THE RESUSCITATION OF THE CENTRAL NERVOUS SYSTEM OF MAMMALS.*

By G. N. STEWART, C. C. GUTHRIE, R. L. BURNS, AND F. H. PIKE.

From the Hull Laboratory of Physiology, the University of Chicago.)

INTRODUCTION.

The literature on anæmia of the central nervous system is extensive. A review of the work on cerebral anæmia up to 1900 is given by Hill.[1] Hayem and Barrier[2] review the work on resuscitation of the isolated brain up to the time of publication of their results. Further summaries of previous work on resuscitation in general are given by Batelli,[3] Prus,[4] and d'Halluin.[5] It does not therefore seem necessary to review the earlier studies. We shall proceed to a description of our own experiments.

A preliminary account of some of the present series of experiments has been given by Drs. Stewart and Guthrie.[6] Our ob-

*The experiments described in this paper were begun by Prof. Stewart and Dr. Guthrie, continued by Dr. Guthrie, Mr. Burns, and Mr. Pike, and concluded by Mr. Burns and Mr. Pike. The paper was written largely by Mr. Pike, with tabulations by Prof. Stewart.

[1] Hill, *Philosophical Transactions of the Royal Society*, 1900, 193, B.

[2] Hayem et Barrier, *Archives de physiologie normale et pathologique*, 1887, x, 3e serie, 1.

[3] Batelli, *Comptes rendus de l'Académie des Sciences*, 1900, cxxx, 800; *Journal de Physiologie et Pathologie générale*, 1900, ii, 443.

[4] Prus, *Wiener klinische Wochenschrift*, 1900, xiii, 451, 482; *Archives de médicine experimentale et d' anatomie pathologique*, 1901, xiii, 352.

[5] D'Halluin, *Comptes rendus de la Société de Biologie*, 1904, lvii, 66; *Résurrection du cœur ; la vie du cœur d isolé; le massage du cœur*, 1904, 118; Th. Lille. *La Presse Médicale*, 1904, xii, 345.

[6] Stewart and Guthrie, *Science*, 1905, xxi, 887.

ject has been to gain, at first hand, a knowledge of the condition of the anterior part of the cord and of the brain centers during total acute anæmia, and to determine the ultimate limit at, or below, which resuscitation is possible.

TECHNIQUE OF THE EXPERIMENTS.

Nearly all the experiments were done on cats. A few of the early experiments were done on dogs. In the earlier experiments in which blood-pressure changes, and the disappearance of reflexes were the only things desired, a tracheal cannula was inserted. In experiments in which it was desirable to keep the animal alive some hours or days after occlusion, a glass tube, narrowed at the end, was inserted through the mouth and between the vocal cords into the larynx after narcosis by inhalation. This latter method of intubation we adopted later as a routine procedure, it being less difficult and requiring less time than tracheotomy. The tube is retained in position by means of a strong cord tied about the lower jaw. Ether, the only anæsthetic used, was administered through the tube. Artificial respiration was accomplished by slipping the free end of the air tube, from a tank of compressed air, with an escape valve in the side, over the end of the glass tube.

Through an incision in the median line in the lower part of the neck, the right innominate and left subclavian arteries were secured. Careful dissection is required to avoid rupturing the pleuræ and the thoracic duct, both of which lie in the field of operation. The truncus thyreo-cervicalis may be mistaken for the vertebral artery.

The manner of origin of the cerebral arteries is of importance in relation to the production of cerebral anæmia. According to Chauveau,[7] the general form of origin of the carotids in vertebrates below man is by the bifurcation of a common trunk (tronc cephalique) arising from the arteria anonyma. (Fig. 1, a.) Quite as often, however, we have found the left carotid arising separately from the arteria anonyma, and the right carotid and right subclavian arising by the bifurcation of a common trunk. This latter form is given as the usual one for the cat by Wilder and Gage,[8] and Reighard and Jennings.[9] (Fig. 1, c.) We

[7] Chauveau, *Traité d'anatomie comparée des animaux domestiques*, 3e ed. par S. Arloing, Paris, 1879.

[8] Wilder and Gage, *Anatomical Technology*, 2d ed., New York, 1886.

[9] Reighard and Jennings, *Anatomy of the Cat*, New York, 1901.

have found, on post-mortem examination, a third form of origin, intermediate between the other two, in which both right and left carotids and the right subclavian artery arise from a common point (Fig. 1, b.) In one case, the left subclavian gave off a branch, of uncertain distribution, proximal to the origin of the vertebral.

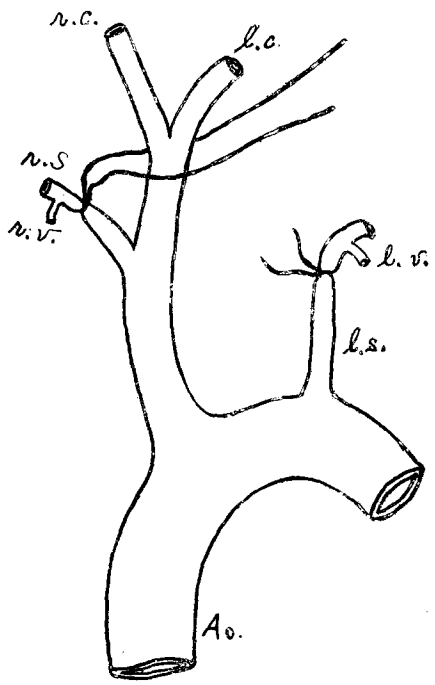

FIG. 1 (*a*). Showing the tronc cephalique of Chauveau.

Ao., aorta ; r.s., right subclavian ; r.v., right vertebral ; r.c., right carotid ; l.c., left carotid ; l.s., left subclavian ; l.v., left vertebral.

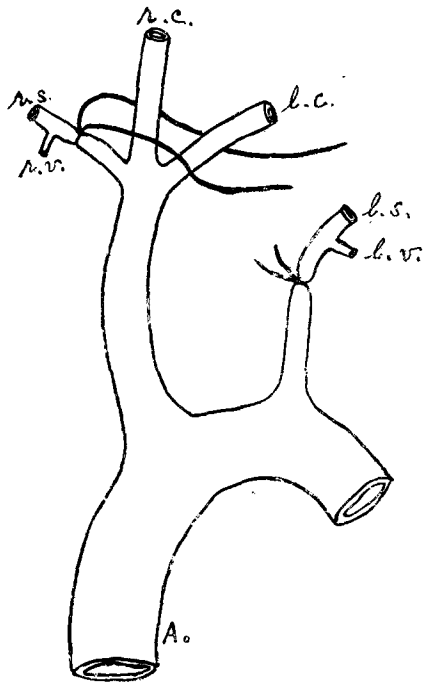

FIG. 1 (*b*). The intermediate type of branching.

Ao., aorta; r.s., right subclavian ; r.v., right vertebral ; r.c., right carotid ; l.c., left carotid ; l.s., left subclavian ; l.v., left vertebral.

Acute temporary cerebral anæmia was produced by passing ligatures around the innominate, and the left subclavian proximal to the origin of the vertebral artery. Traction on the ligatures produced occlusion of the arteries. In case of anomalous origin of the arteries, complete occlusion is assured only when both carotids are clamped separately. In a few experiments the aorta was clamped proximal to the origin of the arteria anonyma.

To keep the animals alive during, and for some time after, the period of occlusion, artificial respiration was employed. The apparatus used for this purpose has proved to be so valuable that we describe it in some detail. An ordinary musician's

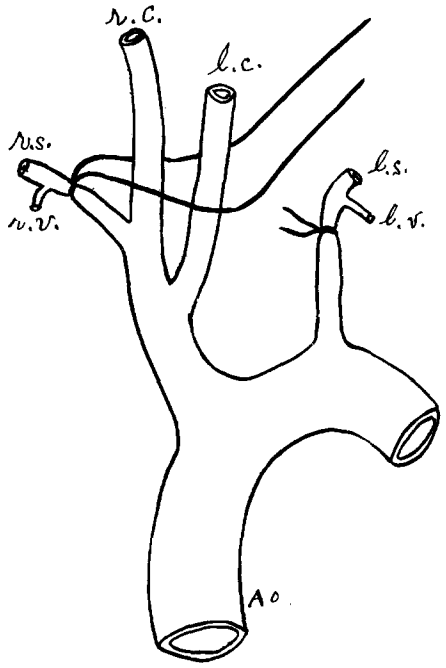

FIG. 1 (*c*).
Ao., aorta ; r.s., right subclavian ; r.v., right vertebral; r.c., right carotid; l.c., left carotid; l.s., left subclavian ; l.v., left vertebral.

metronome was fitted with mercury cups and platinum-wire contacts so as to make and break an electric circuit at each complete vibration. The current from one or two batteries was conducted through the metronome and an ordinary telegraph relay and a time marker in circuit with it. This first relay made and broke the circuit through a second relay operated by the electric-light current. A wire soldered to the bar of the second relay operated a valve in the compressed air tube, the distal end of which was connected with the glass tube in the cat's throat.

Any desired rate of breathing could be obtained by adjusting the metronome.

The blood pressure was always taken from the left carotid artery unless otherwise stated. Sodium-citrate solution was used to prevent coagulation of the blood in the arterial cannula.

When it was desired to keep the animal alive for some time the experiment was done under antiseptic conditions. The neck wound was closed with silk ligatures, sealed with collodion, and bandaged.

Respiratory tracings were made by using the usual tambour connected with the throat tube.

THE GENERAL RESULTS OF OCCLUSION OF THE CEREBRAL ARTERIES.

Tests of Occlusion.—The phenomena of complete occlusion are characteristic and constant. The nose and mucosa of the mouth become white as in death. Respiration ceases, the reflexes disappear, and the pupils dilate completely. The heart is but little affected. Intravenous injection of indigo carmine showed, on post-mortem examination of animals allowed to die without restoration of the cerebral circulation, that anæmia of the brain and medulla oblongata was complete in animals showing these symptoms; that is to say, no trace of the pigment was ever found above the level of the calamus scriptorius. Usually the pigment extended no higher than the third or fourth cervical segment.

Occlusion of the cerebral arteries does not always seem to produce total anæmia, owing, it is to be presumed, to a greater collateral circulation through the spinal arteries. In any event, in a certain number of cases the typical symptoms which we associate with total anæmia are not observed. The persistence of respiration for some time, up to eight minutes, the tardy disappearance of reflexes, and the oozing of a little blood from a nick in the nasal septum distinguish these cases from the first and much the larger group. The disappearance of the reflexes will be considered in detail later in the paper.

Blood-pressure Changes.—When the cartoid artery of the animal

operated on is connected with a mercury manometer, one of the most striking effects of occlusion of the cerebral arteries is the rapid and great rise in blood pressure. There is at first a rise above the general pressure before occlusion, then a fall, succeeded by a second rise and a second rapid fall to the level which is maintained, with only a very gradual fall, throughout the period of occlusion. The numerical values together with the time relations of each are given in Table I.

TABLE I.

Number of experiment	Pressure before occlusion.	First rise to	First rise in	First fall to	First fall in	Second rise to	Second rise in	Second fall to	Second fall in
1	82 mm. Hg.	102 mm.	19 sec.	62 mm.	32 sec.	114 mm.	158 sec.	40 mm.	270 sec.
2	58 " "	112 "	32 "	46 "	23 "	140 "	115 "	54 "	115 "
3	126 " "	156 "	30 "	148 "	60 "	220 "	78 "	100 "	330 "
4	144 " "	174 "	9 "	104 "	30 "	190 "	87 "	64 "	95 "
5	85 " "	103 "	15 "	70 "	13 "	110 "	45 "	20 "	85 "
Mean	99	120	21	98	32	155	97	56	159

Plotting the means of these results, using time as abscissas and pressure as ordinates, we obtain the composite blood-pressure curve shown in Fig. 2.

It will be noticed, on examination of the curve, that (1) the first rise is relatively rapid; (2) the first fall is slightly slower, and sometimes reaches a point below the pressure before occlusion; (3) a second, slower, and usually greater, rise follows, and finally there follows (4) the second fall to a point below the pressure before occlusion, sometimes almost to zero.

The character of the curve is altered when the vagi are divided, the first rise occurring as usual but without the first fall and the second rise.

Section of the cord in the cervical region, as soon after occlusion as possible, causes a prompt and profound fall in pressure.

When both vagi and cord are divided before occlusion a feeble rise of about one centimeter occurs.

To determine the mechanism by which this rise in blood pressure is brought about, we have made a number of experiments. When the abdominal wall is opened, the mesentery exposed and afterward protected from cold, the splanchnic vessels may be observed to contract somewhat, following occlusion. The fall in blood pressure resulting from section of the cord shortly

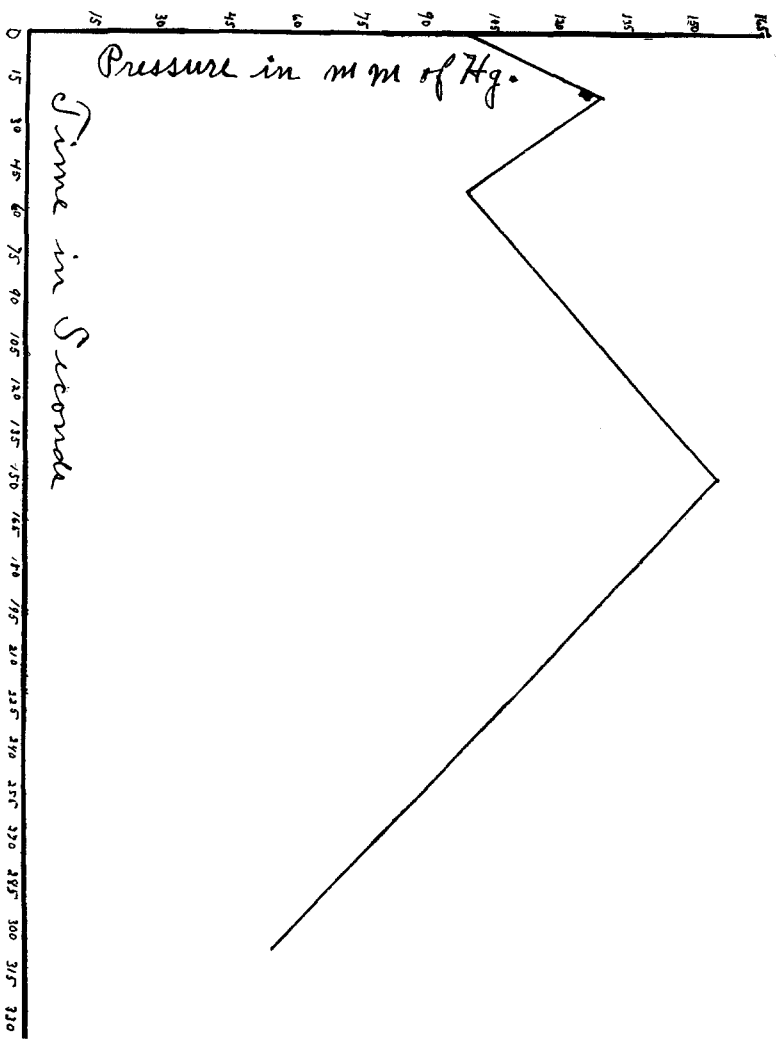

FIG. 2. Composite blood-pressure curve. See Table I.

after occlusion affords further evidence of vaso-constrictor agency in causing the usual rise; and the relatively small rise in blood pressure following occlusion after division of the cord is conclusive proof of the action of the medullary center.

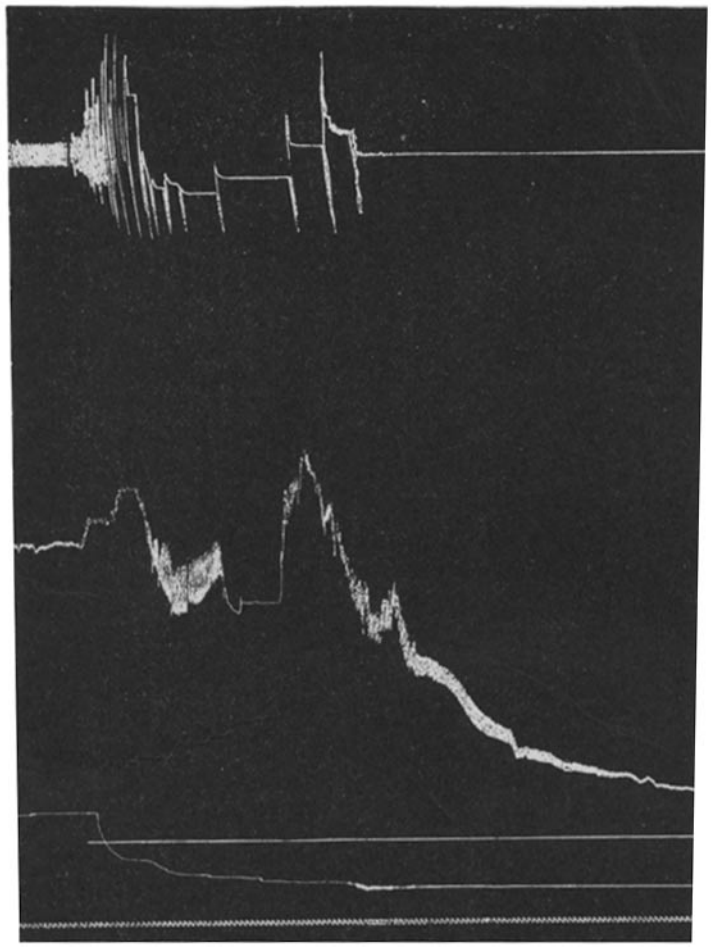

Fig. 3.—Time tracing in seconds. Cannulæ in central and peripheral ends of left carotid. Base line for peripheral (cephalic) pressure first above time tracing; base line for central (cardiac) pressure second above time tracing. Curve of cephalic pressure crosses base line for pressure from central end. Respiration at top, above blood pressure. No artificial respiration. (Expt. 66.)

The cause of the first fall and the second rise we believe to

be twofold. (1) When a typical blood-pressure curve (vagi intact) is examined, an increased oscillation of the manometer is observed to begin near the end of the first fall and to continue until near the crest of the second rise (Fig. 3). Pulse counts taken at intervals during occlusion, and a blood-pressure tracing on a rapidly moving drum show that a period of cardiac slowing intervenes here. This inhibition begins at the crest of the first rise, becomes most prominent about the end of the first fall, and then gradually weakens until it disappears entirely at the crest of the second rise.

Bastgen[10], by the injection of oil into the peripheral end of the carotids, and S. Mayer,[11] by the ligation of the cerebral arteries, produced a high blood pressure with slow pulse. Mayer's curves show a distinct vagus inhibition, but without such a marked fall as in our experiments, although he describes a first rise, a fall, a second rise, and a second fall. He ascribes the rise in pressure to (a) a diminished outflow from the heart and (b) an increased inflow from the veins. Bastgen believes that the fall in pressure is due to vagus inhibition, —a suggestion which we adopt as a provisional explanation of the first fall.

(2) Mayer[12] showed that, in Cooper's experiments, the respiratory and vaso-constrictor centers were more tenacious of life than the other cerebral centers. Schiff[13] showed that the accelerator fibers in the vagus resist degenerative changes longer than the inhibitory fibers. Arloing,[14] who repeated Schiff's work, says there are four kinds of fibers in the vagus, one kind being the accelerator fibers, and confirms Schiff's statement as to their greater resistance to degeneration. Hering[15] and more recently Danilewsky[16] have shown that the accelerators retain their vitality longer after the death of the animal (rabbits), than the inhibitory fibers. It is conceivable that the accelerators are more resistant to anæmia than the inhibitory fibers. The second rise in pressure

[10] Bastgen, Dissertation, Würzburg, 1879.

[11] Mayer, *Sitzungsber. der Kaiser. Akademie der Wissenschaften zu Wien*, 1879, lxxix, 3, Abthl., 87.

[12] Mayer, *Medicinisches Centralblatt*, 1878, xvi, 579

[13] Schiff, *Archiv für die gesammte Physiologie*, 1878, xviii, 172.

[14] Arloing, *Archives de physiologie normale et pathologique*, 1896, viii, 5e serie, 75.

[15] Hering, *Archiv für die gesammte Physiologie*, 1903, xcix, 245.

[16] Danilewsky, *Rousski Vratch* (*Le Médicin russe*), 1904, iii, 641.

is caused by the action of the vaso-constrictor center, and may also be due in part to the action of the accelerators in the vagus. The condition of the vagus center will be considered further in the discussion of the pulse rate.

When the animal has been under anæsthesia for a prolonged period, or when the heart and the respiratory centers have been resuscitated after failure from any cause, or when, for any reason, the vaso-constrictor center in the medulla is in an unstable condition and the Traube-Hering curves appear in the blood-pressure tracing, the first rise of pressure following occlusion and the first fall may be slight or inconsequential, but the slowing of the heart, and the second rise occur as usual. At times, occlusion is followed by the usual first rise, but the first fall in blood pressure is slight, although vagus inhibition may be marked.

After division of the vagi, the first rise in pressure occurs as usual after occlusion, but the period of cardiac slowing and the first fall in pressure are generally absent. We have observed, as did Mayer,[17] that occasional evidences of inhibition are present after section of both vagi. The pathway of such inhibitory influences is unknown to us. It is possible that the inhibition arises from asphyxia from imperfect adjustment of the apparatus. More rarely, the blood-pressure curve following occlusion after section of the vagi approaches the usual form with the vagi intact.

When the cervical cord and the vagi are severed before occlusion, a marked rise of pressure occurs at the instant of division of the cord. A profound fall in pressure follows, then a period of oscillation succeeded by a period of stationary pressure. Occlusion at this time was followed immediately by a slight rise in pressure, approximately 15 mm. of mercury, which persisted throughout the period of cerebral anæmia and fell at the time of release of the cerebral vessels. There was no evidence of inhibition during occlusion. Asphyxiation of the same animal a few minutes later was followed by a curve resembling the usual curve of occlusion, but beginning much more tardily and not reaching as great a height. We are inclined to the opinion that the rise

[17] Mayer, loc. cit.

in pressure following occlusion in this experiment was purely a mechanical effect, i.e., due to confining a given volume of blood in a smaller system of vessels.

Division of the ansa subclavia (Vieusseni), together with all communicating branches from the cervical sympathetic to the vagus below the ganglion nodosum, does not greatly modify the form of the blood-pressure curve following occlusion. In one such experiment, the period of cardiac slowing appeared to be absent, but we have not been able to confirm this result.

In the light of our own results and those of previous observers, we conclude that the vaso-constrictor center in the medulla follows in the wake of the other cephalic centers and loses its power of functioning, but the blood pressure is maintained at a height of 40 to 60 mm. of mercury until the end of occlusion. We decapitated one animal after occlusion. A fall in pressure followed,but, on the intravenous injection of 0.9 per cent. sodium-chloride solution to make good the loss of fluid by hæmorrhage, the pressure rose to 70 mm. of mercury. We conclude that blood pressure is maintained by accessory vaso-motor centers after the medullary center loses its power of functioning.

The Pulse Rate.—The period of vagus inhibition has been mentioned in connection with the blood-pressure changes during occlusion. Reference to the tables will show that, compared with the rate before occlusion, there may be an acceleration or a diminution immediately after occulsion. From the beginning of the period of occlusion on to its close there is a well-defined pulse cycle. The rate immediately after occlusion may be increased for twenty to sixty seconds but this is not a constant occurrence. The period of vagus inhibition follows and with it are associated the secondary respiratory gasps, after which the inhibition gradually weakens and ceases entirely, simultaneously with the gasps, both inhibitory and respiratory centers succumbing to the anæmia at approximately the same time. (Experiment 3, Table III.)[18]. The pulse rate then increases to a maximum after which, if the period of occlusion be sufficiently prolonged, it becomes slower until the moment of restoration of the

[18] Tables II and III are given at the end of the paper.

cerebral centers. Asphyxia, after the vagus loses its power of functioning, produces distinct cardiac slowing. This asphyxial slowing must therefore be susceptible of production without the agency of the vagus center. The correctness of this view is shown beyond all doubt by the fact that asphyxia of the animal after section of the cord and both vagi as described in the previous section, produces marked cardiac slowing (Fig. 4).

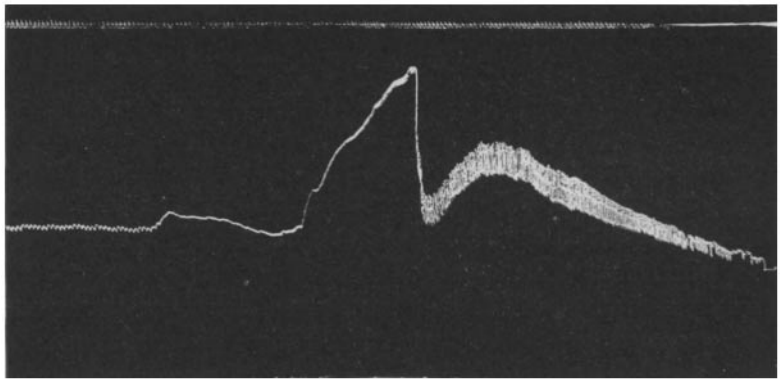

Fig. 4.—Asphyxial rise of pressure after section of vagi and spinal cord. Asphyxia began at signal. Time trace in seconds. Note cardiac slowing. (Expt. 83.)

Respiration —Respiratory movements continue as usual for ten to one hundred and sixty-five seconds, when they cease. After a pause of thirty seconds to two minutes, a secondary series of gasps of the Cheyne-Stokes type occurs (Fig. 3). There may be only one such gasp, or they may continue throughout a short period of occlusion (eight minutes). Hill [19] thinks that a certain arterial pressure in the respiratory center is necessary to induce respiration. On this point we have no direct evidence. We have taken blood-pressure tracings from the cerebral end of the carotid during the period of occlusion (Fig. 3) and have found in each case a prompt fall to zero after occlusion. When blood pressure and respiratory tracings are made in the same experiment, it is found that the Cheyne-Stokes respiration is coincident with the second rise of the blood-pressure curve. We have thought it possible that some blood might reach

[19] Hill, *Cerebral Circulation*, p. 132.

the respiratory center through the spinal artery during the period of high blood pressure, but be insufficient in quantity to maintain the vitality of the vaso-constrictor and the respiratory centers; and that as the pressure fell, all blood disappeared from the medullary centers. This supposition accords with Hill's view, but we have no experimental proof to substantiate it.

The Cheyne-Stokes-like respiration is independent of artificial respiration, occurring alike in its presence or its absence with vagi divided or intact. The exciting cause of the Cheyne-Stokes group then must at this time be independent of any impulses communicated to the respiratory center from the lungs. Nor does the oxygenation of the blood in the trunk affect the vitality of the respiratory center during total anæmia, the gasps ceasing as soon with artificial respiration as without it. It should be noted also that in only one of our experiments was the Cheyne-Stokes respiration absent, the gasps being present even in experiments in which the chest wall had been opened before occlusion. As has been stated, the vagus and the respiratory centers become functionally inactive at approximately the same time. No further respiratory movements occur until after the restoration of the cerebral circulation.

The Disappearance of Reflexes. — Observations have been made on the time of disappearance of the light, lid, corneal, and dilator reflexes. In case of good occlusion, the light, lid and corneal reflexes vanish so quickly as to make an accurate time record almost impossible. In one experiment these reflexes persisted for twenty-seven seconds, but respiratory gasps persisted throughout the period of occlusion, which was ten minutes. We doubt the totality of the anæmia in this and similar cases. In nearly every experiment before occluding the animal was allowed to come out from the influence of the anæsthetic until the pupils were well contracted, and the corneal reflex present in some degree. Often the eyelid closes on being touched directly, while touching the cornea gives no response.

The pupillo-dilator phenomenon is more persistent than the others of this group and is sometimes more persistent in one eye than in the other, but this is probably due to injury of the

left ansa subclavia, as will be pointed out later. Ten seconds to a minute may elapse after occlusion before the pupil begins to dilate. The movement is rapid, four or five seconds being sufficient time to allow of maximal dilation. Occasionally the pupils dilate as usual, contract as the secondary respiratory gasps begin, and again dilate to the maximum before the cessation of these gasps. In no case have we observed the contracted state of the pupils persisting longer than the respiration, a point on which we differ from Cyon.[20] We are unable to see the reason for the persistence of the reflexes for such long periods as he gives, and we suggest that cerebral anæmia in his experiments may have been less complete than our own.

Soon after the dilation of the pupils, the cornea becomes lax, then sunken and furrowed, indicating a reduced intra-ocular pressure due, possibly, to a number of factors, e. g.: (1) a decrease in blood pressure in the vessels in and around the eye; (2) the escape of fluid from the anterior chamber of the eye; (3) loss of tone of contractile tissues of the eye and (4) loss of fluid from both chambers of the eye by diffusion and filtration into the contiguous anæmic areas.

The time of the disappearance of the various reflexes, and of their return after the restoration of the cerebral circulation is given in Table II.

Placing the hand on the chest causes a fall in blood pressure, with a rise when the hand is removed. Striking the abdomen causes a fall in pressure. Pinching the hind-feet with forceps causes a rise in pressure. Similar pinching of the fore-feet gives no result. Stimulation of the central end of the left cut vagus, the right being intact, twenty minutes after the beginning of the occlusion caused a rise in blood pressure. Cutting the right vagus of the same animal two minutes later also caused a rise in blood pressure Stimulation of the central ends of the vagi, both divided, thirty-four minutes after the beginning of anæmia caused no change in the blood pressure. A stronger current applied to the tissues of the neck caused a rise.

Muscular Movements.—There is usually a sudden stiffening of

[20] Cyon, *Comptes rendus de la Soc. de Biol.*, 1900, lii, 372.

all the muscles, following occlusion, with violent movements of the fore- and hind-limbs and tail. Micturtion and defecation may occur. Then the fore-limb movements cease, shortly afterward the hind-limbs relax, and the whole animal lies limp and quiet until after the restoration of the cerebral circulation. The intravenous injection of strychnine sulphate during the period of occlusion is followed by the usual spasms of the abdominal and hind-limb muscles, but no effect, except a possible slight exaggeration of the reflexes is observed in the fore-limbs, and only when the strychnine is injected immediately after occlusion and before the period of high blood pressure. The anterior part of the cat may be completely relaxed and inert while the posterior half may show violent strychnine spasms as in the normal cat. The blood pressure rises after the injection of strychnine. The early exaggeration of the anterior reflexes again suggests the possibility of an increased flow of blood through the anastomotic channels during the period of high blood pressure, but the subsequent complete relaxation of all anterior muscles, even when twice the minimum fatal dose of strychnine is injected, indicates that the anæmia of the anterior part of the cord is very complete.

The picture presented at the close of a typical occlusion is an animal with widely dilated pupils, lax and sunken cornea, motionless eyelids, no tear secretion, no saliva, bloodless mucosa of the nose and mouth, relaxed muscles, no voluntary respiratory movements, low blood pressure, with a heart becoming slow and weak, perhaps stopping if the occlusion be long continued. The whole sequence of events resembles in a general way those found in death by hæmorrhage, as described by Hayem.[21]

THE GENERAL PHENOMENA FOLLOWING RESTORATION OF THE CEREBRAL CIRCULATION.

Blood-Pressure Changes.—The empty cerebral arteries fill rapidly after removal of the ligatures. The mucosa of the nose and mouth lose their pallor and the blood flows freely from a nick in the nasal septum. The manometer may show a fall,

[21] Hayem, *Archives de physiologie normale et pathologique*, 1888, i, 5e serie, 103.

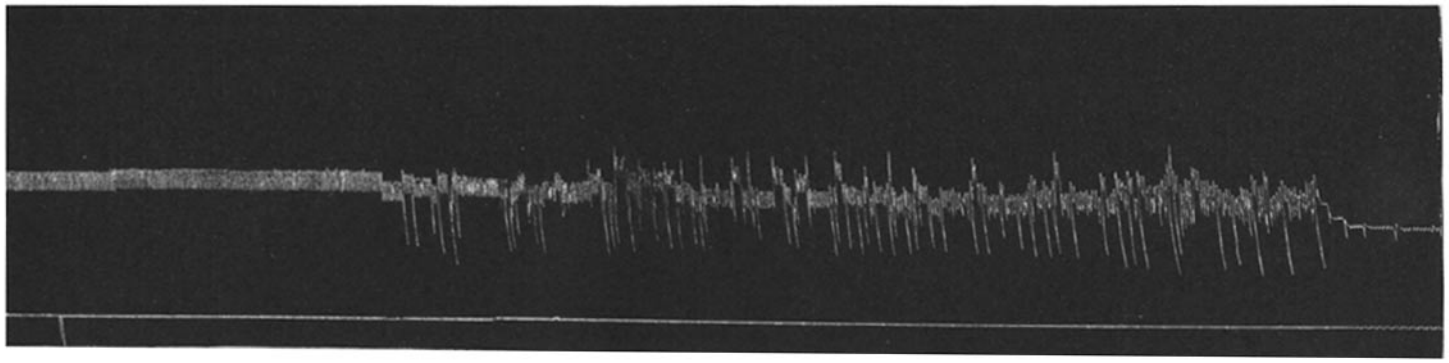

Fig. 5.—Return of the respiration. The cerebral circulation was restored at signal. Note that the first gasp, as indicated by the greater excursion of the writing point of the tambour, was a strong one. Shorter excursions of lever at right of tracing mark the beginning of natural respiration after cessation of artificial respiration. (Expt. 77.)

sometimes very marked. The pressure may even fall to zero, the heart stop, and death result. Examination of the heart, by opening the thorax immediately, may show a dilated right heart with the left ventricle in spasm.

In most cases, a slow rise in pressure succeeds the fall, continuing until the pressure before occlusion is approached or reached. Traube-Hering curves and other irregularities appear in the blood-pressure tracing. Gradually the center apparently becomes more stable in function and the irregularities disappear. Stimulation of the sciatic nerve is followed by the usual rise in pressure at this period, although it may not cause a rise in those cases where the pressure is very low and which terminate fatally.

Pulse Rate.—The rate before release of the cerebral arteries may increase after the restoration of the cerebral circulation, to diminish as the time of the first respiratory gasp approaches (Experiment 10, Table III), again increase as respiration becomes established, perhaps become very rapid, and finally, after some hours or days, return to a normal rate. The tables show pulse counts beginning at the time of release of the cerebral arteries, and continuing for five days thereafter. After prolonged periods of anæmia, the heart may gradually stop.

Respiration.—The disappearance and the return of the respiration are more definitely marked and constant phenomena than the disappearance and return of the eye reflexes.

The animal lies motionless after occlusion, with the blood pressure gradually rising. The first sign of returning vitality in the respiratory center is a strong gasp (Fig. 5) followed by another and another, the rate being about four a minute at the outset, and gradually increasing until spontaneous respiration is established. The respiratory rate is, at first, usually much slower than that of a normal cat, and hours or even days may elapse before the normal rhythm is reëstablished. After prolonged periods of anæmia, e.g., eighty-one minutes, the respiratory gasps may not occur after the release of the cerebral arteries. An occlusion of twenty-eight minutes was followed by a first gasp forty minutes after release. The gasps continued

fifteen minutes, six to eight per minute, and then ceased. Artificial respiration was continued, but dilation of the pupils and, later, failure of the heart followed. Apnœa is frequently met with following long occlusions. Respiratory gasps occur, become almost frequent enough for spontaneous respiration, and suddenly cease. Interruption of artificial respiration at such a time is followed by dilation of the pupils and collapse. If the blood is properly oxygenated, respiratory movements may begin again in twenty to sixty minutes. Cessation of artificial respiration after fifteen minutes of apnœa was followed by fifty seconds of quiet, then a spasm of the fore-legs and chest muscles, a gasp, relaxation of the spasm, and slow spontaneous respiration. In one experiment, apnœa continued for two hours.

It is worthy of note, that, in one experiment in which it was necessary to open the chest walls and massage the heart directly, ten minutes after it had ceased to beat, deep but ineffectual spontaneous respiratory gasps occurred as the blood pressure rose, each of which was followed by a sudden fall of pressure. It appears that, in this condition of the animal, a certain pressure in the respiratory center is necessary, as Hill states, to provoke respiration.

The connection between the vagus and the respiratory centers after occlusion has been noted. Pulse counts indicate a similar connection after restoration of the cerebral circulation, a distinct cardiac slowing, as has been noted, often occurring at the time of the first respiratory gasp. A very early sign of returning function occurring before respiration or contraction of the pupil is the fibrillating movements of the tongue, closely resembling fibrillation of the heart. It is observed after occlusions of ten minutes or more, and continues until the other reflexes are well established. A closely related phenomenon is the twitching of the skin of various parts of the body, but especially of the shoulders and thighs. It generally appears a little later than the fibrillating movements of the tongue, and lasts about as long.

Reflexes.—The light, lid, and corneal reflexes are inconstant. The lid and corneal reflexes may return relatively soon after release of the cerebral arteries, while the light reflex may not be

capable of demonstration until two or three days later. None of them returns after long periods of occlusion, e.g., sixty minutes. The leg reflexes are considered later. The pupillo-dilator action presents some peculiarities. We have never made an experiment in which the pupils remained contracted after failure of respiration. In cases of paralysis of the respiratory center during anæsthesia, the pupil first dilated to the maximum, the animal perhaps made two or three expulsive gasps after which the respiration failed. Respiration was always reëstablished before the pupil contracted much, but the pupil sometimes began to contract before respiration was established. After release of the cerebral arteries gasping respiratory movements appear before complete contraction of the pupil, but the pupil may be narrowly contracted before respiration is fully established, and usually remains contracted in apnœa of brief duration. It is difficult to differentiate in this condition between the action of the cerebral center, and the action of the cervical sympathetic which, as Tuckett [22] has shown, will withstand vastly longer periods of anæmia than the cerebral centers. Two and three days after occlusion may find the pupils widely dilated, while respiration proceeds without difficulty.

Intra-ocular pressure is reëstablished before, coincidently with, or more rarely after, the contraction of the pupil.

The picture presented at this stage is one in which the natural pink has replaced the deathly pallor of anæmia, the tongue is fibrillating actively, the skin twitching, pupils contracted, and respiration spontaneous but slow. The corneal, lid, and light reflexes may be present. If the period of anæmia is prolonged, the cornea may be lax and dry. The tears gather in the outer corners of the eyes and the eyelid trembles preparatory to closing completely and moistening the dull, dry cornea with the secretion which is in waiting. The cat may appear as if asleep with its eyes open, but the picture is soon to change.

The Onset of the Convulsions.—Convulsions, varying in severity from occasional twitchings of the limbs to extreme opsisthotonus and violent struggles, of tonic or clonic type, sometimes begin

[22] Tuckett, *Journal of Physiology*, 1905, xxxiii, 77.

before the full return of the reflexes. Occasionally the cat may lie quiet for one to three hours before the convulsions begin. The head may be drawn back in extreme opisthotonus, or may be bent downward with the back convex. There may be tonic spasm of the fore-limbs and clonic spasms of the hind-limbs. Again, there may be violent clonic spasms in which the animal flings itself about from one side of the room to the other. The cat may lie quietly on its side, the head in moderate opisthotonus, the fore-legs outstretched in tonic extensor spasms with alternate protrusion and retraction of the claws. If the head is gently pushed forward until it is in line with the long axis of the body, the flexor muscles then go into spasm so that the tip of the nose and the hind-feet are approximated. Soon, however, the extensor muscles overcome the flexors, and opisthotonus returns. The convulsions may follow in such rapid succession as to make it difficult to distinguish any interval between successive seizures. At other times intervals of five to twenty minutes elapse between any two convulsions. The pupils dilate widely during the spasms. Respiration may be impeded during the spasms, and rapid during the intervals. Attempts at vocalization are confined, as a rule, to the intervals between convulsions. Stroking the fur, clapping the hands together near the animal's ears, walking across the floor, passing a thermometer bulb into the rectum, and even blowing gently across the fur may throw the animal into spasms. The period of frequent and violent spasms lasts two or three hours to as many days.

Micturition and defecation occur as usual during this period. In all cases in which urine voided after occlusion has been examined, it has contained a substance which, on boiling, strongly reduces Fehling's solution. Polariscopic examination shows it to be dextro-rotatory. In one experiment, three samples of urine voided two hours and twenty minutes, three hours and thirty minutes, and twenty hours respectively, after the beginning of occlusion showed the highest percentage of reducing substance in the second sample. A very slight fermentation occurs with yeast but nothing at all proportional to the amount

of reducing substance present. The nature and cause of this condition are unknown to us.

The temperature is often subnormal, and may not rise to normal for several hours, or even days. It has appeared to us at times that a high temperature may increase the severity of the spasms, while a reduction of the temperature by putting the cat in the ice-box may reduce their severity, but of this we are not sure. The presence of a cloth covering in which the animal can entangle itself increases the severity of the spasms, as the struggles continue until the covering is thrown off. The most successful treatment consisted in keeping the animal as quiet as possible, covering it when practicable to do so without increasing the spasms, but relying mainly upon perfect quiet and freedom from jar to eliminate the spasms. Ether and chloral will stop the spasms, but may stop respiration and heart-beat also. Seizing the feet and stretching the limbs subdue the spasms during the several seconds that the limbs are held.

Severe convulsions may terminate in death twelve to thirty hours after their onset. The direct cause of death is unknown. The condition of the brain and anterior part of the cord at the end of occlusion is such as to allow of no reflexes. Fifty-two minutes after release, following an occlusion of fourteen minutes, there was no response of the anterior part of the cord to the intravenous injection of strychnine. There was no response twenty minutes after release following an occlusion of seven minutes. Strychnine at this time appeared to retard rather than accelerate the recovery of function by the anterior part of the cord. Severe strychnine spasms of the posterior half of the body followed the subcutaneous injection of strychnine, after the return of respiration and eye reflexes, thirty-three minutes after release from an eight-minute occlusion, but the anterior half of the body was relaxed. Seven hours after release from an occlusion of eight minutes, the anterior part of the cord had regained its irritability to strychnine. General spasms appeared, stronger in the hind-limbs than in the fore. On increasing the strychnine, the fore-limbs relaxed before death

while the hind-limbs were still in spasm. Another case presents some unusual features which we give in detail.

Experiment 102. Seven and one-half minutes of anæmia in the morning, with recovery, was followed by 21 minutes of anæmia in the afternoon. All reflexes returned after the second period of anæmia. Respiratory gasps began 16 minutes after release, continued 47 minutes, when a period of apnœa supervened. Artificial respiration was discontinued after 15 minutes of apnœa. The cat lay quiet 50 seconds; spasm of thorax muscles and fore-limbs, then a gasp and relaxation of spasm, and slow, spontaneous respiration followed. Left half of cord hemisected 95 minutes after release. Cat was allowed to remain undisturbed until 5 hours after occlusion. At 8 P. M., cat lay on its side, moderate opisthotonus, strong tonic spasm of fore-legs, hind-legs relaxed. Moving left hind-leg caused convulsive twitchings of both hind-legs, and mild tonic extensor spasm of right hind-leg; pupils normal; left nictitating membrane prominent. Strychnine sulphate (0.6 mg.) subcutaneously. Prick of the needle increased opisthotonus; reflexes increased, general spasms appeared, became extremely violent, and resulted in failure of respiration one hour after injection of strychnine. Fore-legs relaxed 9 minutes before respiratory failure, while spasm of the hind-legs continued up to that time. Heart stopped, all muscles relaxed, whole animal limp. Intubation and artificial respiration. Thorax opened, direct massage of heart. Heart beating regularly at 9 20, 13 minutes after its failure. At 10.40 heart was beating regularly; muscle tonus returned so much that hind-legs and tail moved spontaneously. No reflexes were obtainable anterior to posterior margin of the shoulder. Artificial respiration stopped. Auricular beats of heart observed 18 minutes afterward; no later observations were made.

The first reflex response to pulling or pinching in the front legs occurs in the leg of the same side. Later, striking one fore-leg causes reflex movements of both.

Experiment 28. Occlusion of 10 minutes, 23½ minutes after release, reflex contraction of fore-leg occurs, but only on side struck. Twelve minutes later there is crossing of reflexes, and both fore-legs contract when one is struck.

Experiment 29. Occlusion of 20 minutes; 32 minutes after release, reflex contraction of fore-leg struck, and slight contraction of opposite fore-leg. In 4 minutes more, crossing of reflexes is distinct, and both fore-legs contract when one is struck.

Experiment 32. Occlusion of 50 minutes (aorta clamped); 10 minutes after release, twitching movements of moustache. In 3 minutes, twitching movements of throat muscles over larynx where exposed in neck wound. In 33½ minutes, twitching of muscles over upper ribs in wound. In 55½ minutes twitching of skin of neck. In 67½ minutes respiratory gasps begin, involving muscles in front of neck between the shoulders, gradually spreading from below upward in the neck, including the shoulders; gasps about three per minute. 73 minutes, strong twitching of right shoulder. 77 minutes, slight spasms of shoulders and fore-limbs. Marked reflex on striking fore-limb with strong

crossed reflex of the other. 83 minutes, strong general spasm of anterior end of body. Then a strong gasp, the lower jaw coming down, breast and shoulders coming up.

It is possible that the lower portion of the cervical cord suffers less injury than the upper portion, the medulla, and the brain.

Experiment 18. Anæmia 20 minutes; 110 minutes after release, stimulation of cortex caused jaw movements of opposite side. No other movements except perhaps slight movements of opposite fore-limb. The opening of the cranial cavity was accompanied by some hæmorrhage, but as soon as this was done, deep, regular, spontaneous respiratory movements began, involving head, neck, and thorax down to the diaphragm. It was not observed whether the diaphragm participated in these movements or not. These movements were much more effective for respiration than previous respiratory movements. It is impossible to say whether trephining or hæmorrhage, by reducing intra-cranial pressure, removed the previous cause of the inhibition of the respiratory centers.

Transection of the Cord.—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, dilation of the pupils, cessation of respiration, cardiac failure, and death. The integrity of the spinal centers is necessary for the resuscitation of the cerebral centers. Intravenous injection of warm 0.9 per cent. salt solution has proved useless in averting or remedying such conditions.

Division of the cord after the spasms have become well established is followed by transient shock, recovery, and cessation of the spasms in the hind-limbs. Hemisection of the cord is followed by cessation of spasms in the hind-leg of the same side.

Experiment 50. Occlusion of 15 minutes partial, 40 minutes total, anæmia of brain. In 84½ minutes from release, strong clawing movements of hind-legs, with contraction of muscles of abdomen and thorax, up to neck, during spasms of clawing. Division of spinal cord just below last rib three hours after release. Spontaneous clawing movements of hind-limbs disappear, and do not return. Fore-limbs contract much better on pinching than before division of cord, but reflexes of hind-limbs are much less marked.

Experiments 42 and 43. Occlusion of 60 minutes. Tried to subdue spasms by ether. Death from ether 16 hours after release. Urine collected and kept in an ice-box until next day, and then injected into a half-grown cat. Needle inserted over the liver. Seven hours after, convulsions appeared in second cat; pupils dilated, hair on back and tail, erect. Spasms pass off in 30 minutes. More spasms on second day after injection. Dead on third day. We have neither carefully controlled nor have we confirmed this experiment.

Krainsky[23] has suggested that the presence of certain waste products, e.g., ammonium carbonate, in the blood may cause spasms. Donath[24] has found cholin in the blood of epileptics. More recently, Allen,[25] using a new method of testing for cholin, has failed to find it in certain nervous conditions as reported by other investigators. We have made no chemical analyses of blood or urine beyond those above mentioned. The spasms produced in the kitten by injection of urine from a cat in convulsions might be held to indicate the presence of some circulating toxin, but we do not know that the kitten had not previously suffered from spasms due to another cause. The experiments on section of the spinal cord show that whatever toxins there may be in the blood have no effect on the part of the cord not previously subjected to anæmia.

Other Structures Affected by Anœmia.—The lack of salivary and lachrymal secretion during occlusion, and the reappearance of tears have been noted above.

Experiment 32. Occlusion, 50 minutes. No return of lid or light reflexes. First gasp 67 minutes after release. Stimulation of chorda tympani 3 hours 8 minutes after release gave some secretion.

Experiment 21. Occlusion of 6¼ minutes. Heart stopped 11 minutes, and again 8 minutes. Stimulation of chorda tympani 2 hours and 17 minutes after starting heart gave good flow of saliva.

In Experiment 32, 63 minutes after starting heart, stimulation of right vago-sympathetic nerve gave dilation of pupil, but only to one-half maximum size; pupil quickly contracted. Two hours and 36 minutes after starting the heart, atropine failed to dilate the pupil, even after acting a long time.

Experiment 22. Occlusion, 9⅝ minutes. Atropine dropped in left eye 2½ hours after release gave normal effect.

The chorda tympani, on stimulation, usually gives a secretion of saliva. The salivary flow returns after release of the arteries, and is often very copious. Atropine may fail to give any result. Stimulation of the vago-sympathetic may cause dilation of the pupil, but usually not to more than one-half of maximum size. The vago-sympathetic in a pup retained its power of producing dilation of pupil two hours and eleven minutes after ligation

[23] Krainsky, *Allgemeine Zeitschrift für Psychiatrie*, 1897, liv, 697.

[24] Donath, *Zeitschrift für physiologische Chemie*, 1903, xxxix, 526; *Journal of Physiology*, 1905, xxxiii, 211.

[25] Allen, *Journal of Physiology*, 1904, xxxi, 54

of the aorta. The flow of lymph from a severed thoracic duct continued throughout the occlusion.

The Deportment of the Animal in the Post-Convulsive Period.— Strictly speaking, there is no post-convulsive period except in those animals which recover completely. For convenience of description, we may speak of the period after cessation of the frequent and violent spasms, as the post-convulsive period. It is characterized by infrequency or total absence of convulsions. There are three phases: (a) complete recovery, (b) partial recovery, and (c) death.

(*a*) *Complete recovery.* Experiment 74. Very large male cat. Ether. Intubation. Occlusion of 8 minutes. Pupils dilate completely in 20 seconds, with lax cornea. Respiration ceases in 70 seconds. First respiratory gasps after release of cerebral arteries in 8 minutes. Pupils contracted in 14 minutes. Natural respiration in 18 minutes. Unusually severe spasms began 29 minutes after release, and lasted 1¼ hours. Cat was then able to crawl about, but unable to stand because of paralysis of fore-limbs. Paralysis and wrist-drop entirely gone the next morning (20 hours after release). A peculiar drooping attitude was maintained for 2 days. Afterward the cat appeared entirely normal in every way. When killed by chloroform narcosis 3 months later, lungs showed nodular thickenings and some inflammation. No gross changes in brain.

Complete recovery has resulted after occlusions of five, six, eight, nine and five-sixths, and sixteen and a half minutes.

(*b*) *Partial recovery.* The most interesting case of all comes in this group. Experiment 70. Adult female cat in advanced pregnancy. Ether. Intubation. Occlusion of 10 minutes. Pupils dilated in 15 seconds. Last respiration in 30 seconds. First respiratory gasps 11 minutes after release, spontaneous respiration in 20 minutes. Pupils contracted in 24 minutes. Corneal reflex present in 90 minutes. Convulsions began one hour after release of vessels. Extreme opisthotonus and violent clonic spasms never appeared, but convulsive movements of the limbs were present, without any intermissions, for 3½ days. She lay on her side all the time. Violent spasms resulted whenever the fur was stroked. Walking across the floor caused convulsive starts. The click of the stop watch near her ear, blowing against the fur, or any other slight disturbance caused a convulsive start. The pupils were wide, with light reflex appearing the second day.

On the morning of the fourth day, she was found in a half-sitting posture, head drawn back, and fore-paws outstretched. On the morning of the sixth day, she was able to stand and walk clumsily. Paralysis of limb muscles. but no wrist-drop. She cleaned her paws, purred when spoken to or stroked. Lapped water and milk for the first time since occlusion. Had been fed previously by passing water or milk into her mouth through a tube.

7th day. Walked in a circle, bumping against bars of cage. When placed on floor of room, walked in circle, the size of which was independent of chairs

or tables in the way. Bumped into the objects, probably not because of blindness, but because of lack of control of movements. When put in a cleared space, she walked in a circle as before, going two or three times in the same path, as shown by the marks of her fore-feet, which were dipped in water. Little change in deportment on succeeding days.

12th day. Four kittens were born in the morning. One dead when first seen. Others apparently as vigorous as kittens of a normal mother. Old cat paid no attention to them; apparently totally ignorant of their presence if a few inches away, though they mewed loudly. If a kitten came near enough to touch her nose, she licked it with her tongue, fondled it with her paws when nursing, very much as a normal cat would. If a kitten wandered away, she seemed totally unconscious of its existence, and made no effort to bring it back. The kittens died during the next day.

14th day. Light reflex present in some degree. Cat appeared blind, not closing her eyelids until the eyeball was touched. Refused to walk when placed on the floor. Mewed loudly much of the time, and nothing seemed to pacify her. Appeared deaf to ordinary sounds, but total deafness was doubtful.

15th day. Death by inhalation of chloroform because of puerperal infection. Brain and cord showed no gross lesions on post-mortem examination. A considerable quantity of fat present in omentum and mesentery. Stomach contained undigested meat.

Three stages could be distinguished: (1) a period in which all reflexes, with the possible exception of the light reflex, were present; (2) a prolonged period of convulsions, and (3) a period marked by the loss of intelligence, in which the life of reflexes only was present.

Partial recovery, with paralysis of one fore-leg, and death from accidental strangulation on the ninth day, resulted from an occlusion of eight minutes. There were occasional convulsions following unusually violent attempts to move about in the later period, but there was no loss of intelligence. Another occlusion of twenty-two minutes was followed by paralysis of one fore-leg, but not by any loss of intelligence. Death from pneumonia on the seventh day.

A noticeable feature in all these cases of complete or partial recovery was the prominence of the left nictitating membrane. Frequently also the left pupil was more dilated than the right. We have found that the traction on the ligature under the left subclavian artery usually pulls on the ansa subclavia and the left cervical sympathetic. This injury to the left sympathetic nerve trunk probably explains the inequalities in the eyes.

(*c*) *Death.* After long occlusion, death generally follows in thirty hours or less. No post-convulsive period exists in such cases. One peculiar case comes in this group.

Experiment 83. Occlusion 20 minutes. Symptoms of dementia appeared the third day. Pupils wide and staring; choreic movements of the head. Strong tonic or clonic convulsions followed any attempt at quick or unusual movement. Cat mewed loudly when any one came in sight. Would not eat voluntarily; scratched when milk was passed into her mouth through a tube, but swallowed some of it. Sniffed at a piece of meat held in front of her, but ate none of it. The dementia passed away. On fifth day, cat ate normally, responded to a call, and held her head out to be stroked. Convulsions still followed any complicated or rapid movement. Slow movements were fairly well executed. Kept under observation 9 days, but lost sight of during vacation. Future deportment and circumstances of death, which occurred about 10 days later, unknown.

SUMMARY AND CONCLUSION.

The cerebral circulation was interrupted for periods of three to eighty-one minutes by ligation of the innominate and left subclavian arteries proximal to the origin of the vertebral, in ninety-three cats. Eleven dogs were used in the earlier experiments.

The eye reflexes disappear very quickly and a period of high blood pressure follows the occlusion immediately; vagus inhibition causes cardiac slowing and a fall in blood pressure, followed by a second rise after the vagus center succumbs to anæmia. Respiration stops temporarily (twenty to sixty seconds) after the beginning of occlusion, and then follows a series of strong gasps of the Cheyne-Stokes type, after which it stops until some time after the restoration of the cerebral circulation. The respiratory and vagus centers lose their power of functioning at approximately the same time. Asphyxial slowing of the heart may occur without the agency of the vagus center. The blood pressure slowly falls to a level which is maintained throughout the remainder of the period of occlusion.

The anterior part of the cord and the encephalon lose all function; no reflexes are obtainable. The reflexes of the posterior part of the cord persist; the intravenous injection of strychnine does not affect the anterior part of the cord during the period of occlusion; but does affect the posterior portion of the

cord. There is no secretion of tears or saliva, and the intra-ocular pressure is reduced.

The blood pressure falls still more after release of the cerebra arteries, but soon begins to rise. The respiration returns suddenly, two to sixty minutes after restoration of the cerebral circulation, the first gasp being a strong one. The rate gradually increases until rapid enough for natural respiration. The eye reflexes and intra-ocular tension return more gradually, ten minutes to three hours after restoration of the cerebral circulation. The anterior part of the cord recovers its functions gradually. The first reflexes occur only on the same side as the stimulus, crossing of reflexes, to involve the other side, not occurring till later. As a rule, all reflexes return, and a short period of quiet follows. The anterior part of the cord again becomes irritable to strychnine, but succumbs to its action before the normal part. Spasms, of tonic, clonic, or mixed type, then appear, terminating in (a) death, (b) partial or (c) complete recovery. In partial recovery, disturbances of locomotion, such as walking in a circle, paralysis, dementia, loss of sight, hearing, and general intelligence, characterize the post-convulsive period. After complete recovery, there is a return to normal deportment. No gross lesions of the nervous system, other than a congested appearance of the previously anæmic area, were observed.

Transection of the spinal cord stops the spasms below the level of section. Hemisection of the cord stops the spasms on the same side, below the level of section.

Death, without any return of the reflexes after release of the cerebral arteries, has followed an occlusion of seven and one-half minutes. Respiration has returned after an occlusion of one hour. Five animals have recovered completely after an occlusion of seven minutes or more. Only one animal has recovered completely after an occlusion of fifteen minutes. No animal has recovered completely after an occlusion of twenty minutes.

In Herzen's[26] resuscitation of an animal after several hours of cerebral anæmia, there must have been some anastomotic

[26] Herzen, *Revue médicale de la Suisse romande, 1885*, v, 467.

channels to the brain. Mayer's [27] limit of ten to fifteen minutes of cerebral anæmia, beyond which resuscitation is not practicable, is close to the correct one. It appears to us that, in cases of resuscitation two hours after cessation of the heart-beat, (Prus., loc.cit.) the auricles must have kept up a slow but, in some degree, an efficient movement of the blood through the brain. The truth of this suggestion might be tested by introducing some easily recognized, non-diffusible substance into a vein after the heart-beat ceases to affect a manometer, and later searching for it in the brain and other parts of the body. But, whatever the reason, cerebral anæmia in these cases must have been less complete than in our experiments.

The histological alterations of the cord and brain are now being studied. The results will be published later.

Our thanks are due to Dr. A. Carrel for calling our attention to some of the papers in French.

27. Mayer, *Medicinisches Centralblatt*, 1878, xvi, 579.

TABLE II.

SHOWING LENGTH OF PERIOD OF OCCLUSION, THE TIME OF DISAPPEARANCE, AND THE TIME OF RETURN OF THE REFLEXES AFTER OCCLUSION AND AFTER RESTORATION OF THE CEREBRAL CIRCULATION.

Number of experiment	Period of occlusion in minutes	Time, in seconds after occlusion of disappearance of reflexes				Respiration first ceases (seconds after occlusion)	Last gasp (minutes after occlusion)	Time, in minutes after restoration of cerebral circulation, of return of reflexes				Minutes after restoration when pupil begins to contract
		Corneal	Lid	Light	Dilation of pupil			Corneal	Lid	Light	Respiration	
1	5½	45	—	—	45	—	—	—	—	—	—	—
2	3½	30	—	—	210	—	—	4	—	—	4	1½
3	4⅝	35	—	—	35 200	70	—	15½ 18½	—	—	4¾	2¾ 3½
4	7	20	45	—	180	165	—	—	—	—	2	—
5	6	80	—	44	165	120	—	18	7¾	11	2⅜	7
6	10	15	—	20	—	—	1¾	—	—	—	81	3½
7	5	20	—	20	—	20	2⅜	23	—	23	9½	9
8	5½	45	—	45	75	*	—	—	—	—	—	—
9	5½	—	—	—	—	27	—	27⅔	—	22⅔	16⅔	21
10	12¼ †	15	15	15	—	20	—	§	—	—	—	—
11	25	—	—	—	—	—	—	52	55	52½	38	20
12	22	—	—	—	—	10	7½	48	48	48	30½	—
13	6¼	10	—	—	165	10	5½	—	—	—	31/12	7¼
14	9⅝	27	27	27	240	*	—	11⅙	11⅙	130	—	—
15	5	20	20	20	100	24	2⅝	12½	12½	22½	½	2⅛
16	14	75	75	75	120	45	5¾	37	32	27	20	11
17	10	25	—	25	—	—	1 5/12	25½	25½	32½	5⅙	10½
18	20	75	—	—	75	—	—	39	—	44	5	12
19	25½	40	—	—	120	40	1⅛	—	—	48½	27½	7½
20	50	25	25	25	85	25	3⅜	—	—	—	67½	5½
21	81	35	35	35	35	35	11½	**	—	—	—	—
22	16	15	—	—	15	15	2½	44½	—	—	30	5
23	15	—	—	—	110	18	—	—	—	—	8	3
24	30	15	—	—	565	10	8	37¼	36½	25¼	14¼	10½
25	60′16″	—	—	—	14	14	3⅜	**	**	44½	33⅜	25½
26	81	—	—	—	30	30	3¾	**	**	**	**	**
27	60	—	—	—	120	15	8	**	**	**	**	28
28	51	—	—	—	140	30	10	**	**	**	31	41
29	45	—	—	—	16	44	5½	**	**	**	**	**
30	45	—	—	—	90	65	9	**	**	**	40½	7½
31	41	25	—	—	150	40	7⅓	—	—	—	—	21
32	40	25	—	25	—	15	5	—	—	—	—	5½
33	31	30	—	—	270	35	3	—	32	18	9	3½
34	31	—	—	—	14	35	2	39	—	20	18	23 right eye 86 left eye
35	10	—	—	—	180	120	5	24½	—	—	7	13
36	15	15	—	—	15	50	3½	—	—	—	—	30
37	25¾	—	—	—	—	—	—	**	**	**	**	**

* Persisted throughout occlusion. † Incomplete occlusion.
§ Reflexes returned before end of occlusion. ** No return of reflexes

TABLE II—*Concluded.*

Number of experiment	Period of occlusion in minutes	Time, in seconds after occlusion of disappearance of reflexes: Corneal	Lid	Light	Dilation of pupil	Respiration first ceases (seconds after occlusion)	Last gasp (minutes after occlusion)	Time, in minutes after restoration of cerebral circulation, of return of reflexes: Corneal	Lid	Light	Respiration	Minutes after restoration when pupil begins to contract
38	61	—	—	—	45	—	—	**	**	**	**	**
39	8	—	—	—	—	*	—	20	—	—	23	20
40	10′ 7″	—	—	—	15	30	—	89	—	48	11′38″	24
41	8	—	—	—	20	—	—	—	—	—	$7\frac{2}{3}$	$13\frac{2}{3}$
42	8	—	—	—	35 left 90 right	50	2′35″	—	—	—	$8\frac{1}{3}$	8 left 12 right
43	16′35″	—	—	—	25	50	3	—	—	72hrs.	$6\frac{5}{12}$	10
44	$22\frac{1}{3}$	—	—	—	90	—	5	**	**	**	$12\frac{1}{2}$	42
45	$22\frac{1}{4}$	—	—	—	240	—	5	—	—	—	10	28
46	11	—	—	—	180	65	$5\frac{1}{2}$	33	—	—	$22\frac{1}{2}$	33
47	$12\frac{1}{2}$†	—	—	—	—	*	—	—	—	—	—	3
48	$11\frac{3}{4}$	—	—	—	—	—	$7\frac{7}{12}$	—	—	—	4	4
49	$12\frac{1}{4}$	—	—	—	—	—	—	—	—	—	$18\frac{7}{12}$	$16\frac{3}{4}$
50	$14\frac{1}{3}$††	—	—	—	—	—	$3\frac{5}{12}$	**	**	**	**	**
51	8††	—	—	—	—	—	$2\frac{1}{3}$	**	**	**	**	**
52	$6\frac{1}{12}$	—	—	—	—	—	$1\frac{5}{12}$	$15\frac{1}{4}$	—	—	$15\frac{1}{4}$	—
53	$6\frac{5}{12}$	—	—	—	—	—	$2\frac{5}{12}$	**	**	**	**	**
54	$6\frac{5}{6}$	—	—	—	20	—	5	19	—	—	$9\frac{1}{2}$	$9\frac{1}{2}$
55	7	—	—	—	—	—	$4\frac{5}{12}$	—	—	—	$2\frac{5}{12}$	$2\frac{1}{6}$
56	8	—	—	—	—	15	—	—	—	—	$9\frac{5}{12}$	—
57	$10\frac{1}{6}$	—	—	—	55	—	$1\frac{5}{12}$	$26\frac{1}{3}$	—	—	$3\frac{1}{3}$	20
58	$7\frac{1}{2}$	—	—	—	80	—	$2\frac{1}{3}$	—	—	—	4	16
59	$31\frac{1}{3}$	—	—	—	—	—	2	$47\frac{5}{12}$	—	—	$15\frac{5}{12}$	$23\frac{5}{12}$
60	$14\frac{5}{12}$	—	—	—	—	—	$2\frac{5}{6}$	—	—	—	26	11
61	$28\frac{1}{2}$	—	—	—	70	—	—	—	—	—	39	$29\frac{1}{1}$

The number of the experiment in these tables does not, in general, correspond to the number of the experiment in the series performed.

* Persisted throughout occlusion.

† Incomplete occlusion.

** No return of reflexes.

†† Strychnine injected during occlusion

§§ Secondary series of gasps did not occur.

TABLE III.

SHOWING PULSE RATE AT INTERVALS DURING OCCLUSION AND AFTER RESTORATION OF THE CEREBRAL CIRCULATION.

Number of experiment	Minutes from beginning of occlusion	Pulse rate	Minutes after restoration of cerebral circulation	Pulse rate
1	16	171	49	150
	24	180	99	184
	36	171	126	184
	50	138	148	162
	—	—	172	204
	—	—	209	180
	—	—	222	160
	—	—	265	171
	—	—	270	168
	—	—	277	167
2	10	183	31	125
	16	184	50	120
	27	163	104	120
	40	167	122	122
	—	—	162	128
	—	—	186	150
	—	—	202	167
	—	—	246	180
	—	—	271	171
3	3	108	13½	140
	7*	78	25½	150
	9†	168	53½	155
	18⅝	214	67½	156
	26⅛	200	75½	144
	39⅝	170	109½	138
	—	—	112½	128
	—	—	275½	150
	—	—	313½	184
	—	—	350½	184
	—	—	409½	166
	—	—	485½	192
	—	—	515½	186
	—	—	531½	200
	—	—	582½	158
	—	—	626½	210
	—	—	633½	209
	—	—	645½	209
	—	—	683½	187
4	††	155	27	207
	25	166	393	168
	—	—	408	172
	—	—	448	170
5	3⅝	216	16	166
	13	203	21	150
	20	180	25	162
	25	170	—	—
	30	180	—	—
	35	163	—	—
	40	171	—	—
6	††	157	4	120
	6⅝	180	7	140
	8	180	12	150
	18	165	13½	160
	25	96	37	160
	—	—	276	156
	—	—	590	120
7	—	—	⅛	112
	—	—	6	115
8	††	106	1	112
	1½	120	—	—
9	††	130	—	—
	1½	100	—	—
	2⅛	120	—	—
	4⅝	144	—	—
	10⅝	150	—	—
10	††	156	¾	156
	1½	120	2½	150
	3	156	4	126
	5†	126	6	114
	6½	132	7½	96
	8½	180	8½	114
	9	162	14	156
	—	—	17	180
	—	—	18	162
	—	—	20	150
	—	—	52	180
	—	—	109	180
11	††	156	6½	150
	3⅝	132	12½	162
	6½	126	35½	96
	8½	120	37½	108
	—	—	39	72
12	¼	180	2½	138
	½	168	—	—

* Still gasping.
† Last gasp.
†† Immediately before occlusion.
§ First gasp after restoration of cerebral circulation.

TABLE III—*Concluded.*

Number of experiment	Minutes from beginning of occlusion	Pulse rate	Minutes after restoration of cerebral circulation	Pulse rate	Number of experiment	Minutes from beginning of occlusion	Pulse rate	Minutes after restoration of cerebral circulation	Pulse rate
13	††	150	¶	—	17	††	162	1¾	156
	¾	156	26	102		¶	186	10¾	72
	4¼	156	—	—		3	186	24	144
						5	168	—	—
14	††	150	—	—	18	††	204	—	—
	¶	150	—	—		¶	180	—	—
	1/10	174	—	—		3	192	—	—
	¼	162	—	—	19	††	210	25	156
	2½	156	—	—		—	—	90	168
	4	162	—	—		—	—	45 hours	204
15	††	168	20 hours	138		—	—	7 days	168
	—	—	6 days	162					
16	††	100	—	—					
	5	180	—	—					
	9	112	—	—					

The number of the experiment in the tables does not, in general, correspond to the actual number of the experiment in the series performed.

†† Immediately before occlusion. ¶ Vagi divided.