ether anesthesia. At 10:00 A. M. 10 c. c. of intestinal extract were injected intraperitoneally. The temperature, pulse, and respiration rose markedly, and the dog was very ill, but by 6:15 P. M. his condition was better than that of the other two dogs injected at the same time. Recovery followed, and was complete 15 days later. Two out of the last three dogs lived, while the third (Exp. 15) died, the dog that died being practically the same weight as the dog in this experiment.

EXPERIMENT 11

DECEMBER 22, 1910.

Mongrel bitch; weight, 6 kilos; condition, good. At 11:00 A. M. 10 c. c. of intestinal extract were injected intraperitoneally, and death

occurred probably 14 hours later. At the autopsy, 24 hours after the injection, the body was found to be stiff, the viscera were all injected, and there was free bloody fluid in the abdominal cavity.

EXPERIMENT 12

JANUARY 16, 1911.

Mongrel bitch with enlarged thyroid gland; weight, 10 kilos; condition, good. At 9:30 A. M. 10 c. c. of intestinal extract were injected intraperitoneally. There was fever, with rise of pulse and respiration, but no vomiting or diarrhea. Complete recovery followed.

EXPERIMENT 13

JANUARY 16, 1911.

Mongrel dog; weight, 9.5 kilos; condition, good. At 9:45 A. M. 10 c. c. of intestinal extract were injected intraperitoneally. At 3:15 P. M. the stool was normal, and there was no vomiting. Later diarrhea began. The general condition was poor, with temperature of 38.9° C., pulse of 80, and respiration of 32.

JANUARY 17.

The dog was found dead at 6:45 A. M., 21 hours after the injection.

EXPERIMENT 14

JANUARY 25, 1910.

Bulldog; weight, 15.3 kilos; condition, good. Ether; morphia, gr. 1/2. At 12:00 M. 17 c. c. of intestinal extract were injected intraperitoneally. Subsequently in 3 1/2 hours the temperature fell 0.4° C., the pulse 24 beats, and the respiration rose from 16 to 44 per minute. Death occurred about 15 hours later.

Group II

Injection into the Lumen of the Intestine

EXPERIMENT 15

MARCH 9, 1909.

Mongrel bitch; condition, good. Under ether anesthesia the abdomen was opened, and small, frequently repeated doses of intestinal extract were injected into the jejunum. Ten c. c. were injected every 10 minutes, until 60 c. c. in all had been given. Six hours later the bitch showed great prostration, with vomiting and diarrhea. The temperature was 38.9° C.

MARCH 10.

Great prostration was still present, as well as the vomiting and diarrhea. Temperature, 38.9°C .

MARCH 11.

Condition, better. Temperature, 38.6°C .

MARCH 14.

Temperature, 37.8°C . Condition continued to improve.

EXPERIMENT 16

MARCH 10, 1909.

Mongrel dog; condition, good. At 9:00 A. M., under ether anesthesia, the abdomen was opened, and 20 c. c. of intestinal extract injected into the duodenum. By noon the dog had recovered from the anesthetic, but was greatly prostrated. The temperature was then subnormal. At 1:00 P. M. death occurred, apparently from extreme exhaustion.

EXPERIMENT 17

MARCH 12, 1909.

Mongrel dog; condition, good. Under ether anesthesia 30 c. c. of intestinal extract were injected into the jejunum. By noon the dog had recovered from the anesthetic, but was in poor general condition. He vomited frequently. Temperature, 39.5°C . By 5:00 P. M. the condition had grown worse. There was beginning diarrhea, and the vomiting was more frequent. Temperature, 40.0°C .

MARCH 13.

In the morning the dog was found dead. At the autopsy the jejunum was found to be congested. For 120 cm. below the point of injection it looked very much as if atony of the bowel had been present, owing to the stasis of intestinal contents. Otherwise the findings were negative.

EXPERIMENT 18

MARCH 16, 1909.

Mongrel dog; condition, good. Temperature, before operation, 38.3°C .; pulse, 100. Under ether the abdomen was opened at 9:00 A. M., and 10 c. c. of intestinal extract were injected into the jejunum. By noon the dog had recovered from the anesthetic, but was still somewhat prostrated. There was no vomiting or diarrhea. Temperature, 38.9°C .; pulse, 110.

MARCH 17.

There was some diarrhea, but no vomiting. Temperature, 39.4°C .; pulse, 120.

MARCH 18.

General condition, good. Temperature, 38.3°C .; pulse, 100.

EXPERIMENT 19

MARCH 18, 1909.

Mongrel bitch; condition, good. Temperature, before operation, 37.8°C .; pulse, 100. Under ether the abdomen was opened, and 300 c.c. of intestinal extract were injected into the jejunum. By noon the bitch had recovered from the anesthetic, but her condition was poor, and growing worse. There was frequent vomiting.

MARCH 19.

There was less frequent vomiting, but profuse diarrhea and great prostration. Temperature, 38.9°C .; pulse, 140.

MARCH 20.

The prostration was extreme, but there was still less vomiting. Temperature, 38.3°C .; pulse, 130.

MARCH 21.

Some improvement had occurred. There was no diarrhea or vomiting. Temperature, 38.6°C .; pulse, 130.

MARCH 22.

The bitch was very much better, and convalescing rapidly.

EXPERIMENT 20

FEBRUARY 18, 1909.

Mongrel dog; condition, good. Temperature, before injection, 38.0°C .; pulse, 90.

9:00 A. M.—Under ether anesthesia 20 c.c. of intestinal extract were injected into the duodenum, just below the pylorus, the abdomen having been opened under careful asepsis.

12:00 M.—The dog was vomiting, and had profuse diarrhea. Temperature, 40.0°C .; pulse, 130.

6:00 P. M.—The dog was very ill and extremely prostrated. Neither vomiting nor diarrhea was as severe as before. Temperature, 41.1°C .; pulse, 140.

FEBRUARY 19.

In the morning the dog was still greatly prostrated, but was somewhat better. The vomiting had stopped, but the diarrhea still

continued actively. Temperature, 40.0°C .; pulse, 140. At 6:00 P. M. the condition had continued to improve. The temperature had fallen to 39.4°C ., and the pulse to 120.

FEBRUARY 20.

The improvement had continued, the temperature being still lower. Both vomiting and diarrhea had ceased.

FEBRUARY 25.

The dog seemed in every way to be normal.

EXPERIMENT 21

FEBRUARY 23, 1909.

Mongrel dog; condition, good. Ether. Ten c.c. of intestinal extract were injected into the small intestine, as in the preceding experiment. Immediately after the abdomen was closed the temperature was 37.2°C . and the pulse 100.

4:00 P. M.—The dog had recovered from the ether, but was very sick. He vomited occasionally. Temperature, 37.8°C .; pulse, 120.

5:00 P. M.—The condition was growing worse. Occasional vomiting and some diarrhea. Temperature, 38.5°C .

FEBRUARY 24.

The dog was extremely prostrated. There was profuse diarrhea and some vomiting. Temperature, 39.6°C .; pulse, 140.

FEBRUARY 26.

While some infection of the abdominal wound was present the dog was better. Temperature, 38.3°C .

FEBRUARY 28.

Dog still better. There was no doubt that convalescence would be uninterrupted. Wound, clean. Temperature, 37.8°C .

Group III

Injection Intravenously

EXPERIMENT 22

JANUARY 6, 1911.

Mongrel dog; weight, 11 kilos; condition, good. This was a dog that had previously recovered from an experiment in which a portion of his small intestine had been ligated for 10 hours and then removed.

Ether. Five c. c. of intestinal extract were injected into the external jugular vein at 10:15 A. M. Temperature, 35.0° C. immediately after stopping the ether. At 4:00 P. M. it had risen to 38.9° C.; the pulse was 112, and the respiration 26.

JANUARY 7.

8:00 A. M.—Temperature, 38.9° C.; pulse, 128; respiration, 24.

JANUARY 8.

7:30 A. M.—Temperature, 40.0° C.; pulse, 120; respiration, 18. Appetite and general condition, good.

JANUARY 9.

11:00 A. M.—Temperature, 38.9° C.; pulse, 160; respiration, 18. The high pulse was probably due to the fact that the dog had been disturbed considerably when his temperature was taken.

JANUARY 10.

8:00 A. M.—Temperature, 38.9° C.; pulse, 176; respiration, 18. From this date on the dog made an uninterrupted recovery.

In this experiment the question arises as to whether or not the previous gut-ligation for 10 hours did not confer a certain amount of immunity against the injection of intestinal extract.

EXPERIMENT 23

JANUARY 16, 1911.

Spaniel dog; weight, 8.5 kilos; condition, good. At 9:30 A. M. 10 c. c. of intestinal extract were injected into the external jugular vein. Vomiting and bloody diarrhea soon followed, and the dog was very sick. At 3:15 P. M. the dog was cold and rigid. Temperature, 38.6° C.; pulse, 76; respiration, 44. At 8:00 P. M., 11 hours after the injection, death occurred.

EXPERIMENT 24

JANUARY 16, 1911.

Mongrel dog; weight, 12.5 kilos; condition, good. At 9:00 A. M. 10 c. c. of intestinal extract were injected into the external jugular vein. Constant vomiting followed, and a bloody stool was passed. At 3:15 P. M. the temperature was 38.7° C., the respiration 40, and the pulse too feeble to count. Death occurred at 3:30 P. M., 6½ hours after the injection.

*Group IV**Injection Intraperitoneally of Intestinal Juice from a Dead Dog***EXPERIMENT 25**

NOVEMBER 19, 1909.

Mongrel dog; weight, 7.2 kilos; condition, good. At 9:00 A. M. the temperature was 38.5°C. , the pulse 114, and the respiration 24. Ten c.c. of intestinal extract, made from the small intestine of a dog that had been dead for $6\frac{1}{2}$ hours, was injected intraperitoneally. At 4:00 P. M. the dog was very sick and cold. No knee-jerks or reflexes from a lighted match held near the eyes could be obtained. The muscles were rigid. Temperature, 39.5°C. ; pulse, 84; respiration, 22. At 10:59 the temperature was 38.4°C. ; the pulse, 84; and the respiration, 18. There were still absolutely no reflexes to be obtained, and the condition of collapse was profound. Death occurred at 7:30 A. M., $22\frac{1}{2}$ hours after the injection. The autopsy showed peritonitis to be present.

EXPERIMENT 26

NOVEMBER 18, 1909.

Mongrel dog; condition, good. Temperature, 37.2°C. ; pulse, 84; respiration, 32. At this time 10 c.c. of intestinal extract from the intestines of dogs dead for 16 hours were injected intraperitoneally. The dog became weak and sick, and soon began to suffer from diarrhea. At 12:15 P. M. the temperature was 34.4°C. , the pulse 96, and the respiration 24. Neither knee-jerks nor eye reflexes could be obtained. At 3:00 P. M. the dog was having convulsions, his temperature was still subnormal, and he felt cold to the touch. Reflexes were still absent. At 3:45 the dog was dying. He seemed to be suffering from great pain, for which morphia, q. s., was given. Death occurred shortly after this observation, 8 hours after the injection.

AUTOPSY.—There was much free fluid in the abdomen, but no peritonitis. The intestines were not dark in color, as they were in the dogs receiving intestinal extract from gangrenous intestine.

*Group V**Injection of Sterilized Intestinal Extract (1) Intravenously
and (2) Intraperitoneally***EXPERIMENT 27**

DECEMBER 22, 1910.

Mongrel dog; condition, good. Intestinal extract was heated for one hour to 56° C. on two successive days. On injecting 5 c. c. into the external jugular vein the respiration immediately increased from 20 to 60, and the pulse got very weak and rapid. In 5 minutes the respiration fell to 30, but the pulse continued weak and rapid, rate of 160. The next day the dog was not sick at all, and a complete recovery was made.

EXPERIMENT 28

JANUARY 7, 1911.

Mongrel dog; weight, 9 kilos; condition, good. Five c. c. of the sterilized toxin used in the last experiment were injected into the external jugular vein at 9:00 A. M. At 7:00 P. M. the pulse was too rapid to count, the temperature was 39.2° C., and the respiration 56. The dog was sick, refused food, drank water, had incoördinated movements, and had bloody diarrhea.

JANUARY 8.

General condition, good. Temperature, 38.0° C.; pulse, 60; respiration, 20. After this recovery soon followed and was complete.

EXPERIMENT 29

JANUARY 7, 1911.

Mongrel bitch; weight, 8 kilos; condition, good. Five c. c. of the same sterilized extract that was used in the other two experiments in this group were given intraperitoneally. The effect was very slight, if present at all at any time, and the bitch made an uninterrupted recovery.

*Injection into Dogs of Intestinal Extract from Gangrenous
Intestine of Dogs, or of Extract from Intestine
of Dead Dogs*

EXPERIMENT NUMBER	Weight of Dog	Amount of Ex- tract Injected	Where Injected	Results
GROUP I:				
1	.....	10 c. c.	Peritoneal cavity	Death after 6 hours
2	.....	10 c. c.	Peritoneal cavity	Death after 8½ hours
3	4.9 kilos	10 c. c.	Peritoneal cavity	Death after 12 hours
4	4.2 kilos	8 c. c.	Peritoneal cavity	Death after 16½ hours
5	.....	10 c. c.	Peritoneal cavity	Recovery
6	11.0 kilos	20 c. c.	Peritoneal cavity	Recovery
7	9.0 kilos	10 c. c.	Peritoneal cavity	Death after 15 hours
8	14.0 kilos	20 c. c.	Peritoneal cavity	Recovery
9	7.0 kilos	10 c. c.	Peritoneal cavity	Death after about 18½ hours
10	7.5 kilos	10 c. c.	Peritoneal cavity	Recovery
11	6.0 kilos	10 c. c.	Peritoneal cavity	Death after about 14 hours
12	10.0 kilos	10 c. c.	Peritoneal cavity	Recovery
13	9.5 kilos	10 c. c.	Peritoneal cavity	Death after 21 hours
14	15.3 kilos	17 c. c.	Peritoneal cavity	Death after about 15 hours
GROUP II:				
15	.....	60 c. c. in divided doses	Jejunum	Recovery, but dog very ill
16	.....	20 c. c. at one time	Duodenum	Death after 4 hours
17	.....	30 c. c.	Jejunum	Death after about 18 hours
18	.....	10 c. c.	Jejunum	Recovery, some prostra- tion
19	.....	300 c. c. at one time	Jejunum	Recovery, but very ill
20	.....	20 c. c.	Duodenum	Recovery, but very ill
21	.....	10 c. c.	Duodenum	Recovery, but very ill
GROUP III:				
22	11.0 kilos	5 c. c.	External jugular vein	Recovery, very ill ¹
23	8.5 kilos	10 c. c.	External jugular vein	Death after 11 hours
24	12.5 kilos	10 c. c.	External jugular vein	Death after 6½ hours
GROUP IV:²				
25	7.2 kilos	10 c. c.	Intraperitoneally	Death, 22½ hours
26	.....	10 c. c.	Intraperitoneally	Death after 8 hours
GROUP V:³				
27	.....	5 c. c.	Ext. jugular vein	Recovery after temporary disturbance
28	9.0 kilos	5 c. c.	Ext. jugular vein	Recovery, ill
29	8.0 kilos	5 c. c.	Intraperitoneally	Recovery, no effect

¹ This dog had probably previously acquired immunity—see experimental details.

² Extract made from intestines of dead dogs.

³ The extract ordinarily used, but sterilized by heating.

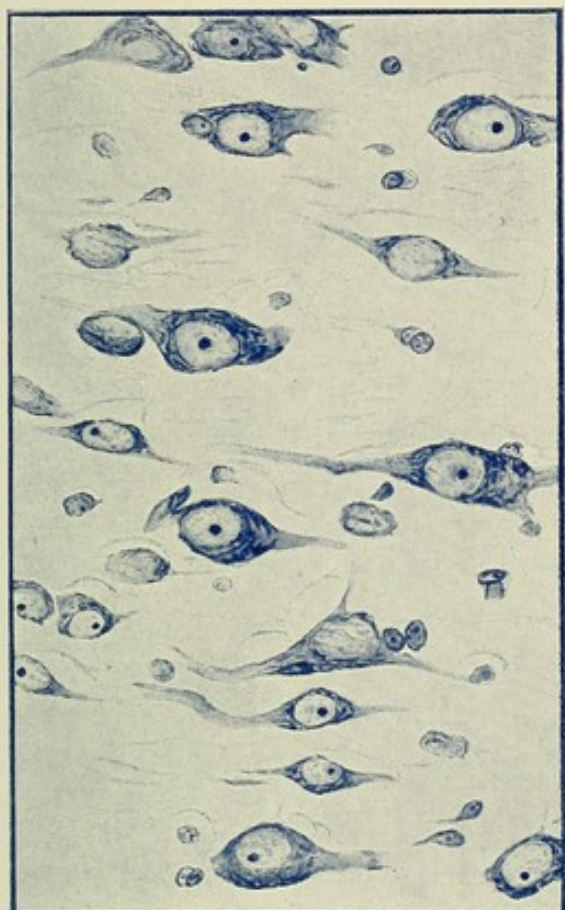


FIG. VII.—CORTEX FROM NORMAL DOG.

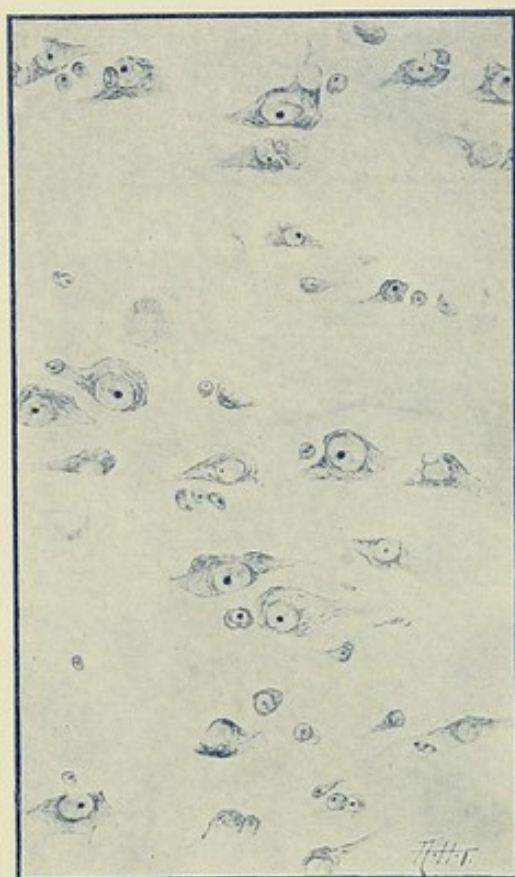
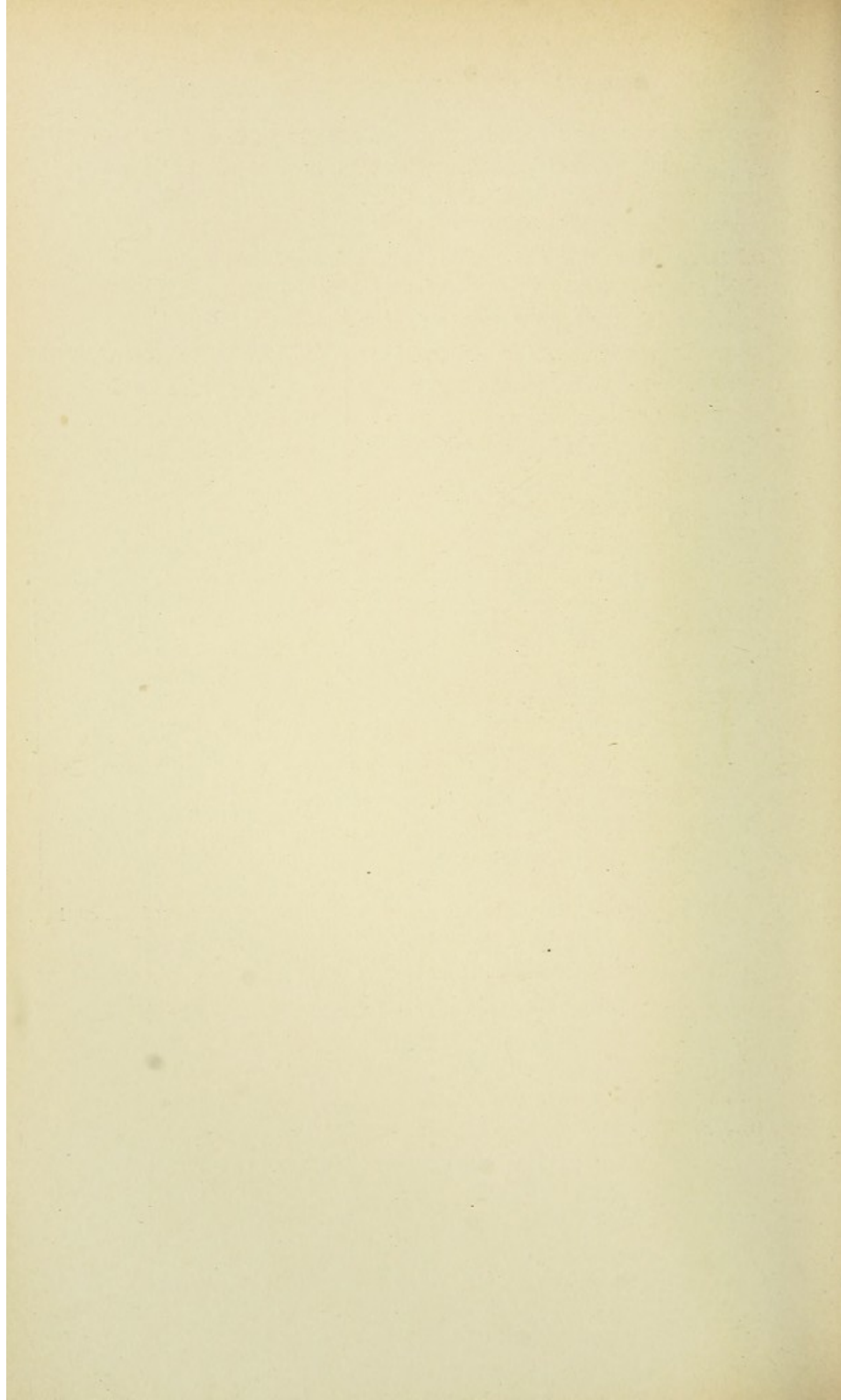


FIG. VIII.—CORTEX FROM TOXEMIC DOG.

BRAIN CELL CHANGES PRODUCED BY TOXEMIA DUE TO ANEMIA OF THE
SMALL INTESTINES OF A DOG.



Summary of Experiments on the Injection into Dogs of Intestinal Extract from Gangrenous Intestine of Dogs or of Extract from Intestines of Dead Dogs

GROUP I.—Injection into the peritoneal cavity.		
Number of experiments.....	14	
Recoveries	5	
Deaths	9	(64.2%)
GROUP II.—Injection into the lumen of the intestine.		
Number of experiments.....	7	
Recoveries	5	
Deaths	2	(28.5%)
GROUP III.—Injection intravenously.		
Number of experiments.....	3	
Recoveries	1 ¹	
Deaths	2	(66.2/3%)
GROUP IV.—Injection intraperitoneally of extract from intestines of dead dogs.		
Number of experiments.....	2	
Recoveries	0	
Deaths	2	(100%)
GROUP V.—Injection of sterilized intestinal extract, such as was used unsterilized in Groups I-III, inc.		
Number of experiments ²	3	
Recoveries	3	
Deaths	0	(0%)

¹This dog may have been rendered immune by a previous experiment.

²Two intravenously, one intraperitoneally.

From both of the series of experiments just presented one fact stood out with striking clearness, and this was the very poisonous nature of the substances absorbed into the circulation from the gangrenous gut, or injected into the circulation in the form of extract. The symptoms of collapse were practically always severe, and were followed (or accompanied) by either a rise or fall of temperature. The change of temperature in either direction might amount to several degrees.

When the gut was obstructed the symptoms were necessarily those of intestinal obstruction. When the gut was not obstructed, or when extract was injected, the symptoms were identical, showing that in clinical cases of intestinal obstruction the mere fact of obstruction is of importance at least in part because it causes damming of the intestinal contents with increased toxin formation from increased bacterial activity, and subsequent increased absorption of the toxins. As long as there is gangrenous bacteria-laden gut present, even if only detached in the abdominal cavity, poisoning will result from the toxins which get into the circulation by way of the peritoneal lymphatics.

In Experiments 27, 28, and 29 of the second series sterilized intestinal extract was injected intravenously twice and intraperitoneally once, and all three dogs lived. Apparently, therefore, the living bacteria present in either gangrenous gut or extract made from it play an important part in the poisoning. That the poisons are present when the bacteria are dead is indicated in Experiments 27 and 28, in which the symptoms which followed the intravenous injection of sterile extract were identical with those caused by the non-sterile extract. Probably products formed during tissue decomposition act together with the toxins from bacteria. In Experiment 29 no symptoms occurred, but the dose of 5 c. c. was but half that ordinarily given intraperitoneally.

In regard to toxemia from gangrenous gut, the amount of gut involved was a minor detail. Gangrene of 10 centimeters of intestine caused just as severe symptoms as did gangrene of 30 centimeters. A much more important factor was the length of time to which the dog was exposed to the toxemia.

In the ligation experiments it was shown that the small intestine of a dog will not endure complete anemia for a longer period than 6 hours without becoming gangrenous. More-



FIG. IX.—CEREBELLUM FROM NORMAL DOG.

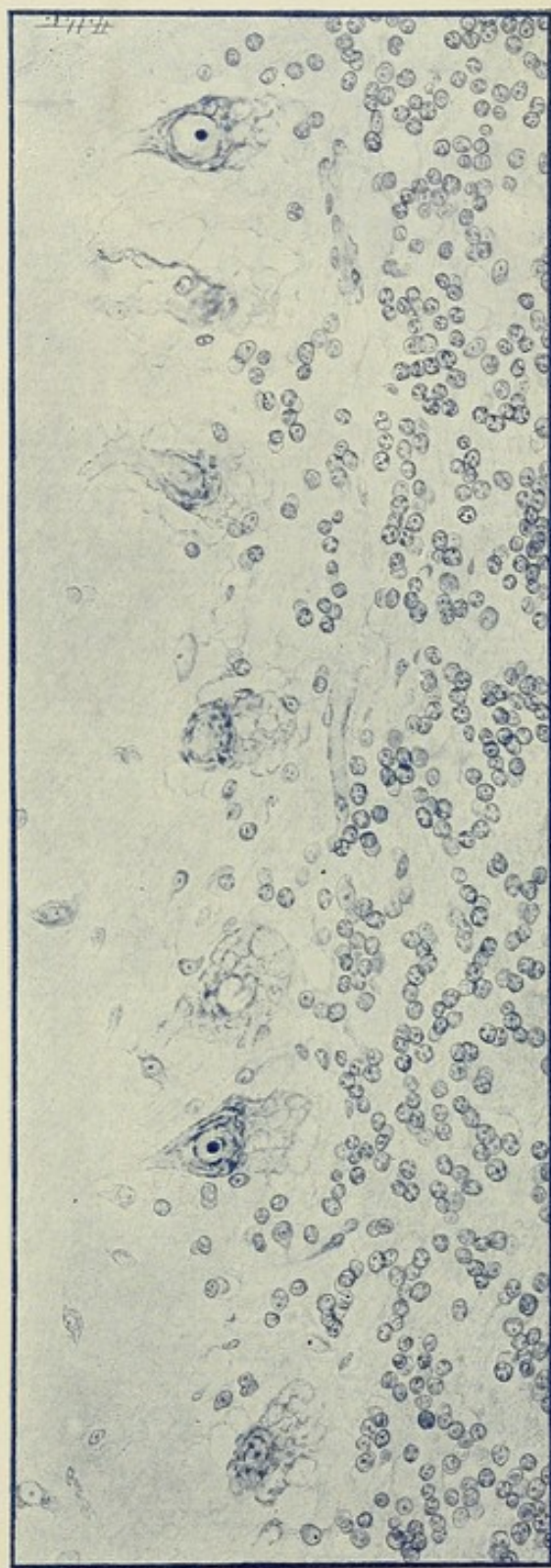
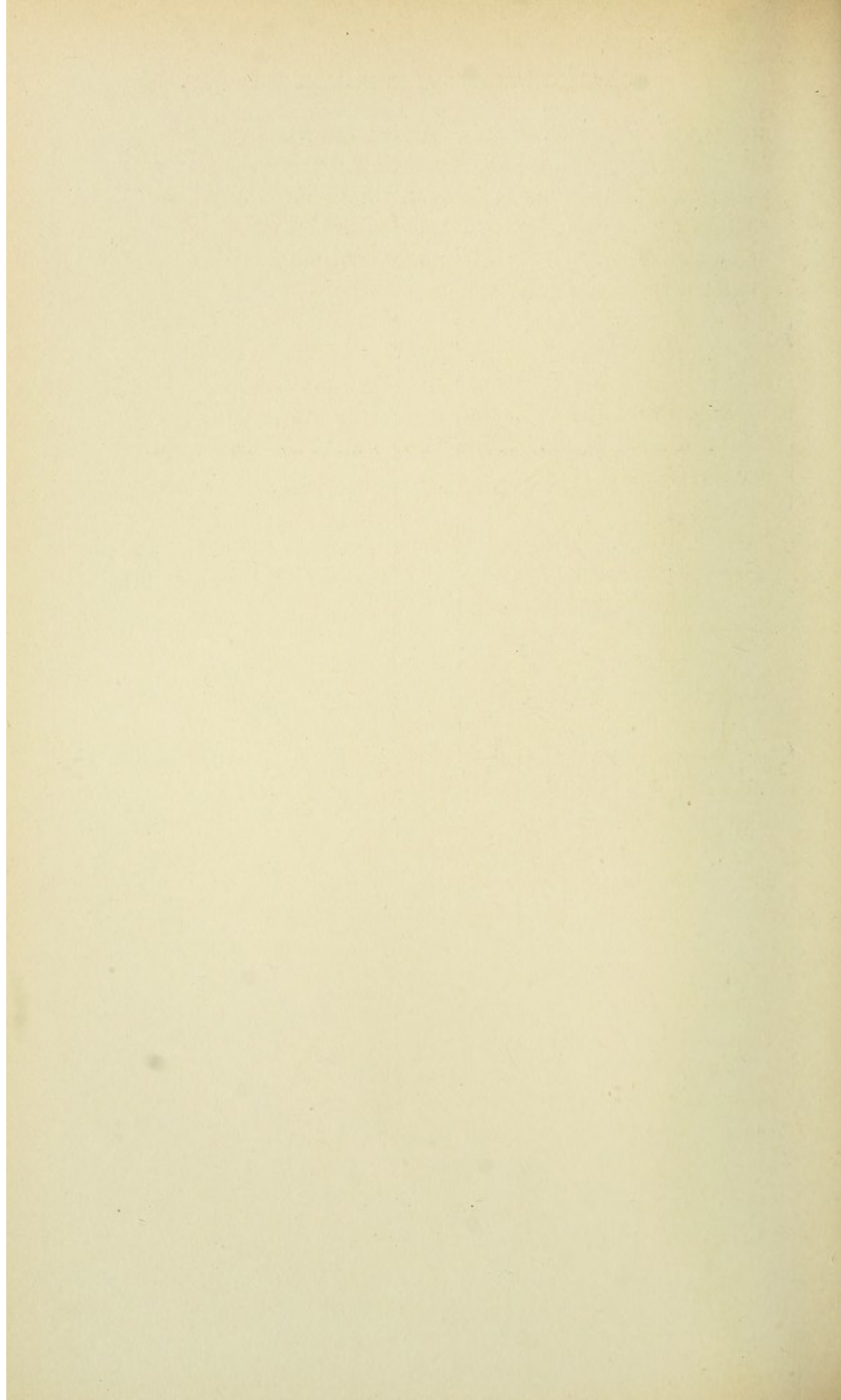


FIG. X.—CEREBELLUM FROM TOXEMIC DOG.

BRAIN CELL CHANGES PRODUCED BY TOXEMIA DUE TO ANEMIA OF THE
SMALL INTESTINES OF A DOG.



over, as shown by Experiments 10 and 23, first series, anemia of five hours may or may not cause gangrene. It is conservative to state that anemia of 3 hours' duration is not permanently harmful to the intestine, and that the danger of partial or total gangrene is in direct ratio to the length of time above three hours that anemia continues.

CONCLUSIONS

From the data of this research a very important principle is established in operations for gangrene of the intestine, viz., that the patient must be protected at all hazards against the absorption of the exceedingly toxic fluid in the gangrenous tissue. The author has witnessed death following a most careful excision of a coil of gangrenous bowel despite the fact that the patient left the table in good condition and that there was absence of peritonitis following the operation.

The clinical symptoms in such cases are largely cerebral. The patient becomes restless, delirious, and unconscious, and is usually entirely free from pain. The pulse and respiration become rapid, the tongue dry, the temperature either high or subnormal. There is usually diarrhea and distention of the abdomen without rigidity or tenderness. Further researches have shown that the real lesion is in the brain cells. Therefore, when operating upon a case of obstruction with a loop of gangrenous intestine present, large clamps should at once be placed on the healthy intestine in such a manner that none of the poisonous substance can be squeezed into the circulation and thus reach the brain. Then, and only then, may the gangrene be removed with safety.

Another point of clinical importance which the experiments demonstrated is that the toxin due to anemic gangrene requires several hours to cause the first symptoms. The injec-

tion experiments, especially the intravenous injections, show that a single dose of sterile toxin can cause grave sickness and even death. When a patient with gangrenous intestine has a certain degree of mental impairment he may have at that moment his fatal dose of toxin. This fact emphasizes the importance of refraining from handling gangrenous intestine, and even more emphasizes the importance of early diagnosis, and the absurdity of waiting for constitutional symptoms in cases of obstruction before advising operation.

In cases of acute intestinal obstruction the most important lesions are in the brain (see Figs. VII, VIII, IX and X).

CHAPTER IX

ANEMIA OF THE KIDNEYS AND SPLEEN

ANEMIA OF THE KIDNEYS

Within the last ten years there has been a renewal of interest in the study of the circulation in the kidneys. Comparatively few investigators, however, have attacked the problem from the very practical operative standpoint of determining how long the renal pedicle may be compressed to the point of total obliteration of circulation without causing damage to the renal structure; in other words, how long the kidneys can endure complete anemia without injury. It is not the intention here to discuss the problems of infarction. Very recently Karsner and Austin have published an account of experimental work of their own, in which they give a good review of the literature of renal infarction, beginning with the classical work of Litten.

Litten found that the kidney of a dog or rabbit could not have its blood supply shut off for more than from one and one-half to two hours without showing marked changes. After long protracted anemia the changes varied in intensity rather than in the extent of involvement.

Carrel has shown that a kidney may be deprived of its circulation for from fifty minutes to an hour and a half and may then be successfully implanted either into another animal or back into its original place. In one striking experiment he reports the removal of a kidney, its reimplantation into the

same animal, and the subsequent removal of the remaining kidney. During the operation the reimplanted kidney was necessarily deprived of its circulation for fifty minutes, but was perfused with Locke's solution during this time. The animal, thus depending for renal function on the one reimplanted kidney, was living and healthy at the end of 23 months, and, moreover, had subjected her kidney to unusual strain during two pregnancies, which resulted in a total of 14 puppies. More striking evidence than this that the kidney of a dog can endure anemia of 50 minutes and maintain functional efficiency could scarcely be presented.

In order to observe "how long the circulation through the renal vessels can be completely obstructed without causing permanent degenerative changes in the kidney," Eisendrath and Strauss clamped the renal vessels of five rabbits for 15, 30, 45, 60, and 90 minutes, respectively, and then studied the effect on the kidney after four weeks had elapsed. In two more experiments the circulation was occluded for two hours in each. In the first the rabbit was killed immediately, while in the second it was killed at the end of 48 hours.

After the clamps had been applied for two hours the gross effect was to cause the kidney to swell and become cyanotic in a marked way. The late effects were quite different, as in the 90-minute experiment the kidney was diminished in size when compared with the other kidney of the same animal, was paler in color, and showed gross evidence of parenchymatous degeneration. In the experiments in which the compression was for less than 90 minutes the size was not materially changed, although in the one-hour experiment the kidney was much smaller and when cut showed parenchymatous degeneration. The histologic changes were very slight when the clamps had been applied for half an hour or less, but in as short an additional time as 15 minutes considerable par-

enchymatous degeneration and interstitial infiltration were caused.

In comparing the results of Eisendrath's and Strauss's experiments with those of Carrel it must be remembered that the rabbit kidney is more sensitive to anemia than the dog kidney. Moreover, in Carrel's experiments the kidneys were removed and perfused with Locke's solution, and, while the latter may have had a beneficial influence, the work of Guthrie would indicate the contrary. Guthrie found that a perfused kidney would not endure anemia so well as a kidney which had been anemic alone. In his experiments on cats anemia of less than an hour did not cause marked changes in the renal structure.

MacNider experimented on cats, permanently ligating the posterior branch of the renal artery of one kidney. He found that ischemia always followed in the part supplied by this branch; that a more or less imperfect collateral circulation developed, which first appeared in the medulla and later invaded the cortex; that by the twenty-fifth day following occlusion the zone of distribution was rather diffusely pink from a more or less even distribution of the carmin injected into the blood vessels, the medulla always containing more of the carmin mass than the cortex, and, finally, that, with the development of obliterative changes in the vessels, the carmin again became more irregularly distributed in the ligated zone. For the detailed and long description of the histologic changes which he found, the reader is referred to the original article.

From his study as a whole MacNider concluded that ligation of the posterior branch of the renal artery leads to necrosis of the greater portion of the cortex and of the superficial portion of the medulla of approximately the posterior one-third of the kidney; that an imperfect anastomosis between the vessels of the two vascular zones is possible and does

develop; that, with the development of the anastomosis, there is, at first, an ingrowth of connective tissue cells into the necrotic zone, followed by an ingrowth of renal epithelium; and that some of the glomeruli are regenerated by an ingrowth of capillary buds, which later become canalized and contain blood. Finally, a secondary fibrosis is inaugurated and, with its development, there is an atrophy of renal tubules, fibrosis of the glomeruli, and obliterative changes in the vessels, the resulting picture being comparable to a chronic interstitial nephritis.

In regard to the problem of regeneration of renal tissue, as MacNider points out, the recent work of Burrows and Carrel is illuminating. After the inoculation of plasmatic media with small fragments of kidney from a cat, exceedingly active growth of the renal cells took place. In one experiment it was found that new epithelial tubules had grown by the beginning of the 7th day. As the authors expressed it: "A few tubes composed of a lumen and limited by epithelial-like cells had passed from the fragment of the kidney for a distance into the plasmatic medium. They had the appearance of renal tubules."

In considering the effects of total anemia on the kidney it should be remembered that considerable histologic change may not be inconsistent with a certain amount of renal function. This fact is brought out in the author's experiments.

Coming to the work on renal anemia done in the author's laboratory, the experiments, all on dogs, were divided into three groups, as follows:

Group I. Experiments in which the renal artery alone of the right kidney was clamped for periods varying from five minutes to four hours (the renal vein and ureter were not included).

Group II. Experiments in which both the renal artery

and vein of the right kidney were clamped for varying periods of time.

Group III. Experiments on dogs from which one kidney had previously been removed.

Group I

Experiments in Which the Renal Artery Alone was Clamped

EXPERIMENTS 1-5 INC.

In these and in all of the following experiments ether was the anesthetic used. With these five dogs the renal artery of the right kidney was clamped for a period varying from 5 to 35 minutes (5, 15, 20, 25, 35). In all instances urine continued to be secreted after the temporary ligation, and in only one—the 35-minute dog—did blood appear in the urine. All of the kidneys were removed at the end of nine days, and sections cut, stained, and examined microscopically.

No permanent changes were found in kidneys rendered anemic for less than 25 minutes, but in the 25-minute and 35-minute experiments varying degrees of epithelial desquamation and edema had taken place. An early change noted was the breaking of the nuclear membrane with diffusion of the nuclear chromatin through the cytoplasm. This condition evidently followed the edematous condition of the cell after the circulation was allowed to return when the clamp was removed. Judging from later experiments it was not an irremediable change. A more detailed study of a 30-minute ligation is given in the next experiment.

EXPERIMENT 6

JANUARY 6, 1910.

Mongrel dog; condition, good, Ether anesthesia. Under careful asepsis the right kidney was exposed and the renal artery clamped for 30 minutes. When the clamp was removed there was no hemorrhage from the capsule, nor could definite pulsations be made out in the kidney. A specimen of urine was not obtained, but a gauze sponge that was held in place over the penis by a bandage, when soaked in a small amount of water, did not give a positive reaction with the benzidin test for blood. The dog was carefully observed for a week, but showed no ill effects from the experiment.

JANUARY 14, 1910.

The dog was again anesthetized and the kidney exposed. The ureter was compressed for twenty minutes. This caused the pelvis of the kidney to dilate, and, on dividing the ureter, a small quantity of urine flowed from it. This was found to contain a few hyaline casts and some blood cells. The latter doubtless came from the edges of the cut ureter rather than from the kidney.

On removing the kidney after separating a few adhesions around it, it was found that very few macroscopic changes had occurred. The capsule was somewhat thickened and adherent, but the line of demarcation between cortex and medulla was preserved. The renal pelvis contained calcareous material, but no well-formed calculi. There were no signs of hemorrhage. Blocks from various parts were removed and sections made.

MICROSCOPICAL EXAMINATION.—The tubular epithelium showed an unevenly distributed desquamation, and where this was absent the portions of the cells toward the lumina had a ragged border. Under a higher magnification the nuclear chromatin was seen to have passed out into the cytoplasm in many of the cells, and in some there was nothing but a shadow of the nucleus remaining. In these cells the staining was diffuse and pale. Some of the tubules contained hyaline and epithelial casts, but they were not nearly so numerous as in experiments in which the time of ligation was longer. Diapedesis had occurred from the glomeruli, the contour of the glomerular vessels not being made out. About the glomeruli there was marked round-cell infiltration, which varied in different parts of the kidney, but seemed to be most marked near the renal capsule. In some areas there seemed to be a certain amount of connective tissue proliferation. Where it was present there was a corresponding narrowing of the lumina of the tubules. This was confined almost entirely to the portion of the kidney nearest the capsule where the blood supply was smallest.

EXPERIMENT 7

JANUARY 8, 1910.

Mongrel bitch; condition, good. Ether anesthesia. The right kidney was exposed, and the renal artery clamped for *45 minutes*. There was no injury of the kidney nor hemorrhage from the capsule when the clamp was removed. The incision was then closed and the bitch returned to the kennel.

JANUARY 9.

The bitch seemed to be in good condition. Pulse rate and temperature normal. A specimen of urine was obtained by pressing over

the bladder. This gave a positive benzidin reaction for blood and contained albumin. The blood test was made every day after this for seven days, but was never again positive. The albumin was constantly present during this time, although in decreasing amount.

JANUARY 19.

The bitch was again anesthetized, the kidney exposed, and the ureter severed. Urine flowed from the ureter, and was found to contain hyaline and epithelial casts. The kidney was then removed and split open. The capsule was thickened and edematous, and more adherent than normal, but, beyond slight general enlargement of the kidney, there were no other macroscopical changes.

MICROSCOPICAL EXAMINATION.—Marked desquamation of the tubular epithelium, with round-cell infiltration around the tubules and glomeruli, was present. The latter was usually in proportion to the former. Throughout the cortex there were newly formed blood vessels, extending inward from the capsule, and this in spite of the fact that there had been no adhesions between the kidney and its bed. The glomeruli were edematous. Their finer structure could not be made out. Most of them showed interglobular hemorrhage and a surrounding zone of round-cell infiltration, as already mentioned. Under an oil immersion lens breaking of the nuclear membrane could be made out with diffusion of the chromatin into the cytoplasm. The desquamation of the tubular epithelium, or raggedness of the parts of the cells toward the lumina, could be seen even more clearly. In areas where the blood supply was less abundant there was extensive proliferation of connective tissue cells, and in other places this was also present, but in lesser degree. As found in the other experiments this proliferation was accompanied by narrowing of the lumina of the tubules, and occasionally by their actual obliteration.

In this instance the changes were, at least in part, of a permanent nature, in spite of the fact that the kidney was still capable of secreting urine. It seems possible that a kidney with such changes might have remained a useful organ.

EXPERIMENT 8

JANUARY 7, 1910.

Mongrel dog; condition, good. Ether anesthesia. The right kidney was exposed, and the artery clamped for 45 minutes. There was no hemorrhage from the capsule, and the macroscopical appearance was normal. The operative recovery was apparently good, and when

the dog was examined at night, about 12 hours after the operation, he seemed still to be in good condition.

JANUARY 8.

The dog was found dead in the morning by the laboratory assistant. At the autopsy a double lobar pneumonia was found, as well as numerous emboli in the lungs. An examination of the kidney failed to show that it was the source of the emboli, but the kidney was much congested and swollen, and the capsule was edematous and thickened.

MICROSCOPICAL EXAMINATION.—The entire organ was edematous, but more especially so around the glomeruli. The tubules contained blood corpuscles, detritus, and a few epithelial casts. The scattering of the chromatin from the nuclei was not found in this experiment, as it was in the preceding ones, and the only change in the cells themselves seemed to be edema. The chief conclusion drawn from the experiment was that the first effect of the return of circulation after anemia is the production of a dropsical condition, and that this is followed by diapedesis.

EXPERIMENT 9

DECEMBER 4, 1909.

Mongrel dog; condition, good. Ether anesthesia. The right kidney was exposed, and the renal artery clamped for 2 hours. Just before the clamp was removed a small incision was made through the capsule. There was no bleeding from this incision. As soon as the clamp was removed free bleeding followed. This showed that the hemostasis had been complete. The operative recovery was good, and, during the next ten days, the dog showed no ill effects from the experiment, eating and drinking as did the other dogs in the kennel.

DECEMBER 15.

The dog was again anesthetized, and the kidney exposed by re-opening the former incision. The kidney was swollen and somewhat edematous and firmly adherent to the overlying peritoneum and to the renal fossa. About the site of the former incision through the capsule there were evidences of an old hemorrhage. On excising and splitting the kidney numerous small hemorrhages into its substance were seen, but the line of demarcation between cortex and medulla remained very distinct. There were no macroscopic areas of colloid degeneration. The left kidney was larger than normal, but showed no other change.

MICROSCOPICAL EXAMINATION.—Throughout the entire kidney there had been extensive interstitial hemorrhages, and round-cell in-

filtration. The glomeruli and tubules showed extensive desquamation of the lining epithelium, causing, as a whole, the appearance of an acute parenchymatous nephritis. The epithelium that had not desquamated stained poorly, presenting a very irregular border to the lumina of the tubules. Numerous epithelial casts could be seen in the tubules. The latter were often greatly dilated, and most markedly in the loop of Henle. Everywhere the most marked changes were found in the glomeruli.

EXPERIMENT 10

DECEMBER 4, 1909.

Mongrel dog; condition, good. Ether anesthesia. The right kidney was exposed, and the renal artery clamped for 3 hours. After removing the clamp the pallor was replaced by redness and congestion. In a few minutes small bleeding points appeared beneath the capsule in some places, while in others this did not occur. As the kidney had not been traumatized by rough handling it was difficult to account for this other than by the fact that internal changes had occurred. Moreover, this phenomenon was observed in several of the other experiments in which the anemia was prolonged. The wound was closed. The operative recovery was good.

DECEMBER 15.

The dog was again anesthetized, and the right kidney removed with difficulty, owing to the formation of dense adhesions. This kidney was considerably larger than the left. It was very edematous, and had subcapsular hemorrhages. Prior to removal section of the ureter showed that no urine was flowing, and none flowed in an hour, even with a small cannula in the proximal end of the ureter to prevent contraction. On splitting the kidney numerous emboli were found, and many areas of infarction and necrosis. The line of demarcation between the medulla and cortex was not very distinct, and the capsule was firmly adherent.

MICROSCOPICAL EXAMINATION.—Throughout the entire organ marked desquamation had occurred, both from tubules and glomeruli, and, in the former, were many hyaline and epithelial casts. There was extensive round-cell infiltration around the tubules and hemorrhage about the glomeruli. Some parts of the medulla had been so damaged that it was almost impossible to recognize the different elements. As in the gross appearance the lack of differentiation between cortex and medulla was very noticeable. The capsule was both thickened and adherent. At the upper pole of the kidney

were many newly formed blood vessels passing into the capsule from the surrounding adhesions.

EXPERIMENT 11

DECEMBER 14, 1909.

Black and tan bitch; condition, good. Ether anesthesia. The right kidney was exposed, and the artery clamped for $3\frac{1}{2}$ hours. At the end of this period the field was still bloodless before removing the clamp. After removing it, there was slight oozing from the capsule, which continued for about five minutes, and blood began to flow again in the renal vein. A small sheet-rubber drain was left in the wound posterior to the kidney and the incision closed around it. Four hours later the urine from the bladder gave a positive benzidin reaction. The urine was tested for blood twice daily, but no positive reaction was obtained after the third day. The bitch was in good condition, ate well, and drank large quantities of water.

DECEMBER 23.

The bitch was again anesthetized and the kidney exposed. Before dividing the ureter it was gently compressed for fifteen minutes, but there was no flow of urine from it at the end of that time. The appearance of kidney and ureter did not differ from that of the preceding experiments, where the anemia was of long duration. The other kidney was larger than normal, but otherwise seemed to be normal. The right kidney was removed. The urine was examined for several days. Albumin was present for nine days, when it disappeared. Blood was not detected.

MICROSCOPICAL EXAMINATION.—The findings were identical with those of the three- and four-hour experiments. The glomeruli showed the most marked changes and were practically destroyed. In the tubules there was marked desquamation, while around them was the usual round-cell infiltration. The capsule was thickened and adherent, and in the adhesions new blood vessels had formed, having grown into the kidney from the outside.

EXPERIMENT 12

DECEMBER 8, 1909.

Mongrel dog; condition, good. Ether anesthesia. The right kidney was exposed, and the artery clamped for 4 hours. On removing the clamp the kidney became congested and pulsating, the latter a phenomenon not noted in any of the other experiments. Numerous bleeding points soon appeared on the surface of the kidney, but the hemorrhage soon stopped. Three hours after the operation the dog seemed

to be in good condition. By pressing over the bladder bloody urine was obtained. The dog was placed in a separate kennel, with a sponge bandaged in place over his penis.

DECEMBER 9.

The sponge showed no macroscopic evidence of blood, but gave a positive benzidin reaction when soaked in water and the solution tested. The same reaction was obtained on the next day, but not thereafter. The incision healed by first intention, and the dog showed no ill effects from the operation.

DECEMBER 19.

The dog was again anesthetized and the right kidney exposed. It was bound firmly down by adhesions which showed a network of small blood vessels. By enlarging the incision the ureter was exposed and divided without further disturbing the kidney. No urine was passed in an hour. The kidney was then removed by cutting widely around the adherent mass. On dissecting out the renal artery from the adhesions it was found to contain an embolus which nearly occluded its lumen. In the renal pelvis there was a considerable deposit of blood and calcareous matter. The capsule was much thickened, adherent, and showed numerous blood vessels extending in from the surrounding adhesions. The line of demarcation between cortex and medulla was very indistinct. Throughout the renal substance numerous small hemorrhages had occurred.

MICROSCOPICAL EXAMINATION.—There had been extensive disintegration of the kidney substance, in many places the change being so great that no normal tissue could be made out. The glomeruli were completely disintegrated, appearing as hyaline masses. The epithelial desquamation from the tubules was very marked. Numerous epithelial casts were present throughout the sections, but only a few were found in the pelvis of the kidney. In one area there had been some proliferation of the tubular epithelium, but no structure of the tubules could be made out. In the places where hemorrhage had occurred there was a surrounding round-cell infiltration, and in none of these places could any of the original structure be made out.

At the time the right kidney was removed the other kidney was examined and found to be somewhat larger than the right, but there was not as much difference in size as in the three-hour experiments. Four days after removal of the right kidney the dog was again anesthetized, the left kidney exposed, and the ureter cut. While under observation for thirty minutes albumin-free urine was excreted. (See Figs. XI and XII.)

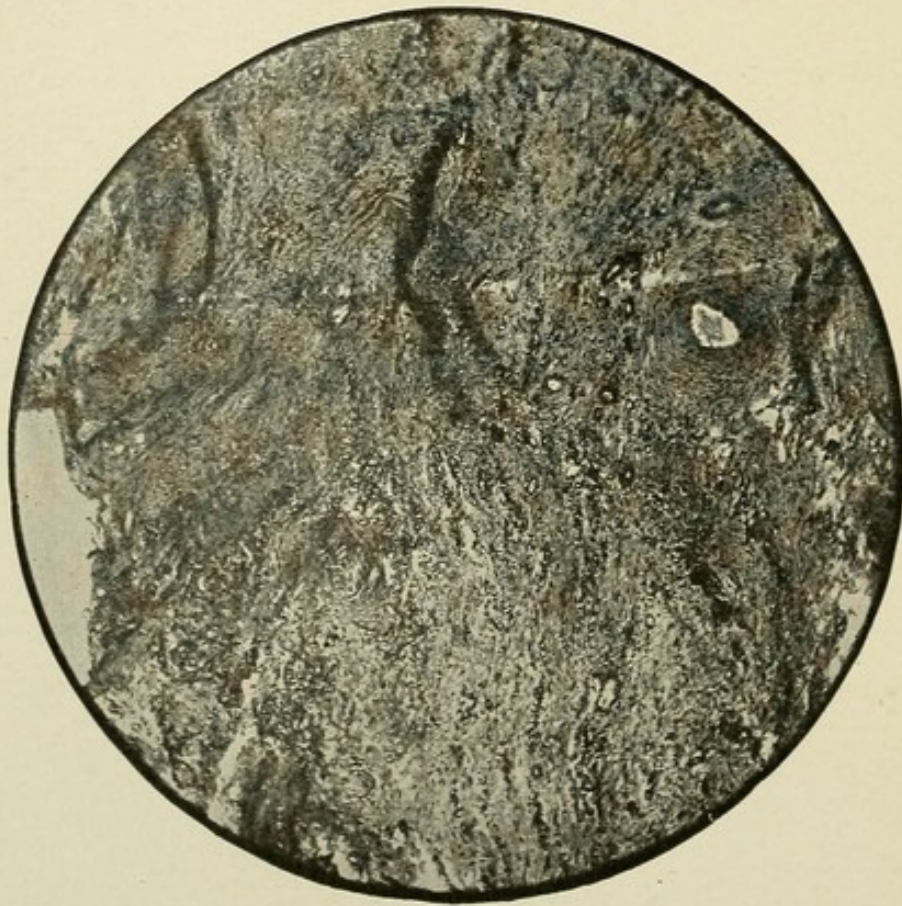


FIG. XI.—ANEMIA OF THE KIDNEY.

Duration of anemia seven hours. Note that the formed elements have been entirely replaced by connective tissue. (Low magnification.)

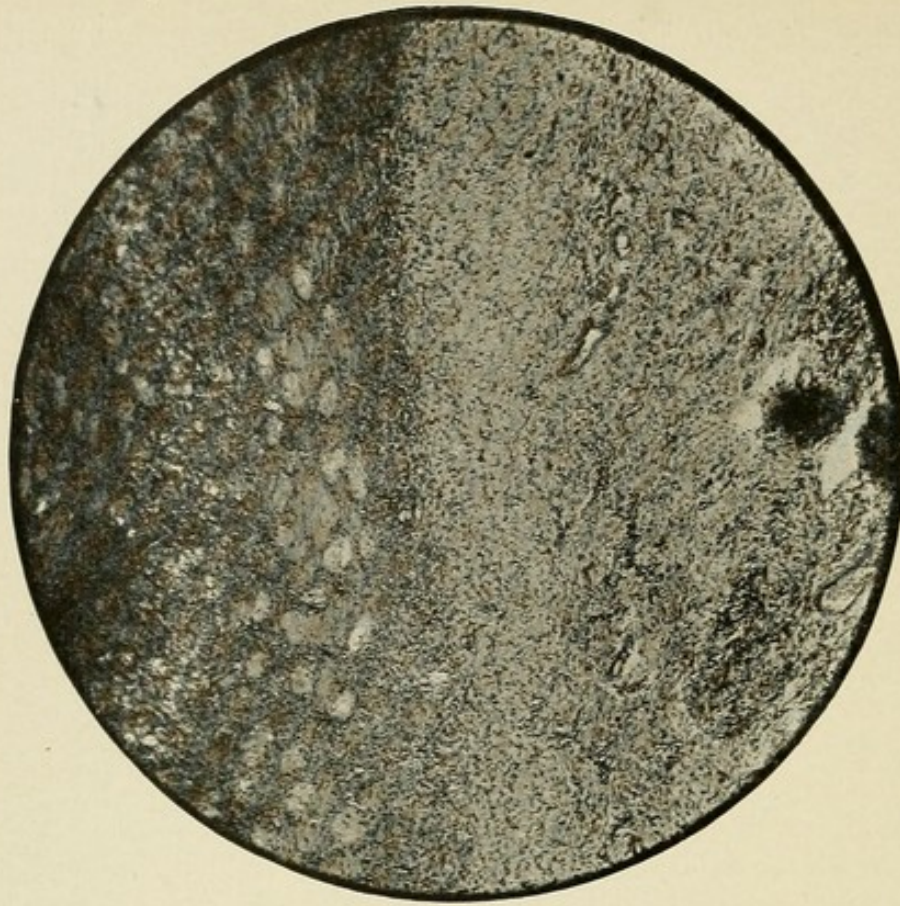


FIG. XII.—ANEMIA OF THE KIDNEY.

Duration of anemia eight hours. In this section the line of demarcation between the cortex (dark area) and the medulla (light area) is still shown, but all parts of the organ are badly damaged. A higher magnification would show marked formation of connective tissue with ingrowth of new capillary vessels, and the capsule would be found to be highly adherent. (Low magnification.)

*Group II**Experiments in Which Both the Renal Artery and Renal Vein
Were Clamped***EXPERIMENT 1**

JANUARY 15, 1910.

Mongrel dog; condition, good. Ether anesthesia. The right kidney was exposed, and both vein and artery clamped for 30 minutes. The incision was then closed. The operative recovery was good.

JANUARY 25.

The dog was in excellent condition. He was again anesthetized, the kidney exposed as before, and found to be secreting urine in which no casts or albumin were present. While there were a few surrounding adhesions the kidney seemed in every way to be normal. The kidney was removed and sections made.

MICROSCOPICAL EXAMINATION.—While there was some desquamation of the tubular epithelium it was not so marked as in the 30-minute experiment in which the artery alone was clamped. The cells showed a dropsical condition similar to that of the other experiment, but the round-cell infiltration was not so marked nor was there hemorrhage into the renal substance. A few of the tubular epithelial cells showed diffusion of the nuclear chromatin, but this also was less marked than when the artery alone was clamped for the same length of time. No casts were found in the tubules. No evidence of connective tissue proliferation was found, and, in almost every respect, the kidney appeared to be normal. The capsule was somewhat thickened, but there had not been any formation of new capillaries.

EXPERIMENT 2

JANUARY 16, 1910.

Mongrel bitch; condition, good. Ether anesthesia. The right kidney was exposed, and both artery and vein clamped for 45 minutes. At the end of this time no gross changes were noted after the blood had again entered the organ. The incision was closed, and the bitch returned to the kennel in good condition.

JANUARY 17.

A specimen of urine was obtained by pressing over the bladder. No blood cells were found in sediment obtained by centrifugalization, but the benzidin test was positive. Albumin was present constantly

until the end of the experiment, while the benzidin test was positive only for four days.

JANUARY 26.

The bitch was again anesthetized, and the right kidney exposed. The ureter was divided. For twenty minutes urine flowed from it. The kidney, as a whole, was swollen and surrounded by adhesions. It was removed and split. The capsule was much thickened, very adherent, and, on stripping it, portions of the cortex came away with it. The entire organ seemed to be edematous, but no evidence of hemorrhage was found.

MICROSCOPICAL EXAMINATION.—Marked epithelial desquamation and round-cell infiltration had occurred. The cortex was very edematous, and did not stain well. The glomeruli appeared as homogeneous masses, devoid of any structure whatsoever. Around them there was considerable hemorrhage. The most marked changes were in the tubular epithelium, which, in some places, was completely desquamated. Cells which had not desquamated had either a swollen nucleus or diffusion of the nuclear chromatin into the cytoplasm. These cells were very indefinite in structure. The condition in this kidney was worse than in the 45-minute experiment, in which the artery alone was clamped.

EXPERIMENT 3

JANUARY 19, 1910.

Black and tan dog; condition, good. Ether anesthesia. The right kidney was exposed, and the artery and vein clamped for a period of 1 hour. The operative recovery was good. Blood was present in the urine for four days after the operation and albumin in large amount throughout the experiment.

JANUARY 29.

The dog was anesthetized again, and the kidney exposed as before. On dividing the ureter six drops of urine flowed in 20 minutes. The kidney was very edematous and bound down by dense adhesions to the peritoneum and intestines. The adhesions were so dense that it was impossible to remove the kidney without injuring the intestines.

MICROSCOPICAL EXAMINATION.—Very extensive hemorrhage and epithelial desquamation were present. In some places the glomeruli were destroyed, with only a mass of blood detritus marking where they had been. In other areas remains of glomeruli were present, but no normal ones were found in any part of the kidney. The

tubules contained numerous epithelial and hyaline casts. In some areas they had been obliterated by connective tissue formation. The desquamation of the epithelial cells was irregular, being complete in some areas and incomplete in others. In but few places could marked diffusion of chromatin be made out. From the extent of the connective tissue proliferation it seemed that the kidney must have been affected, at least to a certain extent, before the experiment, and that the marked extent of the changes after the experiment was due in part to the previous condition. More will be said later about the increased susceptibility to anemia of previously damaged kidneys.

EXPERIMENT 4

MARCH 9, 1910.

Mongrel dog; condition, good. Ether anesthesia. The right kidney was exposed, and both artery and vein clamped for 1 hour. The next morning the urine gave a positive benzidin reaction, but negative reactions were obtained on each of the following six days.

MARCH 19.

The dog was again anesthetized, and the ureter divided. No urine flowed from the ureter while observed for a considerable time. The perirenal adhesions were very dense and firm. The kidney was very edematous and much larger than the other kidney. The capsule was thickened and adherent.

MICROSCOPICAL EXAMINATION.—The tubular epithelium presented ragged borders, and, in many places, had desquamated. The glomeruli presented an appearance like that in the other experiments. While round-cell infiltration was present around the glomeruli it was not present around the tubules. In many cells diffusion of nuclear chromatin had occurred, and, where these cells were most numerous, desquamation was most extensive. The entire organ was edematous, but there was not much hemorrhage. As a whole, the condition was better than in the one-hour experiments in which the artery alone was clamped, but the changes seemed to be limited more to the parenchyma.

EXPERIMENT 5

FEBRUARY 6, 1910.

Mongrel dog; condition, good. Ether anesthesia. The right kidney was exposed, and the artery and vein clamped for 1½ hours. A few seconds after removing the clamp there was slight oozing from the capsule, and the color of the kidney changed from purple to bright red. The oozing continued until the end of the operation.

The operative recovery was good. The next morning albumin was present in the urine, and a positive benzidin reaction was obtained.

FEBRUARY 16.

The dog was again anesthetized, and the kidney exposed as before. No urine flowed when the ureter was divided, although the observation extended over a period of an hour. The kidney was firmly adherent, and could be removed only with difficulty. On section it was found to be very edematous, the line of demarcation between cortex and medulla was not at all distinct, and interstitial hemorrhages were present.

MICROSCOPICAL EXAMINATION.—Extensive desquamation was present in all parts of the kidney. The glomeruli were hemorrhagic, and generally disintegrated, and, with the tubules, were surrounded with round-cell infiltration. In many places the connective tissue had been so freely proliferated that the tubules were occluded in whole or in part. In the patent tubules were many epithelial casts, the adherent cells having largely lost their structure. Nuclear chromatin was frequently diffused into the cytoplasm. The tissues were everywhere very edematous and stained poorly. Newly formed blood vessels had extended from the thickened capsule into the kidney substance. In short the anemia had been of long enough duration to destroy most of the renal parenchyma and produce interstitial proliferation.

EXPERIMENTS 6, 7, AND 8

In these three experiments, the details of which will not be given, the anemia was for longer periods than in the preceding experiments in this series. The changes were in extent rather than in quality. In the three and four-hour experiments renal abscesses were caused.

Summary

The only differences found between the results obtained by clamping the renal artery alone or both the renal artery and vein seemed to consist in the production of greater changes in the latter case and also in greater damage to the parenchyma.

In both series of experiments anemia of over 30 minutes caused permanent parenchymatous degeneration. When the time was increased to one hour the kidney ceased to secrete urine and its functions were lost. Hemorrhage into the renal

substance seemed to depend more on the amount the kidney had to be handled in carrying out the technique than on whether artery alone or both vein and artery were ligated. It was a phenomenon of irregular occurrence at all times. Hemorrhage into the glomeruli was constant after anemia of 30 minutes.

Group III. Anemia of the Kidney of Dogs from Which One Kidney Had Previously Been Removed

EXPERIMENT 1

FEBRUARY 15, 1910.

Ether anesthesia. The dog used in this experiment had previously had his right kidney removed in Experiment 3, Group I. He was in good condition in every way before operation, and made a good immediate recovery after having his left kidney exposed and both the renal artery and vein clamped for 30 minutes.

FEBRUARY 16.

The dog seemed to be in good condition early in the morning, but during the afternoon he was found dead in his kennel. The autopsy revealed a double lobar pneumonia. The kidney was very edematous and had interstitial hemorrhages. There was no urine in the bladder. The renal pelvis was filled with blood. The microscopical examination showed the renal cells to be very edematous and the tubules to be filled with blood corpuscles and detritus.

EXPERIMENT 2

FEBRUARY, 1910.

Ether anesthesia. The dog used in this experiment had previously had his right kidney removed in Experiment 1, Group I. He was in good condition before the operation, and made a good immediate recovery after having the remaining kidney exposed and the artery alone clamped for 30 minutes.

On the next morning pressure over the dog's bladder brought out a small amount of bloody urine, but no more urine could be obtained after that one time. The animal's condition seemed to be good for three days. He then became stupid, refused food, and was found dead on the morning of the fourth day after the operation. The autopsy revealed an acute parenchymatous nephritis of the remaining kidney,

with extensive hemorrhage into the renal substance. The condition, as a whole, resembled that found in the kidney after anemia of one hour in Group I.

EXPERIMENT 3

FEBRUARY, 1910.

Under ether anesthesia the remaining kidney of a dog from which one kidney had previously been removed was exposed, and the renal artery clamped for 30 minutes. The dog died four days later from total suppression of urine. The histological examination revealed changes identical with those found in the other two experiments in this group.

In addition to these three 30-minute experiments three other dogs, which had recovered after removal of one kidney, had their remaining kidney rendered anemic for periods of 20 minutes each. All three died with suppression of urine, the histological changes being the same, only of less degree.

Summary

From these six experiments it was evident that a kidney that is doing an unusual amount of work cannot endure anemia so well as a kidney which is working under a normal load. It might be argued that suppression of urine in these last experiments was due to the operative technique alone, but this argument does not hold, because, when done carefully under proper conditions, almost all dogs survive having one kidney removed. The anemia must, therefore, have been the harmful factor in causing the fatal results. Moreover, dogs in which one out of a pair of kidneys was rendered anemic did not have that kidney permanently injured in the same length of time.

Summary of All Experiments

From all of the experiments in the three groups, as well as from evidence not reported here, the sequence of the changes

following interference with the arterial blood supply to the point of complete occlusion is roughly as follows, it being recognized that the chronological variation is not exact on account of individual differences and other factors not clearly understood:

1. Edema of (a) parenchyma and (b) of interstitial substance.
2. Exhaustion of the cytoplasm of the epithelial cells, and, later, liberation of the nuclear chromatin and its distribution through the cytoplasm.
3. Simultaneously with the exhaustion of the cytoplasm, hemorrhage from the glomeruli and round-cell infiltration around the glomeruli and tubules.
4. Death and desquamation of the epithelial cells.
5. Changes in the structure of the glomeruli.
6. Diminution in and final cessation of the renal functions.
7. Proliferation of connective tissue, beginning in the portions of the kidney less richly supplied with blood. This proliferation is more or less independent of all of the other changes as regards time of onset. It seems to be an effort toward repair.
8. Occlusion of both tubules and glomeruli followed by epithelial regeneration in which the new cells bear little resemblance to the old.
9. Beginning independently of the other changes and continuing after the functional death of the kidney, is the ingrowth of capillaries from the capsule to the cortex, and even into the medulla when the renal artery has been completely occluded.
10. Thickening and adherence of the capsule with pericapsular adhesions. These changes may begin early, but, as a rule, the longer the anemia the more they are marked.

Conclusions

From the foregoing facts it is evident that the following conclusions may be drawn regarding the changes caused by complete obstruction of the arterial supply of the kidney:

1. The gravity of the lesions produced is in direct proportion to the duration of the anemia.
2. The changes which occur after prolonged anemia vary in intensity rather than in variety.
3. More severe changes are produced by occluding the venous circulation as well as the arterial circulation.
4. Whether artery alone or artery and vein are occluded, anemia of over 30 minutes causes permanent changes in the renal structure.
5. Anemia of one hour causes almost total loss of renal function, while anemia of three hours (or less) totally destroys it.
6. After anemia of between 30 minutes and one hour enough functional power may persist to make the organ useful.
7. Anemia of less than 30 minutes causes no histological changes of consequence. Hence, while the human kidney may be more resistant than that of the dog, it would seem that one-half hour should be the maximum time for the occlusion of circulation in the human kidney.
8. Before interfering with the circulation in one human kidney it is as important to ascertain the functional activity of the other kidney as it is when one kidney is to be removed.

II. ANEMIA OF THE SPLEEN

In the following experiments the spleens of dogs were made anemic by occluding the arterial circulation by means of rubber-protected clamps for periods of time varying from thirty minutes to four hours.

EXPERIMENT 1

FEBRUARY 7, 1910.

Mongrel dog; condition, good. Ether anesthesia. Under careful asepsis the abdomen was opened, and the splenic artery clamped for 30 minutes. The dog was in good condition at the end of the operation. The spleen showed no gross evidence of change.

FEBRUARY 8.

No ill effects from operation were visible, the dog eating and drinking heartily and playing around the kennel.

FEBRUARY 21.

The dog was again anesthetized, and the spleen exposed. A few adhesions were found where the clamp had been applied, but otherwise the spleen appeared to be normal. The artery and vein were ligated and the spleen removed. It was not enlarged. No macroscopical changes could be made out from the cut surface. The dog was allowed to recover, and, after living for a week in good condition, was used in a resuscitation experiment, and died.

MICROSCOPICAL EXAMINATION.—The tunica albuginea was thicker than normal, and the blood vessels running through it had thickened walls. The thickening was continued into the trabeculæ. The muscle fibers were apparently undisturbed. In no place was hemorrhage or round-cell infiltration found. The splenic pulp showed more breaking down than was to have been expected. In the Malpighian corpuscles evidences of proliferation were present. On the whole, but little change of consequence had taken place, and, in fact, no more than might have been consistent with healthy variation from the normal.

EXPERIMENT 2

FEBRUARY 8, 1910.

Mongrel bitch; condition, good. Ether anesthesia. Under aseptic precautions the abdomen was opened, and the splenic artery clamped for 45 minutes. The pulse rate had risen from 87 to 132 beats, and the blood pressure fallen from 120 to 80 mm. of mercury at the end of the operation. The general condition was good.

FEBRUARY 9.

Condition, good. Pulse, 110; blood-pressure, 110 mm.

FEBRUARY 11.

Condition, good. Pulse, 110; blood-pressure, 110 mm.

FEBRUARY 15.

Condition, good. Pulse, 110; blood-pressure, 110 mm.

FEBRUARY 21.

The bitch was again anesthetized and the spleen exposed. The spleen was larger and softer than when clamped. There were numerous adhesions about the blood vessels and the upper pole. No hemorrhage had occurred externally. The vessels were ligated, the spleen removed, and the bitch allowed to recover. She showed no after-effects. The blood-pressure became normal in three days.

MICROSCOPICAL EXAMINATION.—The thickening of the tunica albuginea, noted in the previous experiment, was still more marked in this one. There was considerable hyperplasia of the muscle fibers, both in the tunica and the trabeculæ. As the sections had not been stained to show the elastic tissue it is impossible to say whether it was affected or not. The blood vessels had thickened walls. In some places there had been hemorrhages into the trabeculæ, as well as round-cell infiltration. The proliferation of the connective tissue elements along the trabeculæ was apparent, and most markedly so near the hilum. The areas of pulp had been reduced in size, owing to this proliferation. The pulp contained many newly formed cells, which were larger than the others, and stained more intensely. The leukocytes showed all degrees of degeneration, and many of them did not stain at all. In the Malpighian corpuscles hemorrhages were present, which, in many areas, obliterated all traces of structure.

The principal changes, therefore, consisted in increase in the connective tissue elements, a corresponding decrease in the pulp, round-cell infiltration, and intercorpuscular hemorrhages. Consequently anemia of 40 minutes was sufficient to cause the formation of permanent lesions.

EXPERIMENT 3

FEBRUARY 15, 1910.

Mongrel dog; condition, good. Ether anesthesia. Under aseptic precautions the abdomen was opened, the spleen exposed, and the splenic artery clamped for 1 hour. The blood-pressure fell from 115 to 85 mm. during the operation. The operative recovery was good.

MARCH 9.

The dog's condition had been excellent. He was again anesthetized and the spleen exposed. It was found to be so densely adherent that it was impossible to remove it without killing the dog.

MICROSCOPICAL EXAMINATION.—The tunica albuginea was very much thickened. The muscle fibers were markedly hypertrophied. Throughout the connective tissue framework there had been extensive hemorrhage and round-cell infiltration. The connective tissue

around all of the blood vessels was very much thickened, so that the pulp had been so encroached upon as to be entirely obliterated in places.

Around certain blood vessels the round-cell infiltration had been so extreme as to obliterate the trabeculæ. The Malpighian corpuscles varied. In some there had been extensive hemorrhage, while in others the proliferation of the lymphoid tissue had been so extreme as to efface all else. The number of large, deeply staining cells with large vesicular nuclei was greater than in the preceding experiment, and in some areas these cells predominated. Few or none of these cells can be found in a normal specimen.

EXPERIMENT 4

MARCH 16, 1910.

Mongrel dog; condition, good. Ether anesthesia. Under aseptic precautions the abdomen was opened, the spleen exposed, and the splenic pedicle clamped for $1\frac{1}{2}$ hours. The operative recovery was good.

MICROSCOPICAL EXAMINATION.—The tunica albuginea was greatly thickened and edematous. The blood-vessel walls were also thickened, and there had been considerable hemorrhage into the tissues. The amount of connective tissue throughout was very great, so that the individual areas of splenic pulp had been obliterated. With this there was a correspondingly marked round-cell infiltration. The Malpighian corpuscles appeared as masses of red cells, their structure being entirely obliterated. Everywhere there were large vesicular cells with irregularly stained nuclei, many of them broken down with the chromatin diffused through the cytoplasm. Some areas showed nothing but connective tissue and round-cell infiltration. The entire tissue was very edematous, and was filled with broken down masses of leukocytes.

EXPERIMENT 5

MARCH 17, 1910.

Mongrel dog; condition, good. Ether anesthesia. The splenic artery was clamped for 2 hours in the usual way. The dog was in good condition at the end of the operation, but the color did not return to the spleen so rapidly as it did during the other experiments, and there was considerable oozing around the place of application of the clamp.

MARCH 18.

The dog was found dead. At the autopsy the abdomen was found to be filled with blood, the spleen having ruptured near the place of application of the clamp. Sections were not examined.

EXPERIMENT 6

MARCH 18, 1910.

Black and tan bitch; condition, good. Ether anesthesia. Under aseptic precautions the spleen was exposed, and the splenic artery clamped for 2 hours. When the clamp was removed there was some oozing from the place of application. This soon stopped, and the bitch was returned to the kennel in good condition.

APRIL 8.

The bitch had remained in good condition. She was again anesthetized and such a dense mass of adhesions found around the spleen that it could be removed only with great difficulty. The organ, as a whole, was much smaller and firmer than normal, and felt like a mass of fibrous tissue. The artery was occluded with a thrombus.

MICROSCOPICAL EXAMINATION.—No normal splenic tissue was present. From the tunica albuginea dense adhesions extended into the surrounding tissue, and in these adhesions were many capillaries, but the blood vessels in the trabeculae were occluded. The obliteration of the pulp was complete. In one area there was a large infarct which had not stained at all.

This experiment can hardly be considered as one which shows the effect of anemia for two hours, on account of the formation of the thrombus in the splenic artery. Most of the blood supply came from the capillaries in the adhesions. The experiment is of value, however, as showing that thrombosis may readily occur if too long or too great pressure be applied to a temporarily compressed artery.

EXPERIMENT 7

MARCH 18, 1910.

Bulldog; condition, good. Ether anesthesia. Under aseptic precautions the spleen was exposed, and the splenic vessels clamped for 2½ hours. The dog was in good condition at the end of the operation, but was found dead the next morning with extensive hemorrhage from rupture of the spleen. The spleen was much enlarged.

EXPERIMENTS 8, 9, AND 10

In these experiments the splenic artery was clamped for periods

of 3, 4, and 5 hours. In each instance the animals went through the operation well, but were found dead twenty-four hours later from hemorrhage from rupture of the spleen. No changes were found in the organ except marked edema, as there had not been time for tissue degeneration to develop.

Summary

The chief changes caused by anemia of the spleen were marked proliferation of all of the connective tissue elements in the tunica albuginea, around the blood vessels, and in the trabeculæ, and a gradual compensating reduction of the splenic pulp, with its final obliteration. In the experiments in which the anemia was of short duration there was some hypertrophy of the muscle fibers and formation of large cells, which tended to break down and to discharge their nuclear chromatin into the cytoplasm. The chief changes in the Malpighian corpuscles consisted of hemorrhage and proliferation of the lymphoid tissue.

The only constant post-operative clinical change noted was a fall in the blood-pressure which persisted for several days. This fall averaged 30 millimeters of mercury. In experiments in which the clamp was applied for more than two hours rupture of the spleen always occurred. Whether this might have been obviated by permitting a gradual return of the circulation is not known. No changes were noted in the histological structure when the anemia was of less duration than forty-five minutes, but in longer periods permanent damage was done.

CHAPTER X

RESUSCITATION OF THE BODY AS A WHOLE

GENERAL CONSIDERATIONS

The popular conception of death does not permit of its being regarded as anything but absolute in character. This is really the only accurate conception. For scientific purposes, however, it is convenient, if not essential, to divide the process of dying into three stages. It should be recognized that each stage merges into the others—hard and fast lines between them cannot be drawn. In the opinion of the author these stages cannot be designated better than by the terms first employed, so far as is known, by d'Halluin, i. e., apparent death, relative death, and absolute death.

In apparent death, as the term implies, to all outward appearances the vital functions have ceased. Respiration is present, but at such a low ebb that special methods of examination are needed to detect it. It is sufficient to maintain life, and life may persist for long periods of time. The heart beats feebly; possibly so feebly that its action can be detected only with the stethoscope. Motor activity is inhibited. The skin is pale and cold. The eyes may be either closed or open, but are unseeing and motionless. Seldom is there sufficient relaxation of the sphincters to cause incontinence. Unconsciousness may be either present or absent.

Relative death may be defined as the condition of the body during the few minutes between entire cessation of cardiac and respiratory activity and absolute death. In the early stages

of relative death complete resuscitation is possible. In the later stages resuscitation is possible, but there is permanent loss of certain higher functions. In still later stages automaticity of cardiac and even respiratory action may be resumed, but consciousness may never be regained.

At first thought, it would seem that immediately after cessation of the heart action the stagnant blood would be of little use to the surrounding cells. The probability is, however, that stagnant blood contains enough absorbable oxygen to permit the tissues to undergo the stage of relative death. It is hardly credible that interchange of oxygen and carbonic oxid should cease the instant the blood stops flowing past the cells in the delicate-walled capillaries, and while the interchange goes on the individual cells must benefit by it, even if in rapidly diminishing degree. There is every reason to believe that the stage of relative death depends almost wholly on this interchange, at least for the central nervous system.

Absolute death is that condition in which resuscitation of the body as a whole is impossible. The phrase "as a whole" is used advisedly, as different parts of the body, as has been shown elsewhere in this book, may be resuscitated hours or even weeks after absolute death.

The determination of absolute death is unimportant, since in cases of apparently suspended animation time is so valuable that even a second should not be used in any but resuscitative measures. For this reason it is well to proceed at once to a discussion of various methods of resuscitation.

RESUSCITATION OF THE RESPIRATORY APPARATUS

Artificial Respiration

Any method of artificial respiration should aim to reproduce normal respiration as nearly as possible. Careful ex-

perimentation has shown that what must be considered normal respiration varies within wide limits in different individuals. [As determined by Vierordt, a normal average rate of exchange of air per minute is about 5,300 cubic centimeters. This exchange, often called the flow of the tidal air, must not only be sufficient per given respiration, but the number of respirations per given unit of time must be sufficient. Also a test of the efficiency of any method of artificial respiration must show not only that amount and rate can be maintained, but also that about 5,300 cubic centimeters at least can be made to enter the lungs per minute.]

It is beyond the province of this book to discuss the historical side of artificial respiration, but it seems to have been first used largely to resuscitate the apparently drowned. In his recent Hunterian Lectures Keith gives a most interesting historical review of the subject. He mentions the facts that in Amsterdam in 1767 a society was founded for the resuscitation of the drowned or apparently dead, while in 1774 the Royal Humane Society of England was founded with the same objects as part of its purpose. As far as can be ascertained, however, it was not recognized until within recent years that artificial respiration is really the most important of the different measures advocated.

[Of the best known methods for producing artificial respiration those of Silvester (with patient in supine posture), of Howard (with patient in prone posture), of Marshall Hall (with patient alternately in prone and lateral posture), Brosch's modification of the Silvester method (the modification consisting essentially in a further modification of the movement of the arms backward over the head with over-extension of the upper part of the spine), and the method of Schäfer (with patient in prone posture), need no further comment with the exception of the Brosch-Silvester and

Schäfer's methods. Keith states that in 1908 Meyer and Loewy tested the Brosch-Silvester method by Schäfer's plan and found that they could get a respiratory exchange of from 7,000 to 16,000 c. c. per minute, as against 5,850 by Schäfer's method. This claim makes the respiratory exchange greater than that obtainable by any other method. Schäfer compared his own method with the other methods just mentioned, with the exception of the Brosch-Silvester, and found that of these it gave the greatest air exchange. His findings are expressed in the table. No one of these methods, however, can be said to be preëminently the best, because no one method is applicable to all situations under which artificial respiration has to be given.

Schäfer's Table Showing the Relative Efficiency of Methods of Giving Artificial Respiration

MODE OF RESPIRATION	Number per Minute	Air Exchange Per Respiration	Air Exchange Per Minute
Natural.....	13	450 c. c.	5,850 c. c.
Silvester.....	13	175 c. c.	2,280 c. c.
Howard.....	13	310 c. c.	4,030 c. c.
Marshall Hall.....	13	254 c. c.	3,300 c. c.
Schäfer.....	13	520 c. c.	6,760 c. c.

STATISTICS.—Age of subjects, 23. Height, 5 ft. 7¼ in. Chest at mammary line, 38 in. Weight, 10 st. 1½ lbs. Vital capacity, 6,760 c.c. Pressure exerted in performing respiration, 60 lbs.

In 1908 the Fifth Resuscitation Committee appointed by the Royal Society of Medicine recommended that the Schäfer method of giving artificial respiration be adopted as preferable to that of either Marshall Hall or Silvester. It does not follow necessarily that this method is the most efficacious or that perfection has been reached, but, on account of the sim-

plicity and ease of application of the technique, the greater exchange of air than by any other method except the Brosch-Silvester, the postural drainage, and the prevention of the tongue from falling back in drowning cases, it is, at the present time, the method of choice. Keith, who was a member of this committee, does not regard it as being as efficient as the Silvester method when the latter is properly carried out, but he would advise its use unless the proper execution of the Silvester method could be guaranteed.

Schäfer's description of his method is as follows:

"The subject, whether a drowned person or not, is allowed to lie prone, i. e., face downward, no preliminary manipulation of the tongue being required. The operator kneels or squats either across or on one side of the subject, facing the head, and places his hands close together flat upon the back of the subject over the loins, the fingers extending over the lowest ribs. By now leaning forward upon the hands, keeping the elbows extended, the weight of the operator's body is brought to bear upon the subject, and this not only compresses the lower part of the thorax, but also the abdomen against the ground, the pressure being fairly equally distributed. The result of this is that not only is the thorax diminished in extent from before back, but, owing to the pressure which is communicated to the abdomen, the viscera are compressed and tend to force the diaphragm up, so that the thorax is diminished in capacity from above down. This is, no doubt, the reason why the pressure method when applied in the prone position is more effective than when applied, as by Howard, in the supine position. The pressure is applied not violently, but gradually, during about three seconds, and is then released by the operator swinging his body back, but without removing his hands. The elasticity of the chest and

abdomen causes these to resume their original dimensions and air passes in through the trachea. After two seconds the process is again commenced, and is continued in the same way, the operator swinging his body forward and backward once every five seconds, or about twelve times a minute, without any violent effort and with the least possible exertion. This last condition, viz., the absence of muscular exertion, other than that involved in swinging forward and backward, renders it possible to continue the process without fatigue for an indefinite time. It can further be carried out unaided by a woman almost as well as a man, by children upon children; it hardly requires to be taught—a simple demonstration sufficiently teaches it to a large audience. Its advantages in drowning cases over any other method which involves the supine position are sufficiently obvious—for with it there is no risk of obstruction by water or mucus or the contents of the stomach which cannot accumulate in the throat but must come away by the mouth; and the tongue, in place of falling back, as in the supine position, falls forward, and is unable to produce obstruction.”

Resuscitation of the respiratory apparatus is essentially a matter of keeping the respiratory centers from becoming anemic or of restoring to them a normal blood supply if they are already anemic.

“Artificial Respiration” Without Movement of the Thorax.—In 1905, under the title “Concerning Artificial Respiration Through Ventilation of the Trachea,” H. Hirsch, in his inaugural dissertation, describes a method of keeping an animal alive by supplying oxygen to the lungs under pressure without going through the ordinary means of giving artificial respiration. He demonstrated that a dog could be kept alive for hours by this means, all voluntary muscular effort being inhib-

ited by means of curare. He also demonstrated that atmospheric air similarly supplied would not keep an animal alive.

Hirsch's method was to use a Volhard tracheal tube, introducing it into the trachea, inflating the little rubber bag with which the tube is surrounded (thus making an airtight connection between the tube and the trachea), and then measuring the pressure with which the oxygen was introduced. The Volhard tube consists of one glass, hard rubber, or celluloid tube within another, the outer mantle, or efferent tube, being perforated on its sides for a short distance up from the bottom, and the inner, or afferent, tube being open at the end, the stream of oxygen can enter the trachea through the inner tube, while the oxidized air passes out through the outer one. Ten centimeters from the lower end of the outer tube a small rubber bag is placed which can be inflated through a small rubber tube. The pressure which the efferent stream exerts can be measured by connecting the outer tube with a manometer, and counterpressure to prevent too rapid exhalation is thus obtained. For the afferent stream Hirsch used a pressure of 60 centimeters of water. The principle of this method has been recently elaborated by Meltzer and Auer in the Rockefeller Institute and has been used clinically with notable success by Elsberg.

RESUSCITATION OF THE CIRCULATORY APPARATUS

Methods Commonly in Use

General Considerations.—Kuliabko, d'Halluin, Stewart, Sollman, and many others have demonstrated repeatedly that the isolated heart may be made to beat for hours by perfusing it with different solutions, notably Locke's. Moreover, they have shown also that hearts from animals which have been killed may be removed from the body and made to beat again

after as long a time of inactivity as 12 hours, 24 hours, 3 days, and even 5 days (Kuliabko). In experimenting with the hearts of children dying from pneumonia Kuliabko succeeded in reanimating at least certain parts of the heart twenty and thirty hours after death. These facts demonstrate that, up to a certain extent, the heart is an organ whose action is independent of the central nervous system. When an animal is asphyxiated the respiratory action almost always stops first, then the cardiac, and, finally, the cerebral. However, if artificial respiration be supplied the heart will beat for a long time, even when the nervous functions are not resumed. The author has seen the heart continue to beat rhythmically for 12 hours in a decapitated overtransfused dog. The continued heart action is more dependent on the presence of calcium salts in whatever fluid is passing through it than it is on stimulation from the nervous system.

Reanimation of the heart after a long interval has elapsed since its removal from the body does not mean necessarily that it will contract in a coördinated manner as it does during life—there may be contraction of the auricles without contraction of the ventricles. In over one hundred cases tabulated by d'Halluin from his experiments, mostly on the hearts of dogs, there is no instance recorded in which the reverse of this statement was true, i. e., that the ventricles ever contracted without the auricles doing likewise. In 4 instances he obtained rhythmic beating of both auricles and ventricles between 16 and 17 hours after death. The longest time he records after which he obtained rhythmic auricular action, but no ventricular action, was 42 hours. In one case he records "tremulations" of the auricles, in 16 of the ventricles, and in one case fibrillary tremors of the ventricles. To these cases might be added many similar observations by the author.

When death occurs, how long will the heart continue to

beat after respiration ceases? In dogs killed by clamping the trachea, by illuminating gas poisoning, by chloroform, or by ether, the author has made repeated observations in which the heart has continued to beat from one to three or even four minutes, both respiration and carotid pulse being recorded on the same drum. In pure asphyxia he has seen the heart beat for 6 minutes with sufficient strength to make the blood circulate, while contractions have continued for a much longer time.

According to d'Halluin, Vulpian observed fibrillary contraction of the right auricle of a dog 93 hours after death, while Saller and Reid observed heart beats, also in a dog, for 72 minutes. D'Halluin himself observed rhythmic contractions in the auricles and right ventricle of a cat for more than an hour "even though the heart had been withdrawn from the chest and placed on an extemporaneously constructed cardiograph."

In a recent observation made by Dr. F. W. Hitchings in the case of a patient with uremic convulsions, the heart at one time stopped beating effectively, as was determined by the absence of heart sounds (stethoscope) and by the cessation of all radial pulsation, for three and one-half minutes after the complete cessation of respiration. At the end of that time it began to beat again, at first very feebly, and respiration soon recommenced without the use of any measures to restore it. This observation was made near the end of the series of convulsions, and just after the last severe convulsion, death occurring six hours later.

The rhythmic contraction of part of the heart cannot be regarded as sufficient to furnish efficient circulation, and it is doubtful if efficient contraction persists on the average longer than for from three to five minutes. In all cases duration of time between the final cessation of the heart beat and its restoration should be taken as the criterion of temporary sus-

pension of animation, rather than the duration of time from the cessation of respiration. Without doubt in many cases of accident the heart has beat feebly, to be sure, but with sufficient force to supply the brain with enough blood to sustain its functions, when, in the hurry and excitement, the observers could not detect any action and have believed that it was absent. It is in such cases as these that artificial respiration after apparently long intervals of suspended animation has saved life.

In experimenting on dogs the author has found that reanimation of the heart does not always follow artificial respiration and the intraarterial injection of normal saline solution and adrenalin, or transfusion of blood. In some of the cases in which these procedures are begun, even within a couple of minutes of cessation of the heart beat, the heart cannot be made to beat again. The question at once arises as to why this should be. Probably the most frequent cause of failure lies in technical obstacles, such as blood-clot, direct injury, and, above all, because the coronary pressure was not sufficiently raised. Fibrillary tremulation is perhaps the next most frequent cause. Moreover, if infusion be given too rapidly intravenously the right heart may be paralyzed in diastole. The technique, rather than the latent powers of reaction of the animal, is therefore accountable sometimes.

As to the practical application of different methods by which the heart may be made to beat again, it is found that they may be divided into two groups—the indirect, in which the heart itself is not made accessible through an opening in the chest wall or abdomen, and the direct, in which it is made accessible or is directly interfered with, as in tapping. Under indirect methods will be considered in this or the next chapter (1) compression of the chest wall; (2) electrical applications through the chest wall and massage of the heart

itself; and (3) the use of infusions. In discussing all of these methods it is to be understood that the heart has actually stopped beating before beginning treatment, and that artificial respiration is being carried on simultaneously with the treatment. Before taking up each method in detail delirium cordis will be considered briefly.

Delirium Cordis.—Aside from the sensitiveness of the central nervous system to anemia the most serious obstacle in the way of resuscitation is delirium cordis, or fibrillary tremulation. Up to the present time no satisfactory method of overcoming it has been found. When such a method is discovered, one that can be readily applied clinically, a great advance will have been made toward solving the problem of cardiac and, hence, general resuscitation.

In performing experiments on the heart all physiologists have noticed the phenomenon of delirium cordis. Frequent allusions have already been made in these pages to various causes of this condition. Any sufficiently severe stimulus and many stimuli which would not ordinarily be called severe may cause it to appear. The stimulus may be either physical or chemical in nature, and is usually most efficacious when applied directly to the heart. A heart which has ceased beating and has then been made to beat again, whether *in situ* or isolated, may show delirium instead of the normal rhythmic contractions. Faradic currents of even weak intensity may cause it. Direct currents of low voltage, up to 120 volts, are particularly likely to cause it.

Various ways of overcoming delirium cordis have been used, and a few with some success, at least in the laboratory. D'Halluin considered intravenous injections of chlorid of potassium to be the most efficacious treatment. He says: "The heart, after having been poisoned by a massive dose of this drug, may beat again rhythmically under the influence of the

massage in spite of the previous tremulations." Then he goes on to say that this poison when diluted in the entire blood mass does not seem to have any more action on the heart than on the rest of the organism. Of all the many things which he tried this was the least toxic and most easy to use.

Among inefficacious substances used for this purpose d'Halluin mentions copper sulphate, corrosive sublimate, zinc lactate, aluminum sulphate, barium, strontium, strophanthin, digitalin, chloral, atropin, nicotin, magnesium sulphate, saponin, fluorescin, curare, and magnesium citrate. The oxalates, the fluorids, cocain, and stovain were hardly utilizable by reason of the injury which they did to the organism in dosage large enough to stop the tremulations. Only the salts of ammonia could compare with chlorid of potassium, and then action was feeble.

Among inefficacious methods d'Halluin found that electric discharges, faradization of the pneumogastric nerves, local cooling, and bandaging with dressings wet with a solution of cocain were equally useless.

D'Halluin's experience, larger than that of any other one investigator, coincides with the experiences of everyone else, except possibly Prévost and Batelli, who state that a very powerful and rapidly alternating current of electricity will arrest tremulation. Prévost and Batelli's method might be useful in industrial plants in which such currents could be commanded at an instant's notice, special arrangement being made for treating accidents due to electrical shock. Otherwise this method would be entirely impracticable on account of the lack of proper facilities.

Resuscitation of the Heart by Rhythmic Pressure on the Thorax.—In dogs the forcible rhythmic compression of the thorax over the heart by compressing the heart itself and the great vascular trunks, raises the blood-pressure to a certain

extent and thus aids its action. The mere stimulation of the first few compressions has a tendency to make the heart resume automatic action, and a feeble circulation may be maintained by the continuation of the rhythmic pressure upon the chest. If the capacity of the medullary centers be early increased by the subsequent diminution in their relative anemia, the resumption of heart activity is much more apt to be permanent. Success will be in inverse ratio to the feebleness of the heart beat, if present, and to the duration of its inactivity, if absent.

In adults, and especially in children, something can doubtless be accomplished by forcibly activating the elastic chest wall. With the child flat on its back, pressure should be applied at the rate of about 30 to 40 times a minute. This will also afford efficient expiration, as in the Schäfer method the elasticity of the thorax will take the place of inspiratory efforts. Care should be taken not to use too much force, although the action should be firm and vigorous. The applications should continue for at least twenty minutes, or for as much longer if a stethoscope is not at hand so that the lack of heart action can be determined with accuracy. If no action can be detected with the stethoscope at the end of twenty minutes, there is little or no hope that it will be established, and, in all probability, the higher cerebral centers will long have been past hope of recovery.

Resuscitation of the Heart by Electrical Stimulation through the Chest Wall.—In the opinion of the author the advisability of using electric currents for the purpose of inaugurating the heart beat is doubtful. With a current of fixed character and strength uniform results doubtless might be obtained, but the technical side presents what may be insurmountable difficulties, and positive and irreparable harm may be done. The great danger is that of causing fibrillary con-

tractions of the heart muscle, with the result that the heart as a whole becomes an inefficient trembling mass of tissue.

In cases of electric shock the effect on the heart may be summarized as follows:¹

1. Low tension currents (up to 120 volts) cause fibrillary contractions and hence are the most dangerous.
2. Currents of medium tension are apt to have the same effect but are more likely to cause general inhibition.
3. High tension currents cause general inhibition through the central nervous system.

These effects vary with the point and magnitude of the contact, the length of exposure, and the direction of the flow of the current.

In his excellent monograph, "Resurrection du Cœur," d'Halluin says (page 172): "The fibrillary tremors of the heart are the principal obstacle which is opposed to the resumption of the rhythmic function of the myocardium. *Therefore, one will carefully avoid every measure which is capable of provoking them, and one will not run a risk by attempting the direct electrical stimulation of the heart . . .*" What applies to the direct stimulation of the heart applies with equal force to stimulation through the chest wall.

Direct Methods of Resuscitating the Heart.—Three so-called direct methods of massaging the heart have been employed, i. e., methods in which the heart is manipulated after opening the thorax or the abdomen. These are: (1) The intrathoracic, in which the thorax is opened and the heart massaged through the opened pericardium; (2) the transdiaphragmatic; and (3) the subdiaphragmatic. In the second method the heart is massaged from the abdomen through an opening near the ensiform cartilage, the diaphragm being cut through as well as

¹ From a research made in collaboration with Dr. J. J. Macleod. See reference No. 68 in Bibliography.

the pericardium. In the third method the heart is massaged by way of an abdominal incision without opening the diaphragm.

INTRATHORACIC METHOD.—In a total of 50 cases of clinical massage of the heart White found 2 successful, 8 partially successful, and 18 unsuccessful cases in which this method was used. The advantages of this method are that the heart is directly under the hand of the operator, and he can actually see what he is doing. In cases in which wounds of the heart have to be dealt with there is no doubt but that this should be the method of choice. The thorax has to be opened anyway and opening the abdomen would only increase the surgical risk. The great disadvantages of this method are the time it takes to make the exposure, the danger of opening the pleura, the increased danger of causing shock, and the general disadvantage that it is unnecessary for many cases.

THE TRANSDIAPHRAGMATIC METHOD.—In the 50 cases referred to above White found only 3 (those of Mauclaire, Mauclaire and Coqueret, and Green) in which transdiaphragmatic massage of the heart was employed. One of these was partly successful, while the other two were failures. To the mind of the author this method has little to commend itself—if the abdomen is to be opened it is unnecessary, except possibly in very exceptional cases in which adhesions might interfere with getting a good grasp of the heart.

THE SUBDIAPHRAGMATIC METHOD.—This is by all means the method of choice, with, as already stated, the exception of cases in which the heart or thoracic contents have to be exposed on account of traumatism. That the heart can be readily reached through the diaphragm may easily be demonstrated and is well shown in the frozen longitudinal section made by White (see Figs. XIII, XIV and XV). White gives in his table 8 successful, 5 partially successful, and 6 unsuccessful cases of the application of this method. The superiority of

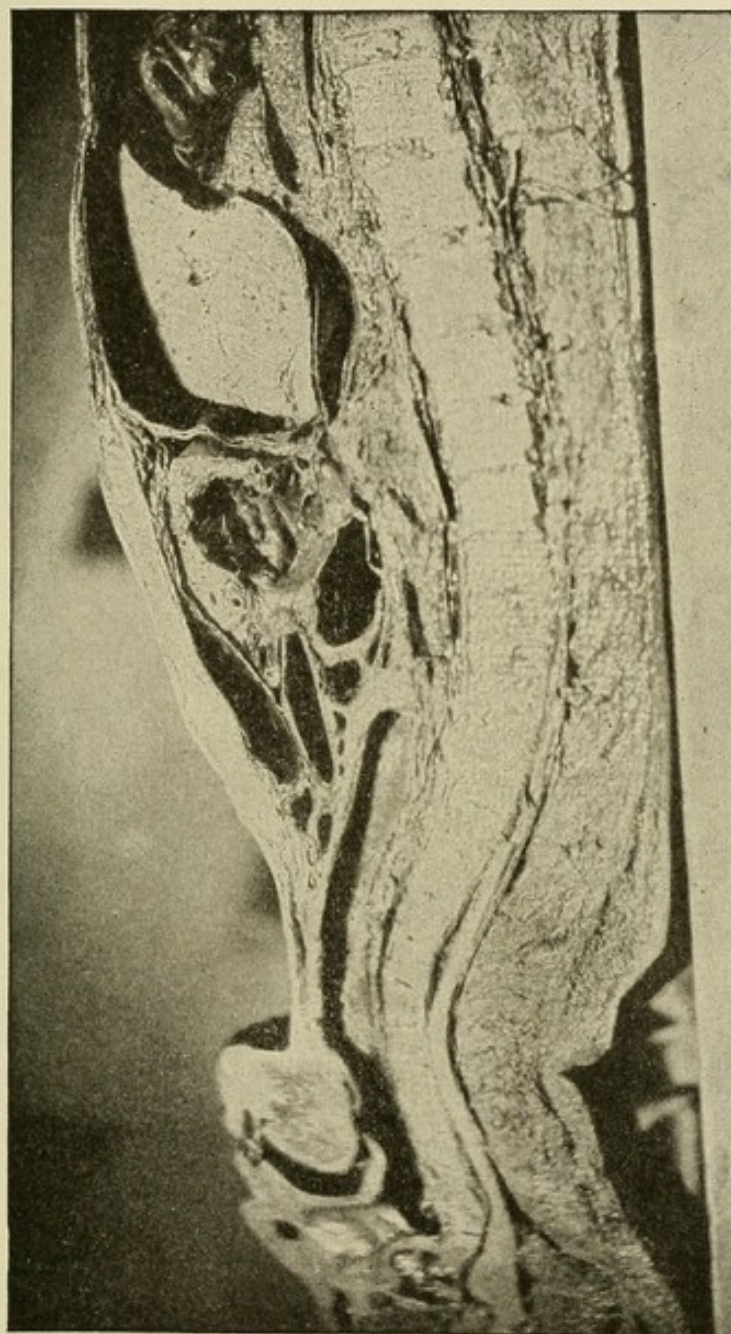


FIG. XIII.—LONGITUDINAL FROZEN SECTION, SHOWING RELATION OF THE HEART TO THE DIA-
PHRAGM.

(Courtesy of Dr. Charles S. White, and "Surgery, Gynecology and Obstetrics.")

this method is indicated by the fact that in only 19 cases, as against 28 in which the direct method was used, there were 8

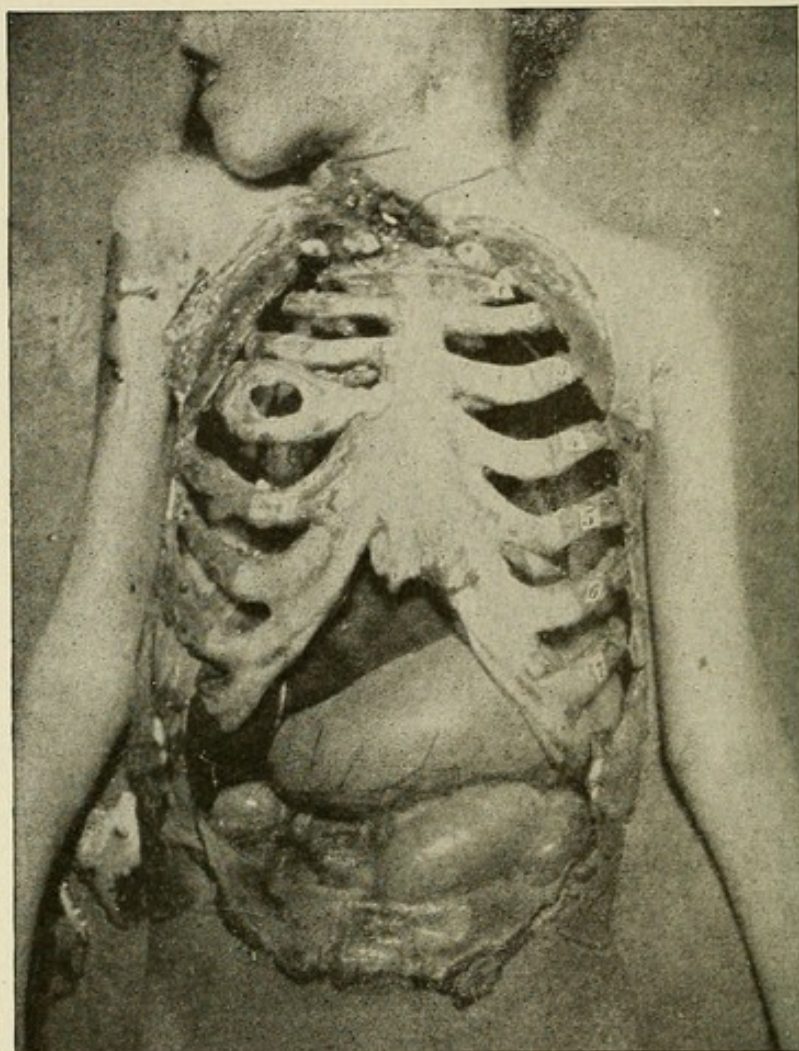


FIG. XIV.—THE THORACIC VISCERA AS SEEN FROM THE FRONT, THE RIBS AND THE STERNUM INTACT.

(Courtesy of Dr. Charles S. White, and "Surgery, Gynecology, and Obstetrics.")

recoveries, or four times as many as in the larger group of cases—42.1 per cent. as against 7.1 per cent. As the majority of major operations are on the abdominal viscera, the incision already made can be used, or enlarged if necessary.

In considering the subject of cardiac massage as a whole it is impossible to refrain from calling attention to the fact

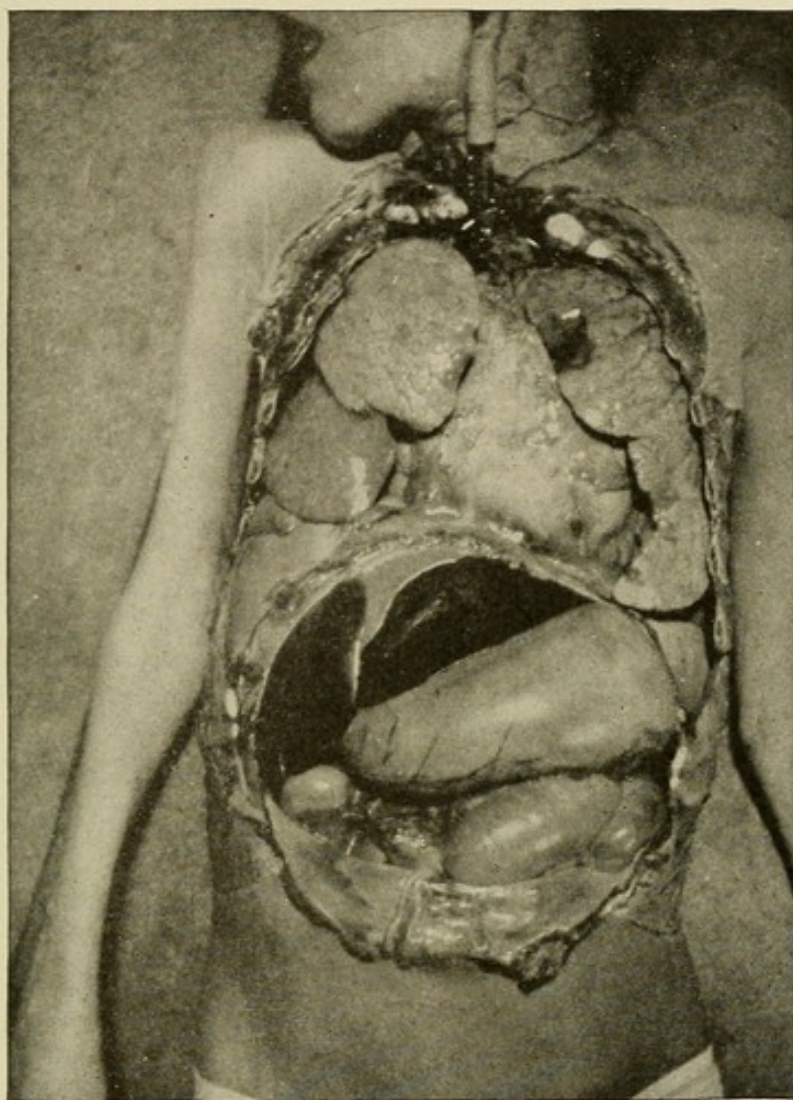


FIG. XV.—SAME AS FIG. XIV, THE VISCERA BEING EXPOSED BY REMOVAL OF THE RIBS AND STERNUM.

(Courtesy of Dr. Charles S. White, and "Surgery, Gynecology, and Obstetrics.")

that in 35 out of 50 operative cases, or in 70 per cent., chloroform was the anesthetic used, and caused, at least in part, the cardiac collapse. In another case chloroform and ether were given, and in still another the "A. C. E." mixture was used.

This fact alone should point the way to the prevention of many accidents which necessitate the use of cardiac massage. Some day the real and constantly present dangers of chloroform will be universally recognized. As long as this anesthetic is used there will be cases of collapse in which desperate measures will have to be taken to save life.

Experiments show that when the heart and the respiration have stopped the brain is paralyzed and can do nothing. And also, that when the heart has stopped it cannot be started by any nerve stimulus.

It is now known that the way to *start* the heart is to raise the pressure in the coronary arteries and to supply oxygen to the lungs and hence to the blood, but that *the way to keep it beating* is to supply oxygen to the brain. This is the key to the entire problem. When the heart acts, then, and only then, can the circulation be reestablished. Confronted with a collapsed patient, in whom suspended animation implies a quiescent heart, how can the blood pressure in the coronary arteries be quickly raised to 40 mm. or more, and oxygen be supplied?

One might answer that cardiac massage should be sufficient to reestablish circulation, but experience has shown that this method gives inefficient coronary pressure, because, 1st, but little blood reaches the heart and hence but little is thrown out, and, 2d, the vascular system is collapsed, so that the small amount of blood which is expelled by the pressure of the hand finds collapsed blood vessels, and therefore the aortic pressure is not raised materially.

It might then be supposed that saline infusion forced into an artery toward the heart would so raise the coronary pressure as to activate the heart, but experiments have shown that this cannot be done effectively. The saline solution is taken up in large quantity by the relaxed blood vessels, but it

escapes from the blood vessels as rapidly as it enters, and collects largely in the abdominal viscera; saline solutions therefore cannot produce the needed rise of pressure in the coronary vessels.

Could not an extreme head-down position of the patient combined with bandaging the extremities and the abdomen throw such a volume of blood into the thorax and into the heart that, by the further assistance of either direct rhythmic compression of the heart or by rhythmic compression of the thorax as a whole, the required coronary pressure would be supplied? Here again experiments have given a negative answer. The relaxed vascular trunks again cause defeat.

Failure of this last measure means that the peripheral resistance must be so raised that the stream of blood which is thrown out of the heart by rhythmical compression may react against it and so raise the aortic and hence the coronary pressure. Can this increased resistance be supplied by electric stimulation of the vasomotor mechanism? All such efforts in the author's hands have failed. It is obvious that the coronary pressure can be raised to 40 mm. or more only by the aid of a drug that will produce a vigorous contraction of the arteries against which the blood thrown out by rhythmic compression of the heart may react.

Fortunately in adrenalin there is such a drug, but adrenalin must be brought into direct contact with the walls of the blood vessels. This can be done by infusing it into the circulation with saline solution. Arterial injection should be employed rather than venous, because the blood-pressure is dependent on the resistance offered by the muscles of the arteries. If injected into a vein the adrenalin must pass through the right auricle, right ventricle, pulmonary circulation, and thence to the left auricle and left ventricle before it comes in contact with the walls of the arteries when, for the first time,

it can be of assistance in raising the aortic and hence the coronary pressure. Not only is this a circuitous route, entailing loss of time, but the adrenalin itself must be somewhat dissipated. It wholly lacks the directness of effect secured by injecting it toward the heart through an artery. Saline-adrenalin arterial infusion toward the heart, combined with rhythmic pressure upon the thorax has proved most efficient in animals.

CHAPTER XI

RESUSCITATION OF THE BODY AS A WHOLE—CONTINUED

The means employed for resuscitation in suspended animation from drowning, from anesthetic accidents, from collapse in operations, from injury, or whatever the cause may be are roughly divided into three classes: 1st, the artificial respiration and stimulant method; 2nd, direct massage of the heart added to artificial respiration and stimulation; 3rd, the adrenalin-saline infusion — rhythmic thoracic-pressure method devised by the author. It is quite obvious that all of the methods have their indications and their limitations.

In the first method, the use of artificial respiration has the great advantage of requiring no special apparatus and being of ready application. The best method for producing artificial respiration has already been considered. Artificial respiration alone cannot inaugurate the heart beat, but when there is still a feeble circulation or when there is no circulation if there is a rhythmic contraction of even the auricles this method may succeed. *Simple artificial respiration is the only hope in drowning and other accidents occurring when professional help is not at hand.* Experiments upon animals have abundantly shown that as far as asphyxia is concerned a very little air sustains the spark of life for a surprisingly long time.

The advantages and the shortcomings of the second method, viz., that of direct or indirect massage of the heart

added to artificial respiration, are as follows: In the first place, it is wholly inapplicable in the hands of the layman. Even in professional hands the large wound made in opening the thorax or the abdomen and inserting the hand is likely to become infected, on account of the want of precaution that haste demands. This constitutes in itself a grave danger. Then, too, aside from the danger of such a wound, the effect of direct massage on the heart itself is most serious. It may cause fibrillary contraction, which is certain to defeat resuscitation, or clotting of the blood in the chambers of the heart may result from the physical injury. The author has frequently seen the latter occur. There is one point of advantage in direct massage of the heart, viz., in the course of abdominal operations there may be sudden collapse. If this happens, with one hand in the abdomen and the other on the chest the heart may be rhythmically compressed. This may be done with little loss of time, while preparations are being made for the application of a better technique to be described later.

The author's experimental researches and the work done by others may now be summed up in such a way as to enable decision, 1st, as to the type of method to be used in any given case, and, 2nd, the most practical technique of performing each method. This summary is as follows:

The various organs and tissues of the body endure anemia in vastly different degrees. The part that endures anemia least well is the brain. The cortex is killed beyond resuscitation in about seven minutes. In order to save the brain reanimation of the body as a whole must begin with reanimation of the heart.

Even while the heart is inactive the blood may be artificially circulated through the brain by rhythmic compression of the thorax and the abdomen. This pressure is doubly benefi-

cent; it simultaneously produces artificial respiration and artificial circulation. It serves to supply to the brain enough oxygen to keep the slender thread of life from breaking. In artificial respiration, by the Schäfer method especially, an artificial circulation of no mean value is simultaneously produced.

It must be borne in mind that when any part of the body, but especially the chest and the abdomen, is subjected to pressure, the valves of the heart and of the veins inevitably cause the blood of the veins to flow toward the heart and the blood in the arteries to flow toward the periphery. Now this is precisely what the heart does. If, instead of a single local pressure, a series of rhythmic pressures upon the thorax and abdomen are made the entire blood stream may be energized and moved, that is to say, the person who makes the rhythmic pressure furnishes an external pseudocardiac action. The author has personally been able to effect a complete circulation in a recently dead subject, producing a radial pulse and bleeding of peripheral vessels, and even to make a blood-pressure of measurable tension (registered by a sphygmomanometer) by the combined effect of a tightly inflated rubber suit covering the lower extremities and the abdomen and strong rhythmic pressure from the broadly extended hands applied upon each side of the chest. Indeed, the face could be made to flush and fade appreciably at will. Undoubtedly such an excellent method as Schäfer's for producing artificial respiration owes its effectiveness as much to the factor of artificial circulation as to artificial respiration. This point seems to have been missed.

Schäfer's method should be used in all cases in the absence of medical assistance or outside of a hospital, and even in a hospital in the absence of immediate surgical aid.

THE AUTHOR'S METHOD OF RESUSCITATION

The author's method is applicable only in a hospital service in which the staff is trained for prompt action, and the simple apparatus for infusion and a bottle of adrenalin are ever in readiness. A staff may be so drilled that the adrenalin may be introduced in two minutes. In the author's method the

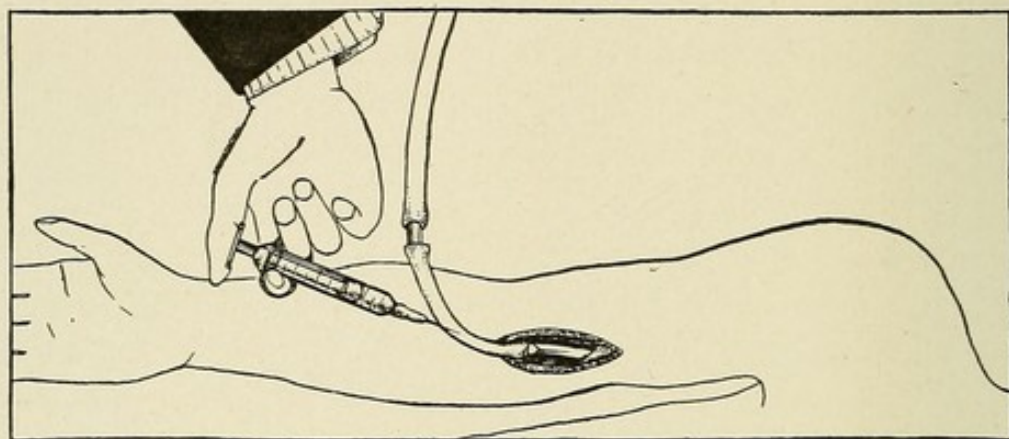


FIG. XVI.—METHOD OF GIVING ADRENALIN BY INJECTING IT DIRECTLY INTO A STREAM OF NORMAL SALINE SOLUTION.

The needle of the syringe is thrust through the wall of the rubber tube, and the adrenalin then injected with rapidity and certainty into the circulation, by way of the flowing saline infusion.

patient is kept in a supine position. Rhythmic pressure is made on the thorax and upper abdomen for the double purpose of producing artificial respiration and artificial circulation. Any artery, but preferably the brachial, is laid bare with rapid strokes of a scalpel, picked up, and an elliptical hole snipped into it with scissors, leakage being controlled by digital pressure or clamps. Into this hole, directed toward the heart, a small cannula of an ordinary "funnel, tube, and cannula apparatus" filled with normal saline solution is inserted and tied. The stream is allowed to flow at once and immediately half the contents of a hypodermic syringe filled with adrenalin chlorid, 1-1,000, is injected into the inflowing saline stream as

near the artery as possible by piercing the rubber tube, or is injected directly into the artery, now distended with salt solution (see Fig. XVI). The instant this is done the rhythmic pressure is rather vigorously applied, so that the adrenalin will be distributed as widely as possible. As soon as the coronary pressure is raised high enough with oxygenated blood the heart will begin to beat with a strong thump. Care must be taken not to cause acute dilatation of the heart, and the flow should be stopped the instant blood begins to be forced back into the tube by the sudden rise in blood-pressure. If resuscitation is successful the artery may then be resected and an end-to-end anastomosis made.

The author's associates, Dr. Lower, Dr. Dolley, and Dr. Sloan, have made a number of attempts at resuscitation, some of which were made before Dr. Dolley and the author ascertained the period during which various parts of the brain can endure anemia. These experiences, amounting to ten in all, may be briefly summarized as follows: The cases of electrocution resisted every attempt at reanimating the heart. Later, in the before-mentioned research with Prof. MacLeod on the attempted resuscitation of electrocuted dogs, it was found that there was fibrillary contraction of the heart, which prevented resuscitation. This gives an almost hopeless aspect to cases of suspended animation from electric shock.¹

In other cases in which the patients were drowned and also in the case of seriously injured persons who died on entering the hospital, it was usually possible to resuscitate the heart and the respiration but impossible to resuscitate the cerebrum.

¹ In order to prevent such accidents an apparatus was devised made of wire netting which fitted snugly around each limb and around the neck, the upper and lower parts communicating with each other by means of insulated wires. In this manner the electric currents received by the head, neck, and extremities were shunted around the vulnerable heart and the apparatus served as a sort of lightning rod.

In one case success might have been attained had there not been a fatal lesion of the brain. In this case the entire occipital skull was crushed deeply into the brain. Even then the resuscitation succeeded beyond all expectations. The heart quickly began beating and a blood pressure of 80 mm. was secured and sustained. The author proceeded to elevate the depressed fractures, the patient moving about during the cutting, but as the fragments were raised blood gushed out from lacerated sinuses. The wounds were packed but the patient soon died.

In another case a patient with a crushed skull who died on arrival at the accident room was reanimated partially, but the reanimation was brief. In this case, also, there was a mortal wound of the brain. As previously stated, the fact, that the cortex, the associative memory part of the brain, was so extremely susceptible to anemia, was not then known.

In three instances, among over thirteen thousand personal operations, the author has seen patients succumb on the operating table under circumstances which permitted an attempt at resuscitation. In the very first case, resuscitation was successful. The patient presented a serious risk, a case of delirious Graves' disease, in which, in the course of operation for excision of the lobe of the thyroid, collapse occurred without warning. The lobe had just been removed and the wound was ready to be closed. The assistant was at once directed to make rhythmic compression on the chest while the jugular vein was opened and adrenalin and saline solution introduced; the patient meanwhile seemed to be dead. The heart began to beat immediately and respiration was soon resumed. This patient survived the immediate effects of the operation and resuscitation, but died later with symptoms of exhaustion and of the disease.

Another case was that of sudden collapse while an at-

tempt was being made to remove a tumor of the brain in a child of eight. The tumor was situated at the cerebellar-pon-tine angle. The patient was in a very emaciated, weakened state, and a poor risk for any operation. In the course of the deep dissection, while trying to dislodge the tumor, the heart and the respiration suddenly stopped, and the child was apparently dead. An assistant kept up rhythmic pressure on the thorax while the author hastily laid bare the axillary artery, picked it up, snipped an oblong opening in it and inserted the cannula of a saline apparatus into it. The solution at once flowed into the axillary artery toward the heart, and 15 minims of adrenalin chlorid solution, 1-1,000, were injected into the rubber tubing near the cannula. In about one minute the heart began to beat strongly, and the saline apparatus was at once closed by a clamp. After a time a sudden strong spontaneous inspiration occurred and eventually respiration was resumed. The wound was packed with iodoform gauze, a dressing was applied, and the patient sent to her room. In several hours absolute death followed without her having regained consciousness.

The last case was that of a middle-aged woman who had a growing tumor of the uterus, operation upon whom had been deferred because of a serious lesion of the heart. At times there had been swelling of the feet and nephritis. Finally the tumor had grown so large and caused so much distress that, despite the risk, operation was undertaken. The patient went through the operation well enough until the wound was nearly sutured and the anesthetic had been removed, when, without warning, the heart stopped. Rhythmic pressure on the chest was at once made, the axillary artery was opened, and adrenalin in saline solution was given as before. There was some delay in securing a response from the heart, but when it came it was energetic. The respiration did not appear

spontaneously for nearly an hour, but meanwhile there was good circulation. The first intimation of inspiration was a sudden, long, deep breath. Following this the respirations were slow, deep, and of a sighing type. In time the respiratory rate increased and the artificial respiration that had still been maintained as a precautionary measure was discontinued. The patient was taken to her bed and Professor G. N. Stewart, the consulting physiologist to Lakeside Hospital, was asked to see her. There were no reflexes, either deep or superficial; no response to painful stimuli; no conjunctival, nasal, laryngeal or pharyngeal reflex; the pupils were contracted and did not respond; and the intraocular tension was markedly increased. The heart beat was regular and ranged from 90 to 100 per minute. The respiration ranged from 12 to 16 per minute. These two functions persisted for about 6 hours, when both gradually failed.

The interpretation of the failure is that the time before inauguration of the heart beat in the course of the resuscitation was unusually long, so that from the moment of collapse and relative death to the moment of reestablishment of circulation was about 9 minutes. It is quite certain that this was a clear case of cerebral death before death of the respiratory and circulatory centers. On the other hand, it is equally certain that had the heart become reanimated as quickly as in former cases the patient would have been resuscitated as a whole.

From the other experiments on the resistance of other tissues than the brain which have been reported in other chapters of this volume it is quite certain that all of the body was alive during the six hours following the resuscitation excepting that part of the brain in which associative memory and other higher functions lie. Assuming, then, that the cortex died on the table and the balance of the brain and all of the remainder of the body lived six hours longer, when did the patient die?

The author and his associates have resuscitated fully one hundred dogs in the course of the original research on resuscitation and in the numerous demonstrations of the technique to those interested. In comparing the results with the resuscitation of patients he is convinced that the human heart is as readily resuscitated as is the heart of the dog.

CHAPTER XII

GENERAL RECAPITULATION

LOCAL ANEMIA

Experimental and clinical observations of total anemia of various organs and tissues of the body have been presented in the foregoing pages. From them the lesson is learned that some organs or tissues, such as the skin, bone, and connective tissue at one extreme endure anemia for many hours, while at the other the brain endures anemia for only a few minutes. Moreover, the component parts of organs endure anemia unequally; the connective tissue framework is more resistant by far than the parenchymal cells, and there is strong evidence that the power to endure anemia is in proportion to the delicacy of the function of an organ or tissue.

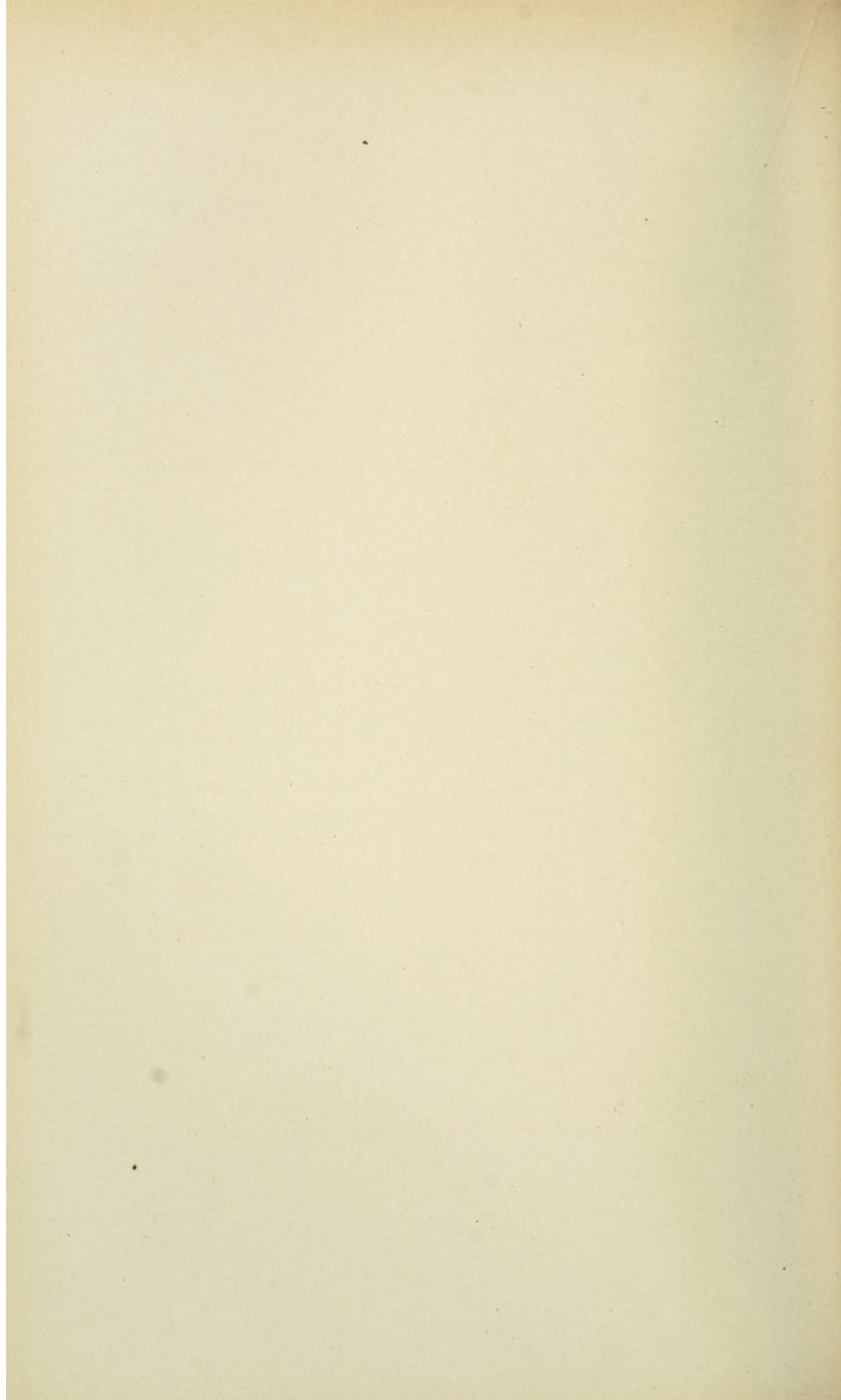
The results of local anemia may not be confined to the immediate organ affected, but may produce constitutional disturbances. For example, anemia of a muscle may result in atrophy and functional death of the muscle while the remainder of the body is virtually uninjured. On the other hand the death of a coil of intestine not only destroys the coil but also results in the formation of a powerful life-destroying toxin which acts by injuring the brain cells chemically. Whether aseptic necrosis of intestine would alone furnish this toxin is of little moment, but doubtless tissue necrosis *per se* assists the toxins of the invading bacteria. Again, aseptic death of a kidney or spleen might cause no general disturbance, while septic death would be sure to do so.

From the fact that there is a pretty sharply defined time limit beyond which organs cannot survive anemia, many important lessons are to be learned. A common example is shown in the application of bandages, too tight applications resulting either in death of a limb as a whole, or death of only certain parts, e. g., of the muscle fibers, and of the skin and connective tissue, the bone alone surviving.

Another important underlying principle which has been strongly proved is that in partly or wholly anemic organs the susceptibility to infection is increased. This is notably true of the intestine as is shown by the ready invasion of bacteria into the intestinal wall, which is not anemic enough to die of anemia alone, and which would not be invaded at all if it were not anemic. This recalls the fact that previously injured or overworked kidneys are more susceptible to anemia than are normal kidneys. It also suggests the necessity of avoiding unnecessarily long pressure of clamps on the intestines and the renal pedicle, not only so as not to cause harm through anemia, but also to avoid lowering the resistance to infection. Finally, these studies also show that unconscious or paralyzed patients should be protected against both anemia and infection by being turned in bed at regular intervals, such individuals having lost the protecting warning of beginning injury which pain would otherwise give.

RESUSCITATION

Whatever the method of resuscitation, the one primary and essential object is to supply the brain with an oxygenated circulation. Artificial respiration can be maintained indefinitely with ease; the heart is rather readily started, but unless cerebral anemia be overcome in less than seven minutes the patient passes into the death that knows no awakening.



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APPENDIX

Through the courtesy of the following Commissions, representing The American Medical Association, The National Electric Light Association, The American Institute of Electrical Engineers, and the Bureau of Mines, their reports and rules are reprinted here on account of their important practical bearing upon the subject of this monograph.

REPORT OF THE COMMISSION ON RESUSCITATION FROM ELECTRIC SHOCK

The electric current may kill either by temporarily paralyzing the nervous control of the muscles of respiration, or by stopping the regular beat of the heart. When the heart is seriously affected it ceases to contract as a whole, but continues to contract in parts here and there, so that it appears to quiver. It is then said to "fibrillate." In this condition the heart fails to keep the blood circulating, and death quickly results. At present no practical procedure has been discovered which will restore the regular beat of the heart in man after it begins fibrillating. Hope of resuscitation is now restricted to proper treatment of the cases of paralyzed respiration; and, since deprivation of oxygen for about ten minutes injures irretrievably some of the nerve centers of the brain, it is particularly important that measures for resuscitation be applied immediately and continued until natural breathing returns. In some instances, however, the heart may be merely weakened without being made to fibrillate; in such cases artificial respiration may be of vital importance, because a greatly weakened

heart leads to impairment or total stoppage of respiration, which in turn destroys the last vestige of the heart-beat. In all cases, therefore, an attempt should be made to restore natural breathing. Fortunately, artificial respiration can be applied by laymen without immediate need of complicated apparatus.

The older rules for artificial respiration, which were widely posted in this country, described the Silvester method, a method which directs that the victim of the accident be laid on his back, and his chest expanded and compressed by drawing his arms forward and then pushing them back against his ribs. After these rules were published, however, a new method of artificial respiration was devised by Sir E. A. Schäfer, of Edinburgh, called by him the "prone pressure method." It consists in laying the victim on his belly and applying pressure rhythmically on the loins and lowest ribs.

Since there was some difference of opinion regarding the relative merits of these two methods of artificial respiration, and since the time seemed ripe for a revision of the old rules and for a possible standardization of new rules for resuscitation, President Gilchrist, of the National Electric Light Association, requested that the American Medical Association and the American Institute of Electrical Engineers coöperate with his own Association in this undertaking. Through the appointment of representatives of these Associations a Commission on Resuscitation from Electric Shock was organized in the autumn of 1911, with the following membership:

For the American Medical Association, Dr. W. B. Cannon (chairman), Professor of Physiology, Harvard University; Dr. George W. Crile, Professor of Surgery, Western Reserve University; Dr. Yandell Henderson, Professor of Physiology, Yale University; and Dr. S. J. Meltzer, head of the de-

partment of Physiology and Pharmacology in the Rockefeller Institute for Medical Research. For the National Electric Light Association, Dr. E. A. Spitzka, Director and Professor of General Anatomy, Daniel Baugh Institute of Anatomy, Jefferson Medical College, and Mr. Wm. C. L. Eglin, Past President of the National Electric Light Association. For the American Institute of Electrical Engineers, Dr. A. E. Kennelly, Professor of Electrical Engineering, Harvard University, and Dr. Elihu Thomson, Electrician, General Electric Company. Mr. W. D. Weaver, editor of the *Electrical World*, was elected Secretary of the Commission.

The Commission was confronted with three problems: (1) The determination of the best manual method of artificial respiration that can be instantly applied by laymen, and the clear description of that method; (2) a consideration of special mechanical appliances for continuing artificial respiration, and the possible invention of a simple and effective arrangement, the action of which might be quickly and easily learned; (3) an investigation of the possibilities of restoring the fibrillating heart to its natural pulsation. The third of these problems has not been solved, and possibly, because of the sensitiveness of important nerve cells of the brain to lack of blood supply, a sensitiveness which results in abolition of their functions when deprived of blood for about ten minutes, the solution of the problem in a manner permitting the life of the individual to continue may be impracticable.

The Manual Method of Artificial Respiration

The advantages claimed for the Schäfer method over the Silvester method are: (1) Greater simplicity and ease of performance; (2) absence of trouble from the tongue falling back and blocking the air passages; (3) little danger of injuring the liver or breaking the ribs if pressure is gradually and not

violently applied; and (4) larger ventilation of the lungs. There is no question regarding the first three of these claims. The claims for larger ventilation Professor Schäfer supported by experimenting on conscious human subjects. He compared the volumes of air taken into and expelled from the lungs by the prone pressure method and by the other manual procedures of artificial respiration. His results showed a to-and-fro tide of air sufficient to maintain life indefinitely when the prone pressure method was used, but a volume considerably less than normal when the Silvester and other methods were employed.

Professor Schäfer's claim for larger ventilation with his method was examined by Drs. Henderson and Cannon mainly on conscious healthy men and by Dr. Meltzer on animals. When, in a conscious person placed in the prone position, artificial respiration is substituted for normal breathing, the result indeed is a taking in and giving forth of air in practically the usual amounts, as can be shown by a gasometer. Consequently when the operator ceases the rhythmic pressure the subject at once takes up his natural breathing again. He does not breathe more rapidly, as he would if the artificial respiration had been insufficient, nor does he cease breathing for a moment, as he probably would if the artificial respiration had been excessive.

Our experiments showed that the pressure applied in the Schäfer method is quite sufficient to expel the air from the lungs to a degree not surpassed by vigorous efforts at expiration. Not only is the chest diameter lessened from front to back, but further, because the pressure on the abdominal viscera tends to force the diaphragm upward, the chest is also lessened in extent from above downward. Schäfer declared that the natural elasticity of the chest and abdomen causes a resumption of their original positions as soon as pressure is

removed, and that consequently air passes into the lungs as in inspiration.

The fundamental question, however, is whether the taking in of air because of the elasticity of the parts will be the same in an unconscious as in a conscious person. If the muscles continue to exert their moderate contraction or tone, as in a conscious person, the parts disturbed by pressure will evidently be restored to their former positions more completely than if the muscles are toneless. Besides this tonic contraction of the muscles as an aid to inspiration, it is highly probable that quite involuntarily the conscious subject permits the normal nervous and muscular mechanism, which naturally acts without involving volition, to expand the chest and thus take in the air. The fact that natural breathing is resumed after a period of artificial ventilation of the lungs, without any indication of too little respiration or too much, rouses the suspicion that the ventilation is, in fact, being regulated by the subject involuntarily. Consequently a testing of the methods of artificial respiration under conditions as near as possible to those in the breathless, toneless subject is desirable.

A critical examination of the Schäfer and other methods of artificial respiration was undertaken, early in 1912, by Dr. Henderson on students who, after over-ventilating their lungs by two or three minutes of voluntary forced respiration, showed a lack of desire to breathe (apnea), lasting from 40 to 80 seconds. Schäfer had, indeed, produced in his tests some degree of apnea, but his subjects took only "several deep respirations," and the apnea seems to have lasted only a brief period during the first part of the artificial respiration. In subjects in true apnea the tone of the muscles would be retained, but the tendency to inspiration after the breath was pressed from the chest would probably be reduced to a minimum. The following figures, obtained by Dr. Henderson,

show the amount (in cubic centimeters) of the exchange of air, as measured by a gasometer connected with the subject's mouth, in men in true apnea, and again without this condition, by different methods of artificial respiration:

	Silvester method	Schäfer method (arms flexed at the sides)	Schäfer method (arms stretched forward)	Natural breathing (at the same rate as the artificial)
Subject normal	500-600	500-600	500-600	500-600
Subject in apnea ..	150-200	125-200	200-300	.....

It is interesting to note that as the period of apnea came to an end the movements of the chest were increased involuntarily to approximately the normal extent. In some cases the artificial movements (on non-apneic subjects) were of somewhat greater amplitude than the natural; but the rate was correspondingly slower, so that they got (or rather, quite involuntarily, they took) exactly the amount of air that they needed—no more and no less. According to the results obtained with the subjects in apnea, the Silvester method is somewhat more effective than the Schäfer, when the subject's arms are at his sides. The latter is, however, the better when the prone pressure procedure is reinforced by the inspiratory position of the chest, which drawing the arms forward tends to induce. In both the exchange of air is considerably less than the usual tidal volume (about 450 c. c.).

These results have recently been confirmed by Liljestrand, Wollin and Nilsson (*Skandinavisches Archiv für Physiologie*, 1913, xxix, 198), who found that the amount of air moved by artificial respiration when the conscious subject was in apnea was much less than in experiments when the same subject was not in apnea. These Swedish observers report an insignificantly greater tide of air (about 0.01 liter) with the Silvester method than with the Schäfer method. They paid no attention to the position of the subject's arms, however,

which we may assume not to have been drawn forward. In fact, so far as we are aware, the advantage of having the subject's arms extended beside his head so as to pull the ribs outward into a more nearly inspiratory position than is otherwise afforded has not previously been referred to by any writer, although it has been reported that the position has been used by English coast guards. The experiments above reported fully demonstrate its importance.

The observations of Liljestrand, Wollin, and Nilsson (in part upon cadavers) likewise indicate that on a toneless body the exchange of air induced by artificial respiration would probably be considerably less than on a man who was merely in apnea. The following observation by Dr. Henderson points to the same conclusion, but suggests that the tone (or elasticity) of the muscles wears off gradually, and is not entirely lost until after a period beyond which resuscitation is in any case impossible. The windpipe of a cat under chloroform was connected with a small gasometer and the volume of the natural breaths recorded. The chloroform was then administered in such amount that respiration failed. Artificial respiration by the Silvester method was given. It afforded a movement of the gasometer at first only about a quarter as large as the natural, then about a third, then about a half, and then spontaneous breathing returned. Chloroform was again administered until both breathing and heart action had ceased. Artificial respiration now gave only 15 per cent of the normal volume. Five minutes later, *i. e.*, six minutes after death, it was only 8 per cent, and after another five minutes only 5 per cent.

A modification of the Silvester method has been suggested by Brosch, in that the arms after being drawn past the head are pressed downward so that the chest is raised away from contact with the body's support. A large ventilation, even as great as from 1 to 3

liters for each respiration, has been reported as occurring in this procedure. But the violent and painful character of the manipulation must lead to as great participation as possible by the subject in order to minimize the degree of dislocation of the parts, and the volumes of air breathed in and out do not therefore represent solely the mechanical effects of the procedure. The Brosch modification of the Silvester method has not commended itself as a means of artificial respiration.

Dr. Meltzer examined the efficacy of the two methods on dogs after completely abolishing, by means of curare, all possibility of muscular participation by the animal and also all muscular tone. Twelve minutes was the longest time during which respiration was sufficient to keep the heart beating when the Silvester method was used, while with the Schäfer method the shortest time was eighteen minutes and the longest thirty-one.

The foregoing observations indicate that, so far as the amount of ventilation of the lungs is concerned, the Schäfer method, reinforced by the extension of the arms forward, is decidedly better than that suggested by Silvester. And this advantage, taken in conjunction with its greater simplicity and safety, caused the Commission to vote unanimously in favor of the prone pressure method of artificial respiration as an effective means of giving immediate aid.

After a careful consideration of the conditions under which accidents occur, and of the need for clear and brief statements of the proper procedures, the Commission prepared a description of facts and procedures, which has been issued as a booklet. Since the manual procedure is not well learned merely by reading about it, superintendents, foremen and others having charge of men are advised in the booklet to give practical instructions and demonstrations on the use of the rules to all employees. Besides the booklet the Commission has prepared a slight abbreviation of Sections 1, 2, and 3 of

the Instructions, which has been issued as a chart to be posted in central stations where accidents are likely to occur.

Mechanical Devices for Artificial Respiration

The Need for Mechanical Devices

In experimental attempts to cause death of animals by ether, chloroform, illuminating gas, drowning, etc., respiration sometimes returns spontaneously after a complete suspension for two minutes and longer. For this reason it is often difficult to decide whether the restoration of respiration has really been brought about by any manipulation which has been applied. Only when such manipulation, applied to a living animal unable to breathe, keeps up a sufficient exchange of respiratory gases to maintain the circulation for a considerable period, and when discontinued no spontaneous respiration sets in, is the conclusion strictly justified that the manipulation is efficient for artificial respiration. The keeping alive of completely curarized animals by artificial respiration is therefore the most rigorous proof for the efficiency of any method. The methods applied to human beings have not been tested in this rigid manner. The air exchange effected by the various methods has been determined on healthy conscious individuals, not on the relaxed victims of drowning and shock, and the recovery of the victims by one method or another is cited as evidence of the value of the method. Keith has examined the annual reports of the Royal Humane Society for the past 140 years, and in hundreds of instances recovery of the apparently drowned has been reported when, at different times, the chief means employed were fumigation (rectal), or warmth, or inflation (mouth to mouth), or friction, or artificial respiration by manual methods, or combinations of these (see *Lancet*, 1909, p. 897).

Since a certain percentage of cases recover spontaneously, each one of these methods has been credited with causing recovery, and yet an examination shows that some of them, as fumigation, friction, and warmth, have no direct effect on breathing. Although the manual methods of artificial respiration provide an exchange of air, the amount of which in the toneless victim has not been accurately determined, they probably afford a sufficient exchange of air until dangers from temporary causes are averted. Thus, in mild cases of respiratory failure, in which reflex irritability of the breathing mechanism is retained, and therefore a tendency to recovery exists, these methods may be of the utmost value in reestablishing the normal movements. Certainly, in all cases when breathing is suspended and no better means are at hand to supply air to the lungs, manual methods should be used, and of these the most commendable is the prone pressure method with arms extended forward. Even a relatively poor method of artificial respiration, if begun immediately, may maintain life and permit ultimate recovery in cases in which an ideal method with all the resources of laboratory and hospital would be ineffective after a delay of a few minutes. If, owing to delay, certain cells of the brain have been deprived of their supply of oxygen for more than the critical period (rarely more than ten minutes), it is utterly impossible for any later treatment to restore them to their normal condition.

Because the amount of ventilation supplied by this modified prone pressure method in apneic subjects may be close to a dangerous minimum, mechanical devices assuring more efficient respiration than can be assured by manual methods are desirable. In order to test the action of devices now being advocated, a subcommittee, with Dr. Meltzer as chairman, was appointed. The apparatus examined was used according to

directions, and the effects were demonstrated before the members of the Committee.

Commercial Mechanical Devices

At least four machines for performing artificial respiration are now in the market—the Pulmotor, the Dr. Brat Apparatus, the Lungmotor, and the Salvator. The last two devices have not been examined. The first two machines are alike in providing for inspiration by oxygen pressure and for expiration by suction. In the pulmotor the inspiratory air contains only 60 per cent oxygen, while in the Dr. Brat apparatus it is all pure oxygen. In the latter apparatus the respiratory changes are made by hand, while in the pulmotor they are made automatically by the mechanism of the instrument. The apparatus of Dr. Brat was used by some surgeons in experimental intrathoracic work while its inventor was alive, but it seems never to have become a successful commercial article. The pulmotor, on the other hand, although it has lacked scientific, surgical, and medical sponsors, has received wide publicity through the daily press.

The Pulmotor

The pulmotor is manufactured by the Draeger Works in Lübeck, Germany, manufacturers of various rescue apparatus. The firm has a very active agency for its goods in Pittsburgh. Although several years have passed since the pulmotor was introduced in Germany, the medical literature of that country has only one publication on this machine, a short article by Dr. Roth (*Berliner klinische Wochenschrift*, Sept. 18, 1911), known for the Roth-Draeger inhalation apparatus. In this article Dr. Roth states that he had made experiments on animals and human cadavers with the machine several years before. He found that air is liable to be driven into the stomach,

but that this can be prevented by pressure on the trachea. Although years passed by after the introduction of this apparatus and although Germany has many active life-saving societies, no medical report of its use in a single case has appeared in the very prolific medical literature of that country. Jelineck (*Wiener medezinische Wochenschrift*, 1912, No. 25) mentions the efficiency of the pulmotor, but his knowledge of the machine is derived from the brief article of Dr. Roth and from a report sent to him by the Pittsburgh agency, that Dr. Sherman, in Pittsburgh, saved two lives with this machine.

In the medical literature of this country the following notices have been found :

The *Journal of the American Medical Association* for August 31, 1912, contains an answer to a question regarding the pulmotor, with a reference to Dr. Roth's article and to the reports in Chicago newspapers.

McCombes, of Philadelphia, in an article on illuminating gas poisoning in the *American Journal of Medical Sciences*, Oct., 1912, says of the pulmotor: "It maintains artificial respiration perfectly. Reports from all over the country relative to its efficiency have been received. Whenever possible it should be used." He does not say from whom and by whom the reports were received. From a study of the wording of this writer it is highly probable that he had neither personal experience with cases nor any medical literature at his disposal.

In volume VI of *Keen's Surgery* is an article by W. L. Estes (Director, Physician, and Surgeon-in-Chief of South Bethlehem, Pa.), in which there is a picture of the pulmotor used in the act of resuscitation. Quoting the *Survey*, he states that the Red Cross First Aid car is equipped with "the pulmotor for restoring respiration to asphyxiated persons." Not a single report of personal knowledge has been found in a

standard medical journal. And only when an observer publishes his experience in detail, gathered in a number of cases, can we judge whether his observations are unbiased, his statements truthful and his conclusions justifiable.

By the kindness of the head physician to the New York Edison Co., opportunity was obtained to examine 21 records of gas poisoning in which the pulmotor was reported as having been used with success. Most of the reports were written by chauffeurs and a few only by physicians. In most of the reports no distinction was made between unconsciousness and absence of respiration. In a few cases only was there reason to suppose that respiration might have been suspended. Letters sent to the various physicians mentioned brought either an unsatisfactory answer or none at all. Of two additional cases which were reported no machine was used in one, and in the other, a case of opium poisoning, an entirely different method (intratracheal insufflation) was employed.

A series of reports made by miners to the Bureau of Mines and another series made by several physicians were examined. The miners' reports comprise few cases. In one case, according to the daily press, the man was revived by the pulmotor, while the report does not even mention the pulmotor, and the physician in attendance expressed the belief that success was due to hypodermic treatment. Of the remaining nine cases four were revived by the administration of oxygen, and two by the Silvester method of artificial respiration in combination with oxygen. In the seventh case (Webb) the Silvester method had been applied for three minutes and was followed immediately by the pulmotor for six minutes. In the eighth case (Burgess) the pulmotor was first applied thirty minutes after the victim had been removed from the gas atmosphere. No statement was made as to what was done for him in the interim. In the ninth case (Enzian) Dr. McGuire,

of Wilkes-Barre, "endeavored for two hours to revive her by artificial respiration. Failing in this, a pulmotor was brought a distance of eight miles, and under the manipulation of Mr. G. T. Holdaman the patient was revived in two or three hours." Cases eight and nine, in which the victims lived a long time before the application of the pulmotor (half an hour and two hours), do not present convincing evidence. In case seven the pulmotor did at least as much as the Silvester method; but that does not show it did more, since the same result might have been attained if the pulmotor had been used first and the Silvester method later. These reports are in no manner satisfactory documents for demonstrating the superiority of the pulmotor as a device for artificial respiration.

The second series consists of statements of physicians transmitted by Dr. Wm. O'Neil Sherman, chief surgeon of the Carnegie Steel Co. in Pittsburgh. It comprises reports of seven cases in which the pulmotor was used successfully. Dr. Sherman himself reports two cases. In the first (June 20, 1912) a collapse occurred during an amputation, "breathing ceased, pupils dilated and did not react to light, with a very small, thin pulse." "The pulmotor was brought into use, and as a result the patient *soon began breathing normally* (italics ours here and elsewhere), recovering from the collapse in ten minutes." In the second case (Dec. 20, 1912) nitrous-oxid-oxygen anesthesia was being given, "when respiration suddenly ceased, eye reflexes absent, pupils fixed, cyanosis gradually increasing, pulse weak and slow. Artificial respiration (Silvester method)—tongue drawn out, cyanosis becoming greater. Artificial respiration was continued with no sign of returning respiration for two and a half minutes. Pulmotor was then used; respiration returned in *one to one and a half minutes*; cyanosis soon cleared up, and the operation continued under ether."

Dr. Urmson, Newcastle, Pa., reports (Dec. 23, 1912) the case of a man overcome by gas . . . "it was impossible to detect any sign of respiration. Mask was applied and pulmotor started; in a *short time* patient showed marked signs of improvement." This patient recovered.

Dr. Botkin, Duquesne, Pa., reports (April 20, 1912) the case of a strangulated man, his clothes having been caught in the drill of the press. Respiration stertorous, 10 or 12 per minute. "We immediately cleared his mouth and throat of mucus and gave oxygen by use of pulmotor." "It did splendid work, inflating his lungs fully and regularly, and established normal respiration." (Natural respiration had not stopped in this case.)

Dr. Evans, Union Mills, Youngstown, Ohio, reports (Dec. 17, 1912) the case of a man overcome by gas, "unconscious, scarcely if any respiration, pulse weak. Pulmotor applied, kept going for five minutes, respiration returned, pulse became stronger and consciousness returned."

Dr. Rossiter, company surgeon, Swissdale, Pa., reports two cases of "gassing." In one case (Nov. 21, 1912) "the patient was unconscious, not breathing, no pulse, and I was not [*sic*] able to detect only faint flutter of the heart. The pulmotor was used, and in the course of about ten minutes the man showed signs of life, and after keeping it on for about twenty minutes he was almost completely revived." In the second case of "gassing" (Dec. 28, 1912) "the patient was unconscious, had no pulse, no signs of respiration, very feeble heart, loss of all reflexes. Before I arrived the hospital attendant performed artificial respiration in connection with the inhaling device of the pulmotor. I continued this treatment after my arrival for about one-half hour, at the end of which time there was very little change in the patient. I then switched over the pulmotor and adjusted it without pulling

out the tongue or pressing on the larynx. In the course of *a few minutes* the patient began to move his head, and in ten to fifteen minutes he started to fight and wanted to sit up." (In this case manual artificial respiration combined with oxygen was capable of keeping up the respiratory function for longer than half an hour.)

In five of these cases the pulmotor was used only a few minutes, and furthermore respiration was restored so soon after it had ceased that the conclusion that the pulmotor was essential is not justified. The evidence is similar to that in the cases of the apparently drowned, previously cited, who were restored by fumigation or friction. In another case spontaneous breathing was not absent, and therefore the credit of restoration does not belong to the instrument. The last two cases are the most favorable to efficiency of the pulmotor, and in one of these the support of life by manual respiration for more than half an hour is rather in favor of that method.

Although the cases reported above do not furnish convincing proof of the necessity or the exceptional value of the pulmotor, that instrument is probably capable of creditable performance, and doubtless has, in some instances, favored the restoration of normal breathing. Its present vogue, however, is not supported by a critical examination of the principles involved in its mechanism or of its effects when used for long periods. As stated above, no well-considered testimony to its action is to be found in medical literature, and in this country at least its loudest sponsors are the newspapers, which have spread the impression that the pulmotor is a perfect and most reliable resource when respiration is suspended.

A high official of one of the important electric companies in the country testified to a member of the Committee: "We have to buy these machines, even if they are no good, as an

evidence of our good faith and our desire to do everything possible to safeguard the public and employees."

Experiments with Commercial Devices for Artificial Respiration

The effects of the Dr. Brat apparatus and the pulmotor were studied by the subcommittee in experiments on anesthetized and curarized animals. The animals were thus doubly prevented from making any response to the action of the apparatus, and were, therefore, in a condition analogous to extreme prostration. The Dr. Brat apparatus, obtained by courtesy of the Westphalia Engineering Co., was used in a few experiments only, but the results were in essential points similar to those secured with the pulmotor. One pulmotor used was loaned by the Pittsburgh station of the Government Bureau of Mines. On returning the machine, Mr. Paul, the mining engineer in charge of the station, stated that the machine was in the same good working condition when returned as it was when sent. Another pulmotor, loaned by the New Haven Gas Co., was also tested, and gave confirmatory results. Experiments were performed on dogs, cats, and rabbits. The oxygen was applied through specially constructed masks adapted to the individual animals. The efficiency of these masks was tested by other respiratory apparatus at hand in the laboratory. The tongue was kept well pulled out. In several experiments the trachea was connected by means of a lateral cannula with a water manometer. In some cases also the intrapleural pressure was measured, and in others the thorax was opened and the behavior and appearance of the lungs observed.

Of eleven dogs only one small animal (under 4 kilos), completely curarized, could be kept alive by means of the automatically working pulmotor for as long as one hour. The animal remained in fairly good condition, had about thirty

respirations per minute, and no air entered the stomach. In another dog the usual laboratory method of artificial respiration (inflation of the lungs) had to be substituted for two to three minutes every eight or ten minutes in order to keep the animal alive. The respiratory movements would go on with the pulmotor regularly for a while, and then they would begin to change from a slow to a rapid rhythm, and the pulse would gradually become dangerously slow. In two other animals the pulmonary respiration would continue regularly at one position of the head, but stop at the slightest change from that position. On other occasions changes in the respiration would occur without any visible cause. In the majority of the animals respiration could not be kept up even for five minutes when left to the automatic activity of the apparatus. The result was evidently better when the respiratory alternations of the machines were guided by hand, so as to have sixteen to twenty respiratory cycles per minute. But even under these circumstances the circulation could rarely be kept up in a normal state for longer than twelve or fifteen minutes.

When the thorax was opened the lungs were seen becoming gradually smaller and smaller. In a young dog and in a cat the unopened thorax was also observed getting smaller as soon as respiration was started by the pulmotor. An equilibrium was soon reached, and the respiratory changes in the size of the thorax apparently took place then within the normal expiratory diameters. The respiratory changes in the tracheal manometer would often be only from a more to a less negative pressure, never positive. The changes in the tracheal pressure amounted often only to 30 or 40 millimeters of water. When the thorax was opened, after the pulmotor had been used for a while, the lungs often presented an uneven appearance, small collapsed areas alternating with much dilated areas. After connecting with the ordinary laboratory respiratory ap-

paratus this unevenness soon disappeared. When the pulmotor was connected directly with a tracheal tube respiration was kept up in a more reliable way, especially in cats and rabbits. When regulating the respiration by hand air often entered the stomach. Pressure upon the trachea or larynx rather prevented the entrance of air into the lungs and increased its entrance into the stomach.

These observations on animals indicate that there are two factors which interfere with the efficiency of the pulmotor as a reliable device for artificial respiration. The first is its automatic activity and the ease with which inspiration is turned into expiration. Inflation and deflation of a bag—the method used by agents to demonstrate the action of the pulmotor—is deceptive, because the bag, unlike the air passages of the body, offers no resistance until full. As soon as the inspiratory blast meets an obstacle in the air passages it is automatically cut off and turned into expiration, and thus frequently no efficient inspirations are performed. In lower animals, certainly, the blast often meets obstacles while passing from the pharynx into the alveoli, and the inspiratory pressure of the automatically working pulmotor is in many cases insufficient to overcome them. When guided by hand the inspiratory pressure is permitted to increase; hence the greater efficiency under these circumstances.

The second harmful factor brought out by these experiments is the performance of expiration by suction. In normal respiration expiration is accomplished by a power which does not suck, but drives the air out by the elasticity of the distended or compressed tissues, aided, sometimes, by muscular contraction. The finer bronchioles have no cartilages; when air is sucked out from the trachea and larger bronchi, the bronchioles are liable to close before the suction reaches the alveoli. Furthermore, when the air is actively sucked out the

walls of many of the bronchioles and alveoli are liable to collapse and stick together, so that the next inspiratory pressure, which is barely sufficient to overcome the elasticity of the lung, is not strong enough to overcome the resistance offered by the adherent surfaces. The successive additional respiratory changes may therefore take place largely in the bronchial tree and not sufficiently in the alveoli; that is, there may be a lessened exchange of gases while the movements of the thorax still simulate normal respiration. Hence failure of the circulation ensues with diminution of the size of the lungs and the thorax. This obstacle, however, need not remain permanent. After several attempts an inspiration may finally succeed in driving air into all the isolated alveoli or into many groups of them; hence the occurrence of changes in the respiratory rhythm of some animals, and the uneven appearance of the surface of the lungs in others. On the other hand, in some one or other individual animal the passage into the larynx, the organization of the bronchial tree, etc., appear to be well adapted to the rhythm of the pulmotor, which therefore may be capable of keeping up the respiration of such an animal even when it is completely curarized.

Finally observation shows that the entrance of air into and escape of air from the stomach may cause movements of the thorax which simulate respiration while actually no air enters or leaves the bronchial tree.

Upon the basis of these observations the conclusion was reached that the automatic mechanism of the pulmotor, while being an ingenious technical contrivance, instead of assuring artificial respiration, may interfere greatly with its efficiency, because it is liable to cut off inspiration prematurely. The management of the changes in the phases of respiration when the pulmotor is worked by hand is more reliable. But when handled in this manner no practical difference exists between

the pulmotor and the Dr. Brat apparatus, at least so far as the mechanism is concerned. In both machines, however, the expiration is accomplished by suction, which is again a serious defect. The sucking action of these devices might prove even dangerous if they were used continuously to keep up respiration for a long time. In connection with the experiments on animals, which in most instances could be continued a relatively short time only, it is pertinent to recall the fact that the successes reported by the physicians connected with the Carnegie Steel Corporation were obtained in cases in which the pulmotor was used for a short period only.

That both machines are heavy, expensive, and waste a great deal of oxygen, with which they are not sufficiently provided, are minor points in their disfavor. The absence of careful analysis of the action of the pulmotor in clinical cases, the ease with which it may fail to cause inflation of the lungs, the bad effects which occur if its sucking action in expiration is permitted to continue for a long period, are all important considerations which should be taken into account in judging the instrument. When they are taken into account the high credit given the machine in popular opinion seems not to have a substantial foundation.

In view of the facts obtained by a study of the Dr. Brat apparatus and the pulmotor the members of the subcommittee agreed upon the following suggestions: In cases without any respiration the pulmotor should be used only when guided by hand and then not faster than twelve to fifteen complete respirations per minute; when left to run automatically it is liable to be inefficient and dangerously deceptive. Because of suction on the lungs neither the pulmotor nor the Dr. Brat apparatus should be used longer than for a few minutes (five to six) at a time, and, if there be no better contrivance, should be alternated with the Schäfer method combined with oxygen inhala-

tion. In cases of slow and stertorous breathing, however, both machines can probably be used for a longer time with benefit and without danger.

Dr. Meltzer's Mechanical Method of Artificial Respiration

About a year ago Dr. Meltzer published a brief communication on pharyngeal insufflation as a method of artificial respiration. It was based upon the following considerations: When air is insufflated into the pharynx it may escape from there through the nose, the mouth, into the stomach, and into the lungs. In order to have it enter the lungs the facilities for escape through the other exits must be prevented or greatly reduced. The escape through the nose was practically prevented by the elastic tube in the pharynx which raised the soft palate and thus shut off the exit into the nasopharynx. The escape through the mouth was sufficiently restricted by applying pressure under the chin.

The evil effects of the entrance of air into the stomach were met by two methods: In one a tube was introduced into the stomach; this tube restricted on the one hand the entrance of air into the esophagus, and on the other hand readily removed the surplus air from the stomach. In the other method a heavy weight was placed upon the abdomen, which effectively restricted the entrance of air into the stomach and prevented its passage into the intestines. The inspirations were thus provided for by rhythmical insufflations through a catheter, the inner end of which was placed in the pharynx, while the outer end was connected with hand bellows or a respiratory apparatus. The expirations took place during the pauses between the insufflations by the elastic recoil of the extended ribs and of the compressed abdominal viscera. The expired air escaped through the mouth alongside the tube. Experiments on curarized animals (dogs, cats, rabbits, and monkeys)

have shown definitely that pharyngeal insufflation as described above is capable of keeping up efficient artificial respiration for many hours.

When Dr. Meltzer later attempted to apply this method on human beings he found that it failed to work; here the insufflated air escaped so readily through nose and mouth that the remaining pressure was insufficient to produce an inspiration. Furthermore, pharyngeal insufflation in its original form did not sufficiently provide for getting rid of the expired air. During the past year the method has been improved, and as a result the following simple and effective devices are suggested (see *Journal of the American Medical Association*, 1913, 1x, p. 1407):

Two methods may be used to convey the air to the respiratory passages—the pharyngeal and the mask methods. In the pharyngeal method insufflation takes place through a metal pharyngeal tube which has been made to fit the human anatomy. The tube (see Fig. 1) measures about four centimeters transversely and three centimeters vertically; the lower (tongue) side is flat, while the upper (palate) side is round. The upper side is longer than the lower. When the tube is inserted the end of the upper side should touch the posterior wall of the pharynx, while the lower side terminates at about the root of the tongue. The entrance to the nasopharynx is thus closed, while air enters freely into the lower pharynx. The size of the tube almost completely prevents the escape of air through the mouth. The outer end of the tube carries a neck for connection with the respiratory apparatus, and has a hole through which a well-fitting tube can be introduced into the stomach. When not used this hole is kept closed by a movable plate.

The neck of the pharyngeal tube is connected by means of a short piece of strong rubber tubing with the proximal end

of the "respiratory valve" (see Fig. 1). This little device is a metal cylinder containing a valve which is readily moved by a ring outside. When the ring is moved to the right, air or oxygen passes through the cylinder in the direction of the pharynx, thus causing an inspiration. When the ring is moved to the left, the cylinder is closed for the inspiratory air or oxygen, and instead an opening is made above the valve through

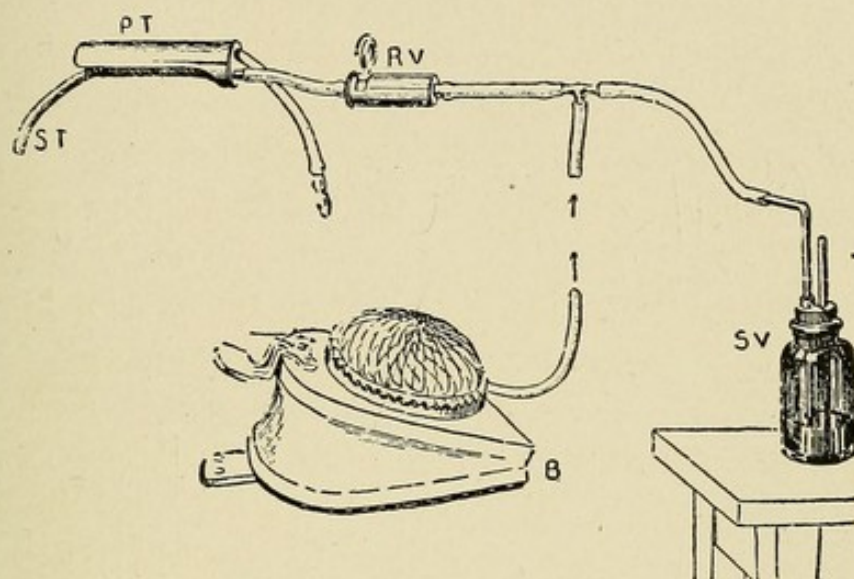


FIG. 1.—ARRANGEMENT OF THE MELTZER APPARATUS FOR ARTIFICIAL RESPIRATION. P. T., pharyngeal tube. R. V., respiratory valve. The ring turns the valve; turning to the right (facing the pharyngeal tube) brings an inspiration and to the left brings an expiration. B, foot-bellows. S. V., safety-valve. The bottle of the safety-valve should be shorter and have a wider diameter than the one in the figure; it is less likely to turn over. S. T., stomach-tube introduced through the opening in the pharyngeal tube.

which the expiratory air can readily escape. The cylinder can be conveniently held in the hand and the ring moved to right and left by the thumb. The distal end of the respiratory valve is connected either with foot bellows, which give practically a continuous air current, or with an oxygen tank. A safety valve is interpolated between the source of pressure and the respiratory valve; some heavy weight and a strong belt to compress the abdomen complete the outfit.

The procedure is as follows: (see Fig. 2) (1) Heavy weights should be placed upon the abdomen. (The pressure may be reinforced by a belt. A broad belt alone is insufficient.) (2) The tongue should be pulled out by means of proper tongue forceps, and the pharyngeal tube inserted as far as it may go. For the sake of being in readiness, the respiratory valve should be kept attached to the pharyngeal tube.

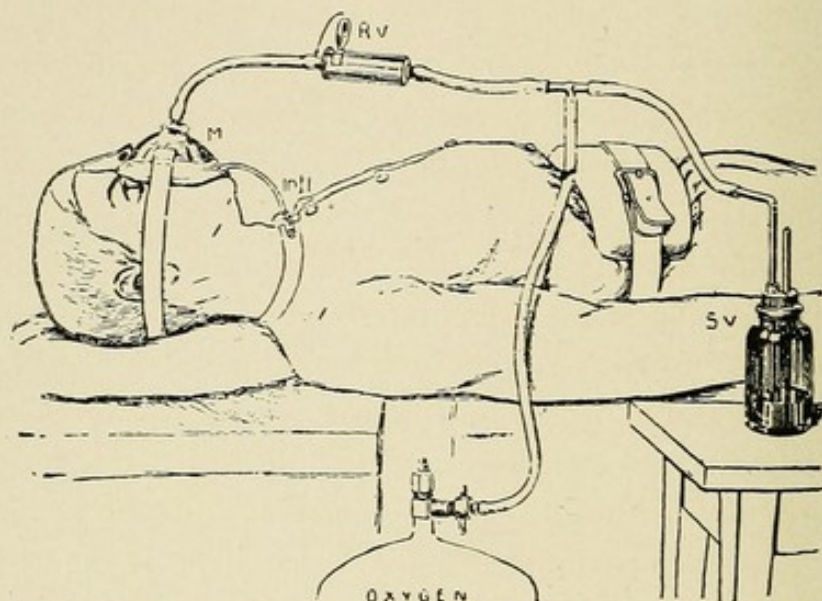


FIG. 2.—MELTZER APPARATUS IN USE. M., mask. Infl., tube for inflating the rubber ring around the rim of the mask. R. V., respiratory valve. S. V., safety-valve. An oxygen cylinder provides here the insufflation pressure. The figure shows also the weight on the abdomen and the belt around it.

The connecting tube should be strong and short (the latter in order to have the expiratory dead space as short as possible. (3) The distal end of the respiratory valve should be connected with the apparatus supplying the pressure, *i. e.*, bellows or oxygen tank plus safety valve. The respiratory valve should now be turned for two to three seconds to the right and as long to the left.

Respiration should not be repeated more frequently than twelve to fifteen times per minute. In case of necessity the same man may work with his hand the respiratory valve and

with his foot the bellows; and if there are no weights at hand he may rest part of his own weight upon the abdomen of the victim. In case of collapse and suspension of respiration during an abdominal operation, when no weights can be placed upon the abdomen, a large stomach tube (33, French size) should be pushed through the opening in the pharyngeal tube; it will slip down readily into the stomach and render the necessary service. It would probably be better to do this in every case, but untrained laymen, who in most cases may have to render the first aid, might hesitate to insert the stomach tube. The pressure upon the abdomen may likewise render good service to a failing circulation. Experiments on lower animals show that in failing circulation strong pressure upon the abdomen raises the blood pressure effectively and fills the heart, and thus also, of course, may benefit the medulla.

When a suitable pharyngeal tube is not at hand, artificial respiration may be executed with the aid of a well-fitting face mask provided with a tube for connection with the respiratory valve. All other parts needed for artificial respiration are the same as with the pharyngeal tube, except that no stomach tube can be introduced. No time should be lost in fastening the mask; it should be pressed to the face with one hand, while the other hand is working the respiratory valve, until more help is obtained.

Both methods have been tried on numerous animals and have been demonstrated, keeping animals alive for many hours while under the exacting conditions of curare and ether and of opened thorax. The methods have also been proved efficient in causing inflation of the lungs in cadavers in rigor or after hours on ice. Even when rigidity of the walls obscured external movements auscultation demonstrated clearly the entrance of air into the lungs. Especially in cases dying with pulmonary edema, the rhythmical crackling which could be

readily heard was very convincing. The pharyngeal tube seemed to work somewhat more efficiently than the mask method.

The apparatus which Dr. Meltzer has devised has the following commendable features: (1) Its positive action is determined by the operator, and not left to a mechanism which may fail to operate. (2) It is free from the sucking action during expiration. Expiration results from the natural recoil of the disturbed parts. (3) It is light. (4) It is relatively inexpensive. (5) It is simple. (6) It embodies in a form which can be used by laymen a method of artificial respiration which has been employed for many years in scores of laboratories and on thousands of animals, and is known to be effective and free from danger.

These are virtues which stand out prominently at points where present commercial devices are in fact most defective. The Commission therefore recommends this apparatus as a satisfactory means of continuing artificial respiration and suggests that in cases of suspended breathing the modified prone pressure method be supplemented as soon as possible by the use of the Meltzer apparatus.

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REPORT OF THE COMMISSION ON RESUSCITATION FROM MINE GASES

The Committee on Resuscitation from Mine Gases, which was appointed in June, 1912, has visited mines in the soft and hard-coal regions in Pennsylvania, has met and had discussions with men engaged in first-aid work, has witnessed demonstrations of methods of giving artificial respiration, has examined critically these methods, has studied old and new devices to maintain breathing, and as a result herewith offers a review of its findings, and some suggestions which, the Committee believes, will increase the chances of reviving victims of mine accidents.

Two classes of accidents requiring methods of resuscitation occur in mines: (1) shocks from the electric current, and (2) poisoning or suffocation by mine gases. Although the present Committee was not asked to consider means of resuscitating victims of electric shock, most of its members have also been members of a Commission on Resuscitation from Electric Shock and have had to deal with both problems. And in some respects the matters of primary importance in both conditions are the same. Thus in electric shock respiration may be suspended or the heart may become ineffective from weakness or fibrillary contraction, and in consequence the body is not supplied with oxygen. Lack of oxygen in the tissues is also the fundamental difficulty in persons overcome by mine gases. Deprivation of oxygen for about ten minutes may injure irremediably some of the most essential nerve cells of the brain. In both conditions, therefore, the prime necessity for promoting survival is the prompt supply of oxygenated blood. From this it follows that, when spontaneous breathing has stopped, methods of artificial respiration are the most valuable means of bringing back a normal condi-

tion of the body. And yet not all methods are equally useful for this purpose, even though they may cause an equal ventilation of the lungs. The reasons for this statement will become clear if we consider the various conditions of accident which bring about a serious diminution of oxygen in the tissues.

Simple Asphyxiation.—If in electric shock the nervous control of the muscles of respiration is temporarily paralyzed, the heart continues for a few minutes to pump blood through the body, but because the blood is not supplied with oxygen the heart soon stops beating effectively and the victim dies of asphyxia. The same result follows in drowning, and likewise in suffocation when carbon dioxid or excess of nitrogen has largely replaced the oxygen of the atmosphere. In such cases artificial respiration, in which the lungs are at once adequately supplied with ordinary air, is a sufficient treatment.

Carbon Monoxid Poisoning.—If the victim has been overcome by carbon monoxid (CO), the principal poisonous substance in illuminating gas and in the gases after mine explosions, the case is somewhat different. The poisonous character of this substance depends primarily upon its strong chemical affinity for the hemoglobin of the blood—the substance which normally transports from the lungs through the body the oxygen used by the tissues. The affinity of CO for hemoglobin is between two and three hundred times as great as that of oxygen for hemoglobin. Carbon monoxid, however, does not form a permanent combination with hemoglobin any more than does oxygen, but unites with it or separates from it according to the law of mass action in amounts determined by the partial pressure of oxygen and CO in the atmosphere breathed. When a miner after a dust explosion, or a person in a room into which gas is escaping, breathes for a number of hours an atmosphere containing a small amount of CO , a condition of partial saturation of the hemoglobin is attained.

Thus, if air containing only 0.1 per cent. of CO is breathed continuously, it will, because of its great affinity, unite with about half of the hemoglobin of the blood. The hemoglobin combined with CO cannot transport oxygen, and the subject is thus brought into a condition of partial suffocation. Since the demands of the tissues for oxygen vary with their activity the first effect is a lessened ability to work. Walking becomes difficult, then impossible; after a time consciousness is lost; and ultimately, unless the subject is removed from the atmosphere, death from asphyxiation ensues.

If before death the subject is brought into an atmosphere free from CO, the combination between this gas and hemoglobin immediately begins to break up. The separation is more rapid if pure oxygen is breathed. Even if merely air is breathed the hemoglobin may thus after ten or fifteen minutes be freed to a degree sufficient to transport the necessary amount of oxygen, *i. e.*, the percentage saturation of hemoglobin with CO may be reduced below the danger point. Usually within six or eight hours practically all the CO is eliminated, and the hemoglobin is then just as efficient for the transportation of oxygen as if the subject had never been poisoned.

In spite of the elimination of CO, however, in a large percentage of cases the subject does not recover. He may die during the next few days, or weeks, or may continue to live with impaired sight or disturbed mentality. These effects, however, according to available evidence, are in the main not due to direct poisonous action of CO, but to deprivation of oxygen. Men employed in gas works and constantly breathing amounts of CO insufficient to interfere with oxygen transportation by the blood do not show cumulative ill effects, and in animals which have no hemoglobin CO is an entirely inert gas. Thus insects in an atmosphere containing even a high percentage of the gas are quite unaffected so long as there is a

percentage of oxygen present reasonably equivalent to that in the air. Furthermore, as Haldane has shown, a mouse just overcome by CO recovers quickly and will even run about, if exposed to two atmospheres of oxygen in a pressure chamber, so that a quantity sufficient to supply bodily needs can be carried by the blood in simple solution. Such a mouse removed to air may suffer a recurrence of symptoms if it has not breathed the oxygen long enough to set free from CO a sufficient amount of its hemoglobin. In persons dying as the result of CO poisoning the blood, if they have survived more than twelve hours, usually contains no noteworthy amount of this gas. What, then, is the cause of death?

At autopsy such cases exhibit distinct areas of cell degeneration in the brain. From this and other evidence, it is clear that the fatalities are the result of an insufficient oxygen supply during the time the subject was breathing the atmosphere containing CO. If the pathological changes are well started no amount of oxygen, nor any other treatment, can restore the damaged nerve cells. If they have not been much damaged, recovery may follow even without therapeutic assistance. There is, perhaps, no class of cases of disease, or any form of poisoning, in which it is so difficult for even an expert to decide with any degree of accuracy whether such treatment as was given played any considerable part in the recovery of the patient. A large number of cases of illuminating gas poisoning which happen in all American cities in which a high percentage of water gas is used recover spontaneously. The subject is found in the morning in a room smelling strongly of gas, unconscious, breathing stertorously, with eyes half closed and rolling, and with teeth frequently clenched. The person making the discovery turns off the gas, opens the windows, and telephones for the doctor and for the ambulance. By the time such assistance arrives the mere breathing

of fresh air has already reduced the amount of CO in the blood so that the hemoglobin set free is sufficient to transport the oxygen that the patient needs. If the degenerative process in the brain cells has not been started before the patient was discovered, recovery ensues. If, on the other hand, the amount of hemoglobin combined with CO exceeded a figure between 60 and 70 per cent., so that only 30 or 40 per cent. of the hemoglobin was available for the transport of oxygen, and if the patient has been in this condition for half an hour or more, degenerative processes and death or serious nervous or mental impairment will certainly follow. At the time when the patient is discovered, or even for an hour or more thereafter, it is quite impossible for anyone to state whether the degree of poisoning has passed the danger point. The subject may be profoundly unconscious, and not only apparently, but actually, at the point of death, and yet, if the length of time during which the deficient oxygenation of the brain cells has continued has not been too great, a half hour in the fresh air will be enough to effect an apparently remarkable recovery. It is a natural mistake for the attending family or ambulance physician to regard the recovery as due to his efforts, when, as a matter of fact, it might have occurred if he had done nothing whatever. It is altogether probable that many of the brilliant recoveries, claimed in the newspapers as due to this or that device, occurred in the victim's breathing spontaneously, and therefore not requiring artificial respiration.

As in simple asphyxia, however, so also in carbon monoxid poisoning, there is a critical period beyond which recovery is out of the question. It is of the utmost importance in every case, therefore, to supply the cells with oxygen as soon as possible, on the chance that the critical period has not been reached. And because the surrender of carbon monoxid by hemoglobin proceeds more rapidly when pure oxygen is

breathed, and, further, because breathing pure oxygen increases the supply to the tissues by increasing the amount dissolved in the blood, the proper treatment for CO poisoning is the breathing of oxygen. If the victim, though unconscious, is breathing in nearly the normal manner, he may be allowed to inspire the oxygen himself. If the breathing is slow and irregular, or if it has stopped entirely, as may be the case in sudden exposure to concentrated CO, artificial respiration should be performed, but with the administration of oxygen.

In both simple asphyxia and in asphyxia from CO₂ and CO, therefore, artificial respiration may be essential to recovery of the victim. A consideration of the efficiency of different means of artificial respiration is obviously important. Two general methods of producing artificial respiration are advocated: (1) the manual method, which can be utilized wherever the air is good by any intelligent adult, and (2) the mechanical method, by which the lungs are inflated by pumping air or oxygen into them. These two general methods will be considered in turn.

* * * * * * *

(*Note.—The description of these methods has already been given in the Report of the Commission on Resuscitation from Electric Shock.*)

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**RULES FOR RESUSCITATION FROM ELECTRIC
SHOCK**

**RECOMMENDED BY
COMMISSION ON RESUSCITATION FROM ELECTRIC
SHOCK¹**

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Superintendents, foremen, and others having charge of men are advised to give practical instructions and demonstrations on the use of these rules to all old and new employees.

Physicians who may be called upon in cases of shock should be given copies of these instructions and, where practicable, placed in communication with the physician of the electrical company.

The prone-pressure method of artificial respiration described in these rules (Section III) is equally applicable, after clearing the mouth and throat of froth, to resuscitation of the apparently drowned, and also to cases of suspended respiration due to inhalation of gas or to other causes.

Treatment for Electric Shock

An accidental electric shock usually does not kill at once, but may only stun the victim and for a while stop his breathing.

The shock is not likely to be immediately fatal, because:

(a) The conductors may make only a brief and imperfect contact with the body.

(b) The skin, unless it is wet, offers high resistance to the current.

Hope of restoring the victim lies in prompt and continued use of artificial respiration. The reasons for this statement are:

(a) The body continuously depends on an exchange of air, as shown by the fact that we must breathe in and out about fifteen times a minute.

(b) If the body is not thus repeatedly supplied with air, suffocation occurs.

(c) Persons whose breathing has been stopped by electric shock have been reported restored after artificial respiration has been continued for approximately two hours.

The Schäfer, or "prone pressure" method of artificial respiration, slightly modified, is illustrated and described in the following resuscitation rules. The advantages of this method are:

(a) Easy performance; little muscular exertion is required.

(b) Larger ventilation of the lungs than by the supine method.

(c) Simplicity; the operator makes no complex motions and readily learns the method on first trial.

(d) No trouble from the tongue falling back into the air passage.

(e) No risk of injury to the liver or ribs if the method is executed with proper care.

Aid can be rendered best by one who has studied the rules and has learned them by practice on a volunteer subject.

Instructions for Resuscitation

Follow these Instructions Even if Victim Appears Dead

I.—Break the Circuit Immediately

1. With a single quick motion separate the victim from the live conductor. In so doing avoid receiving a shock yourself. Many have, by their carelessness, received injury in trying to disconnect victims of shock from live conductors.

Observe the Following Precautions

(a) Use a dry coat, a dry rope, a dry stick or board, or any other *dry nonconductor* to move either the victim or the wire, so as to break the electrical contact. Beware of using

metal or any moist material. The victim's loose clothing, if dry, may be used to pull him away; do not touch the soles or heels of his shoes while he remains in contact—the nails are dangerous.

(b) If the body must be touched by your hands, be sure to cover them with rubber gloves, mackintosh, rubber sheeting, or dry cloth; or stand on a dry board or on some other dry insulating surface. If possible, use only *one* hand.

If the victim is conducting the current to ground, and is convulsively clutching the live conductor, it may be easier to shut off the current by lifting him than by leaving him on the ground and trying to break his grasp.

2. Open the nearest switch, if that is the quickest way to break the circuit.

3. If necessary to cut a live wire, use an ax or a hatchet with a dry wooden handle, or properly insulated pliers.

II.—Send for the Nearest Doctor

This should be done without a moment's delay, as soon as the accident occurs, and while the victim is being removed from the conductor.

The doctors entered on the opposite page are recommended:

Name

Address

Telephone Call

Name

Address

Telephone Call

Name

Address

Telephone Call

Name

Address

Telephone Call

III.—Attend Instantly to Victim's Breathing

(1) As soon as the victim is clear of the live conductor, quickly feel with your finger in his mouth and throat and remove any foreign body (tobacco, false teeth, etc.). Then begin artificial respiration at once. Do not stop to loosen the patient's clothing; *every moment of delay is serious*.

(2) Lay the subject on his belly, with arms extended as straight forward as possible, and with face to one side, so that the nose and mouth are free for breathing (see Figure 1). Let an assistant draw forward the subject's tongue.

If possible, avoid so laying the subject that any burned places are pressed upon.

Do not permit bystanders to crowd about and shut off fresh air.

(3) Kneel straddling the subject's thighs and facing his head; put the palms of your hands on the loins (on the muscles of the small of the back), with thumbs nearly touching each other, and with fingers spread over the lowest ribs (see Figure 1).

(4) With arms held straight, swing forward slowly so that the weight of your body is gradually brought to bear

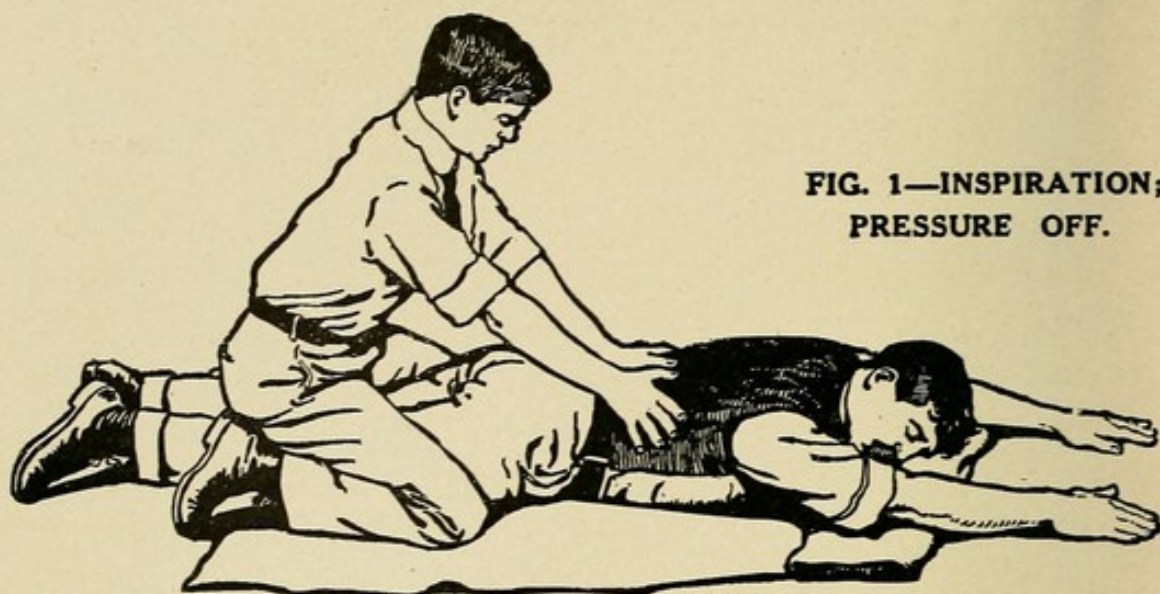


FIG. 1—INSPIRATION;
PRESSURE OFF.

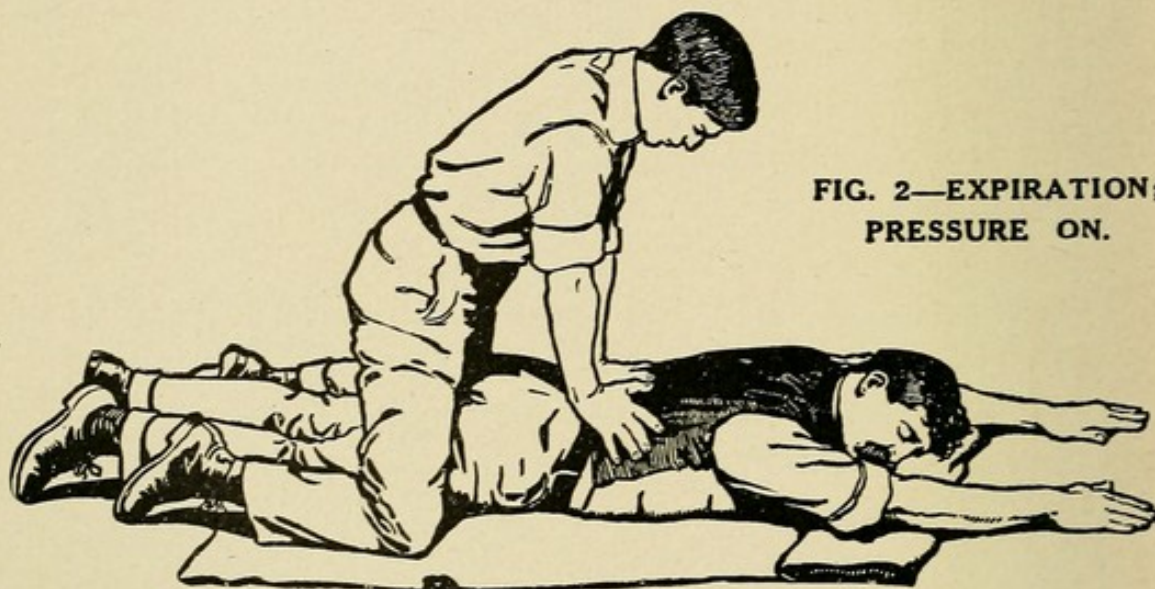


FIG. 2—EXPIRATION;
PRESSURE ON.

upon the subject (see Figure 2). This operation, which should take from two to three seconds, *must not be violent*—internal organs may be injured. The lower part of the chest and also the abdomen are thus compressed, and air is forced out of the lungs.

(5) Now *immediately* swing backward so as to remove the pressure, but leave your hands in place, thus returning to the position shown in Figure 1. Through their elasticity the

chest walls expand and the lungs are thus supplied with fresh air.

(6) After two seconds swing forward again. Thus repeat deliberately twelve to fifteen times a minute the double movement of compression and release—a complete respiration in four or five seconds. If a watch or a clock is not visible, follow the natural rate of your own deep breathing—swinging forward with each expiration, and backward with each inspiration.

While this is being done, an assistant should loosen any tight clothing about the subject's neck, chest, or waist.

(7) Continue artificial respiration (if necessary, two hours or longer), *without interruption*, until natural breathing is restored, or until a physician arrives. Even after natural breathing begins, carefully watch that it continues. If it stops, start artificial respiration again.

During the period of operation, keep the subject warm by applying a proper covering and by laying beside his body bottles or rubber bags filled with *warm* (not hot) water. The attention to keeping the subject warm should be given by an assistant or assistants.

(8) *Do not give any liquids whatever by mouth until the subject is fully conscious.*

First Care of Burns

When natural respiration has been restored, burns, if serious, should be attended to until a doctor comes.

A raw or blistered surface should be protected from the air. If clothing sticks, do not peel it off—cut around it. The adherent cloth, or a dressing of cotton or other soft material applied to the burned surface, should be saturated with picric acid (0.5 per cent.). If this is not at hand, use a solution of baking soda (one teaspoonful to a pint of water), or the

wound may be coated with a paste of flour and water. Or it may be protected with a heavy oil, such as machine oil, transformer oil, vaselin, linseed, carron, or olive oil. Cover the dressing with cotton, gauze, lint, clean waste, clean handkerchiefs, or other soft cloth, held lightly in place by a bandage.

The same coverings should be lightly bandaged over a dry, charred burn, but without wetting the burned region or applying oil to it.

Do not open blisters.

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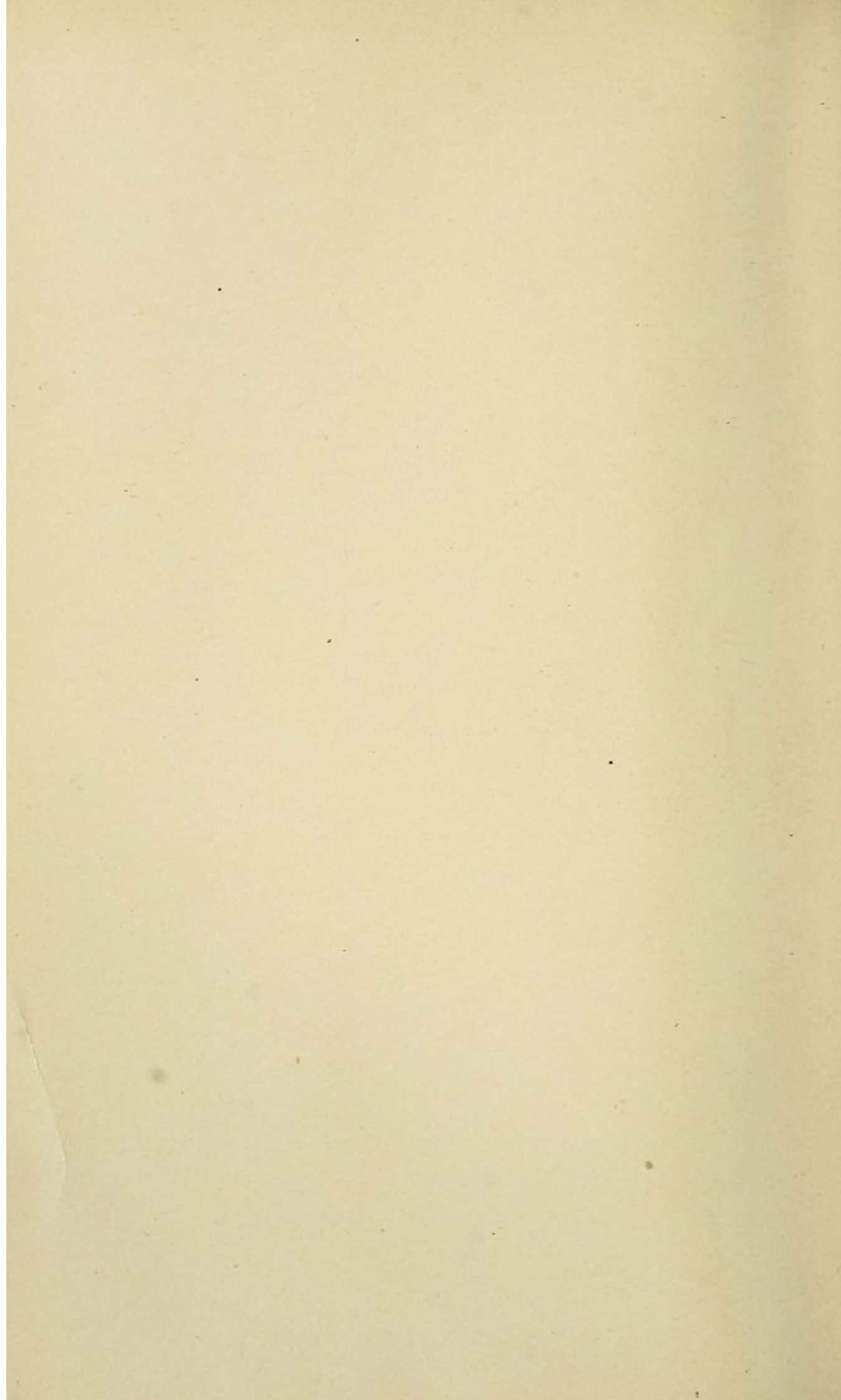
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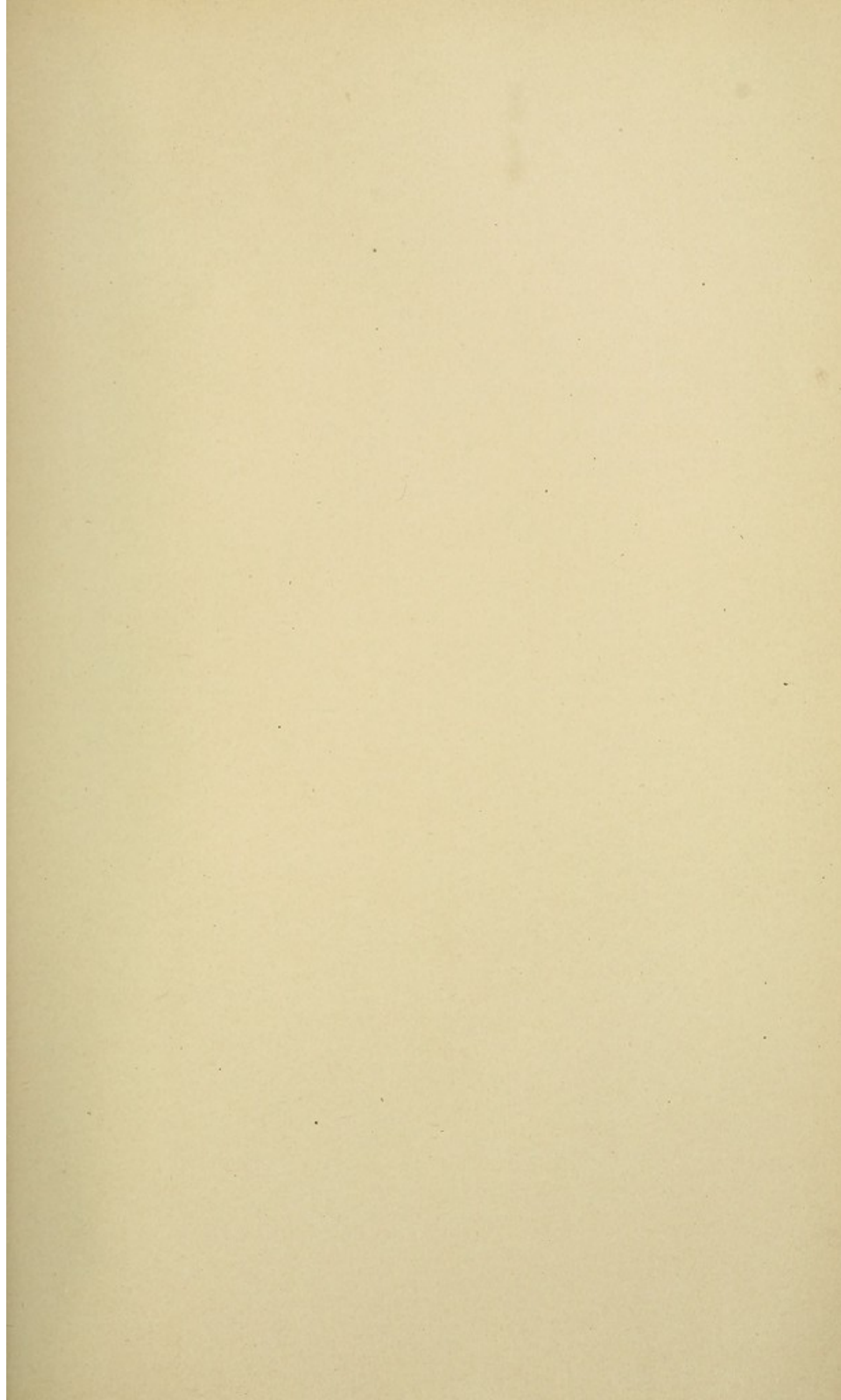
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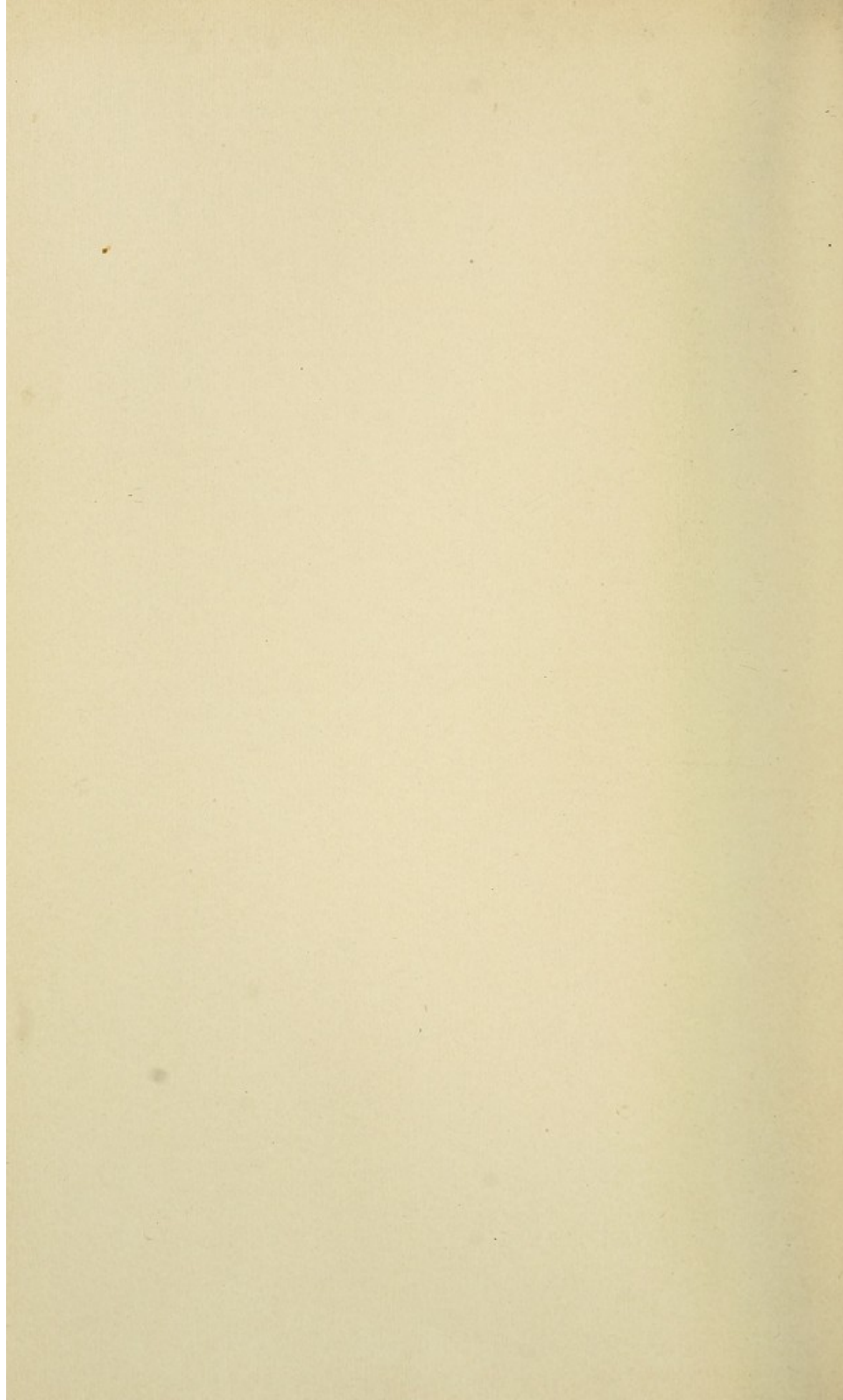
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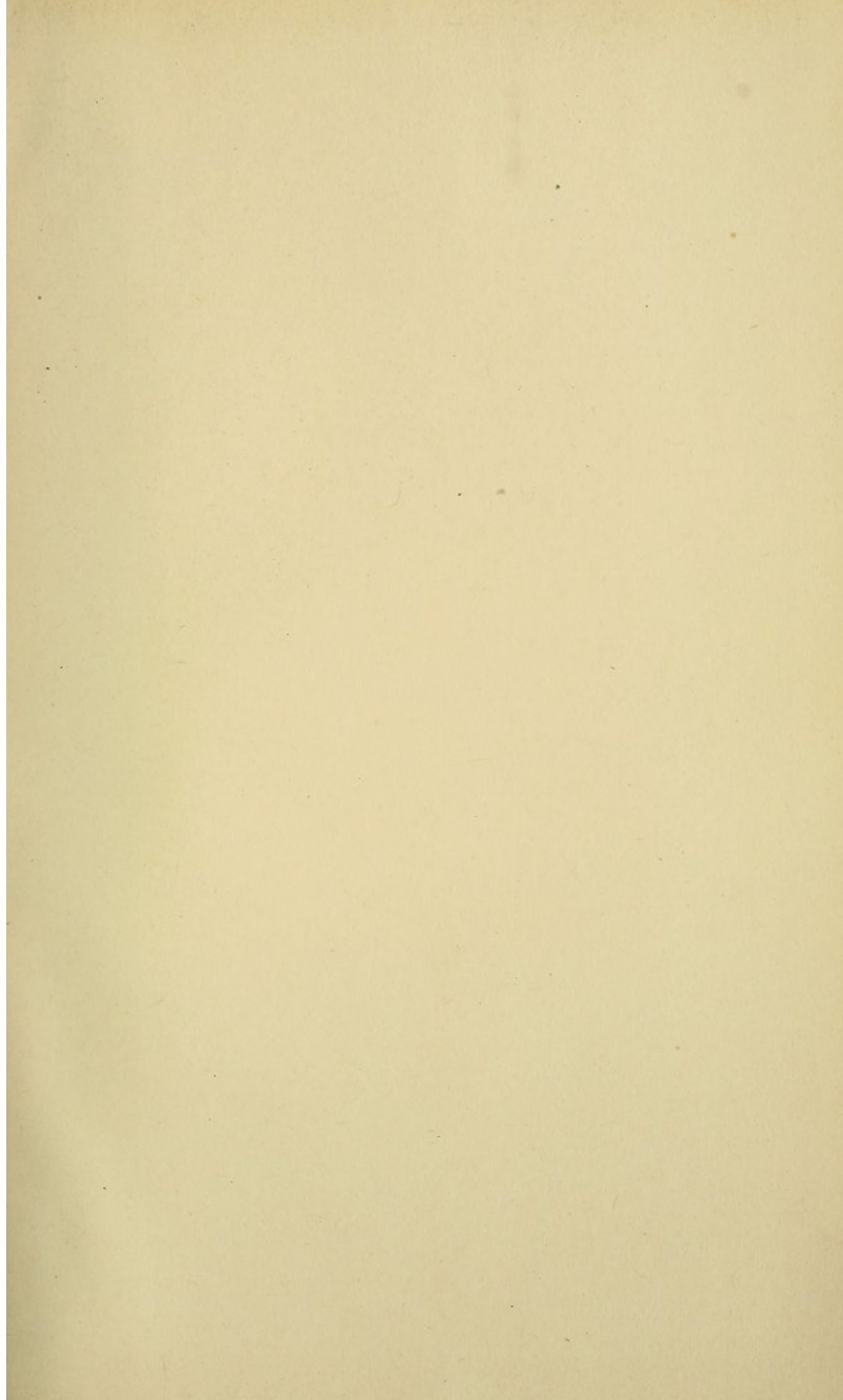
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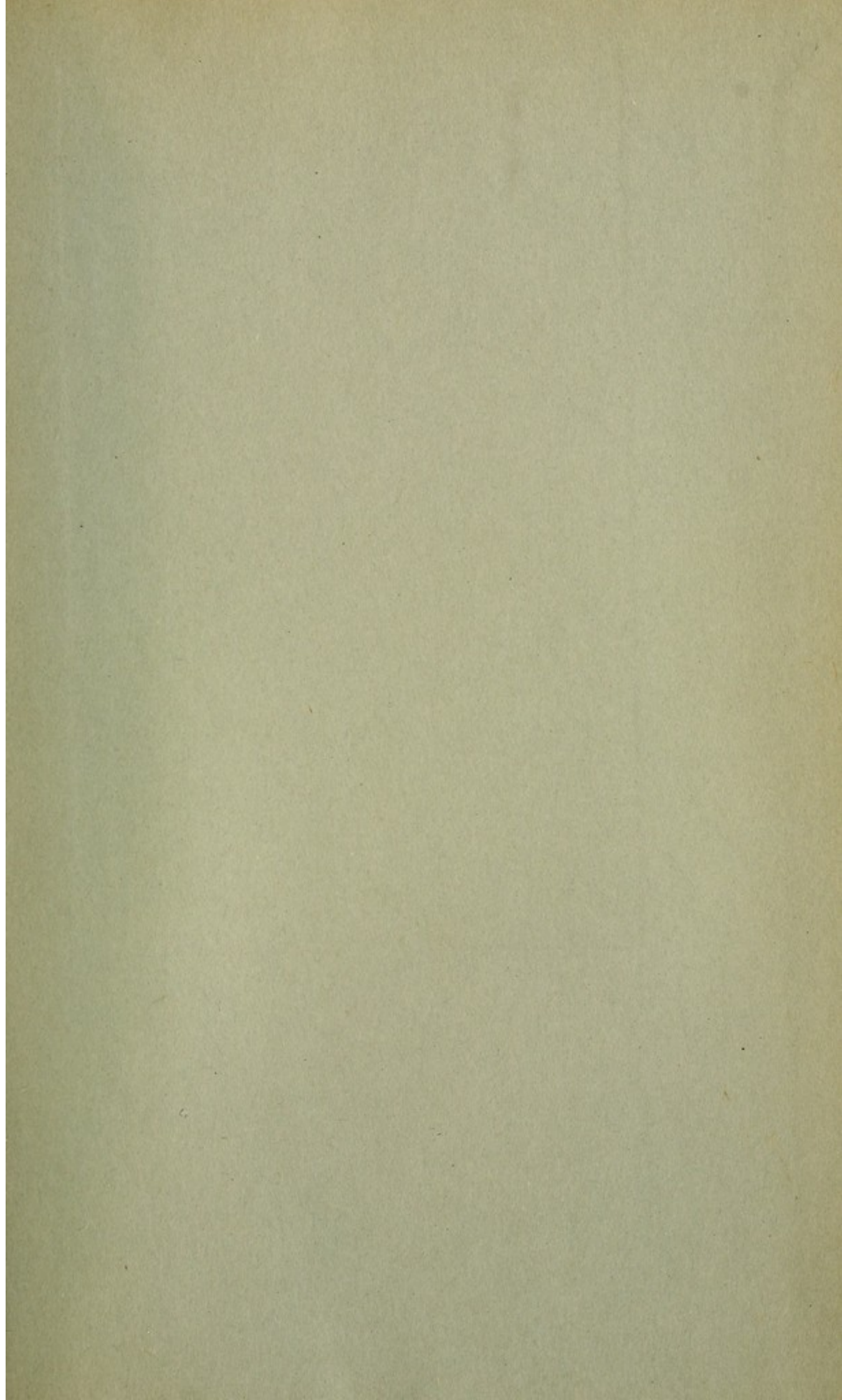




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