VII. *On the Effects produced on the Circulation and Respiration by Gun-Shot Injuries of the Cerebral Hemispheres.*

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[Plate 3.]

Introduction.

There exists,* so far as we know, no research in which the effects upon the circulation and respiration produced by a bullet passing through the cerebral hemispheres have been investigated. We have for this reason conducted a number of experiments in which etherised animals—dogs—have been shot with bullets of various calibre, the blood-pressure (central and peripheral), respiratory, and other curves being written before and after the shot. The results we obtained almost immediately were so clear and decisive, as well as contrary to generally received opinions on this subject, that the questions involved appeared to us worthy of prolonged investigation, of which the following is an account.

It has long been recognised that the fatal influence of the projectile may be exerted immediately or tardily : in fact, that we may speak of a primary source, and a secondary source, of death respectively. We may anticipate what follows by saying that we have found, as the result of an extensive series of experiments, that the primary cause of death is not as previously supposed, arrest of the heart by so-called shock, but that it consists in a sudden cessation of the movements of respiration, which, however, can be artificially restored. It will be seen that the conclusions derived from these observations have an unforeseen bearing on the proper method of clinically dealing with this condition.

Historical Introduction.

As we have above stated, we are not aware of any researches in which direct observation of the pulse and respiration has been made at the time of the infliction of

* Some months after this paper was read there appeared a valuable work on "Concussion of the Central Nervous System," by Dr. Polis, published in the 'Archives de Chirurgie,' August, 1894, in which results confirmatory of our own are described.

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the injury. We have, however, collected from the literature of gun-shot injuries such facts as receive general acceptation at the present day: and, further, have arranged together the results of previous experiments by various investigators who have thrown light on the causation and mode of production of the destructive effects exerted by bullets on solid bodies and animal tissues.

SEYDEL ('Lehrbuch der Kriegs-Chirurgie,' Stuttgart, 1893) states, p. 20, that in the general shock immediately following the infliction of any severe gun-shot wound there are, so far as the pulse and respiration are concerned, the following changes: "The pulse is small, often scarcely perceptible, very frequent, and easily compressible. The respiration is accelerated and very superficial."

In speaking of the symptoms due to local injury (p. 142), he re-states these changes without alteration, except in cases where a general increase of intra-cranial pressure occurs as a result of hemorrhage into the skull cavity.

MCCORMAC attributes the symptoms of gun-shot injury of the brain to the compression brought about by hemorrhage. In cases where there is direct injury to the medulla oblongata, he states that that is accompanied by the occurrence of CHEYNE STOKES' respiration and a slow pulse. (Article "Gun-Shot Wounds," 'HEATH's Dictionary of Practical Surgery,' 1887.)

The history of the experiments which have elucidated the physical conditions produced in substances of varying density is given in an Appendix, see p. 252, and wherever any special point is discussed in the paper.

METHOD OF INVESTIGATION.

Anæsthetic.—The anæsthetic we have invariably employed has been ether administered by a funnel attached to the tracheotomy tube. The anæsthetic was removed just before the moment of firing the shot, so as to avoid error arising from an excess of the drug.

Record of the Circulation.—The movements of the heart and the pressure of the blood were recorded by means of an ordinary mercurial manometer, the cannula being placed in the femoral artery, or, more rarely, in the carotid. Care was taken only to employ one carotid in any one experiment, so as to avoid the interference (HURTHLE), however slight, which ligature of the two vessels brings about.

In certain cases the cannula was placed in the peripheral as well as in the central end of the artery, with the object of comparing, as far as possible, the effects due to the vaso-motor system as distinct from the alterations in pressure produced by the heart.

Record of the Respiratory Movements was obtained by means of a Paul Bert exploring tambour applied to the thorax of the animal by a strap passing round it and attached to each end of the tambour. This apparatus consequently records only the movements of the expansion and contraction of the whole chest.

Record of Movements.—At the moment of penetration by the bullet there ensued definite motor phenomena, which we were able to record. Thus, the muscles contracted powerfully and then relaxed. This was graphically recorded by attaching the rectus femoris muscle to a Fick spring myograph.

Record of the Changes in the Intra-cranial Tension.—To record changes in the intra-cranial tension, a steel tube, 1 centim. in diameter, was screwed and fixed by a vice immovably in a trephine hole, filled with ·6 per cent. NaCl solution, and then connected by a rubber tube with a writing tambour.

For purposes of direct observation of the pressure upon and dislocation of the brain an opening was sometimes made in the postero-parietal region, and the dura mater divided.

Record of the Moment of Firing.—To obtain this, the following expedient (Woolwich method) was resorted to :—Across the muzzle of the rifle or pistol was stretched a very fine brass wire, which the bullet divided in its course, and the rupture of which caused an electric signal to mark on the paper.

Record of Time.—The time was recorded in the experiments with accuracy by a metronome beating seconds, and transmitting its rhythm by an electric signal to the kymographic paper.

Rifles Employed.—We have used the following arms to obtain our results :—

(*a.*) Rook rifle . ·38 calibre, short cartridge, conico-cylindrical bullet.
(*b.*) ,, ,, . ·22 ,, ,, ,, ,, ,, ,,
(*c.*) Saloon pistol ·22 ,, cylindrical bullet, with hemi-spherical ends.

In fig. 1 (Plate 3) are shown the cartridges and bullets of the natural size. The muzzle velocities of the rifles and pistol were very kindly measured for us by Mr. H. T. ASHTON, at the Royal Laboratory Velocity Range, Woolwich, by direction of Dr. ANDERSON, who most courteously gave us every assistance. To Mr. ASHTON we are indebted for the following figures, which are derived from the observed velocities (distance of screen noted below), according to BASHFORTH's tables for ogival-headed projectiles :—

(*a.*) Rifle . . . ·38 calibre (60 ft. 0 in. screen used.) Mean of three observations : muzzle velocity, 970 feet per sec.
(*b.*) ,, . . . ·22 ,, (60 ft. 0 in. screen used). Short cartridge. Mean of four observations : muzzle velocity, 1029 feet per sec.
(*b′.*) ,, . . . ·22 ,, (90 ft. 0 in. screen used). Long cartridge.* Mean of three observations : muzzle velocity, 1076 feet per sec.
(*c.*) Saloon pistol ·22 ,, (60 ft. 0 in. screen used.) Mean of five observations : muzzle velocity, 646 feet per sec.

* Used very rarely. See list of *post mortem* examinations at the end of the paper.

Ammunition Employed.

The following table shows the composition of the cartridges used :—

	Weight of powder.	Weight of bullet.
	gramme.	grammes.
(*a.*) ·38 calibre, Short cartridge, ELEY's manufacture	·68	8·05
(*b.*) ·22 „ „ „ Rifle, American manufacture	·17	1·87
(*c.*) ·22 „ Saloon pistol, ELEY's manufacture	·07	·97

In (*c*) the finest sporting powder was used. The remarkable excellence of ELEY's ammunition and accuracy of filling, &c., was strikingly borne out by the great constancy in the muzzle velocity obtained with ammunition (*a*).

RESULTS OF THE PRESENT INVESTIGATION.

We will discuss the effects observed according as they relate to the following systems :—

A. Respiratory.

B. Cardiac. {Rhythm / Force} of the heart beat.

C. Vasomotor.

D. Muscular.

A. *Effect upon the Respiratory System.*

(1.) *Phenomena observed at the Moment of Shot.*

The effect produced upon the respiratory movements was invariably the same in all cases in which the skull was intact, and in which the bullet penetrated the brain with moderate velocity. The effect was sudden and complete arrest of the respiratory movement (see fig. 5, *et seq.*). The immediate effect of the passage of the bullet through the hemisphere was almost invariably a very marked and sudden inspiratory spasm.

In a few instances there was noted expiratory spasm. In a smaller proportion still the respirations simply ceased, the chest assuming a midway position.

This arrest was in practically all cases permanent unless artificial respiration was commenced, when in a certain number of cases the respiratory movements could be re-established (*vide infra*).

In all tracings of the arrest it will be seen that the chest ultimately assumed a position of equilibrium, probably by relaxation of the tone of the respiratory muscles.

Under these circumstances the recording lever reached a point midway between the inspiratory and expiratory apices of the curve taken before the shot.

(2.) *Mode of Recovery of Respiratory Movements.*

(*a.*) Spontaneous.

(*b.*) After artificial respiration has been established.

(*a.*) *Spontaneous Recovery of Respiration.*—This event (very rare with the skull intact, that is, not opened previous to the shot) (see p. 242) presented itself in one case, in which the bullet traversed the frontal lobes near the base midway between the optic chiasma and the anterior pole of the hemisphere, and is interesting because the arrest of the respiration by the shot was followed by a period of asphyxia of such length as to nearly reach the physiological limit usually assigned, viz., of four minutes. The recovery of respiration was exactly the same as that described under (*b*). The full discussion of this important point will therefore with advantage be postponed.

(*b.*) *Recovery after Artificial Respiration.*—Recognising from the first the fatal character of the arrest of the respiration, we instituted artificial respiration a few (10 to 30) seconds after the shot, and found that the respiratory movements could be restored except under circumstances to be alluded to directly. When recovery occurred it presented the following characteristics. The respiration returned by small inspirations, usually at long intervals. Very often these inspirations were of a sighing character, and consequently the tracings frequently exhibited two or three apices on each respiratory movement. The movements gradually deepened in extent and increased in frequency.

If the recovery took place during the execution of artificial respiration, the natural respiratory movements occurred between the artificial ones.

Very commonly at the commencement of the recovery, and occasionally also as the respiratory centre died, the phenomenon of shallow respirations alternating with deep ones was observed.

After the fact of variability in depth, alteration in regularity of the rhythm is the next most important factor. This was well exemplified in Experiments 9, 22, 32, where it was seen that both the recovery and failure of the respiratory centre was accompanied by great irregularity in the rhythm of its discharge.

That the recovery of the respiratory centre is complete under the circumstances just detailed, was tested by us in two ways, (1) by inducing asphyxia, (2) by dividing the vagi.

(1.) Upon clamping the trachea the expiratory convulsive respiratory movements which followed were in every respect characteristic of the usual disturbance of the respiratory centre effected by asphyxia.

(2.) Division of the vagi called forth the typical deep inspiration, the prolonged pause, and the collapsing expiration, characteristic of the section of these nerves,

B. *Effect upon the Heart Beat.*

The prevailing opinion among clinicians, that the chief pathological effect of the passage of a bullet through the cerebral hemisphere is exerted upon the heart, is, as we have already stated, not borne out by the exacter methods of experiment.

The effects actually noted by us are best described under the headings of

(*a.*) Rhythm,
(*b.*) Force,

and must be further arranged as primary and secondary according as to whether the effect is produced at the moment of the shot by virtue of the passage of the missile within the skull, or whether it is due to rise of the intra-cranial tension in consequence of hemorrhage, &c. We will reserve the discussion of the changes in blood pressure until we discuss the vasomotor phenomena under Part C.

Primary Effects.

(*a.*) *Rhythm.*—The passage of the bullet through the hemisphere has either no influence, or produces a very slight effect upon the heart rate.

Thus of 59 observations the rate was absolutely unaltered in 26 instances; very slightly slowed (7·5 beats in a minute) in 4 cases; slightly slowed, *i.e.*, a diminution of from 15 to 45 beats per minute, in 18; and in 11 slightly accelerated.

From these facts it is obvious that the cardio-vasal nerve centres are unlike the respiratory centre, in that they are not so notably influenced by the presence of the bullet.

Where change occurs in the heart rate it appears to be the result of an excitation, chiefly of the vagal centre. We shall further discuss this matter in considering the secondary effects.

(*b.*) *Force.* The force of the heart beat at the moment of the shot was roughly estimated by the excursions of the manometer, and as will doubtless be anticipated, in a very large majority of cases, did not show any material alteration. Thus, of the 59 experiments above quoted, in no less than 43 the force of the heart beat was unchanged, while in seven it was very slightly diminished, and in only two instances considerably so; these last being cases where the ·38 cal. rifle was employed. In seven experiments the force was slightly increased. Thus, on the whole the action of the heart seemed to be scarcely affected at the moment when the bullet traversed the hemisphere (see, however, also the discussion of the changes in the blood pressure on p. 231, *et seq.*).

We will now consider the changes secondarily produced on the heart beat, *i.e.*, a few seconds after the shot had taken effect, until the end of the experiment.

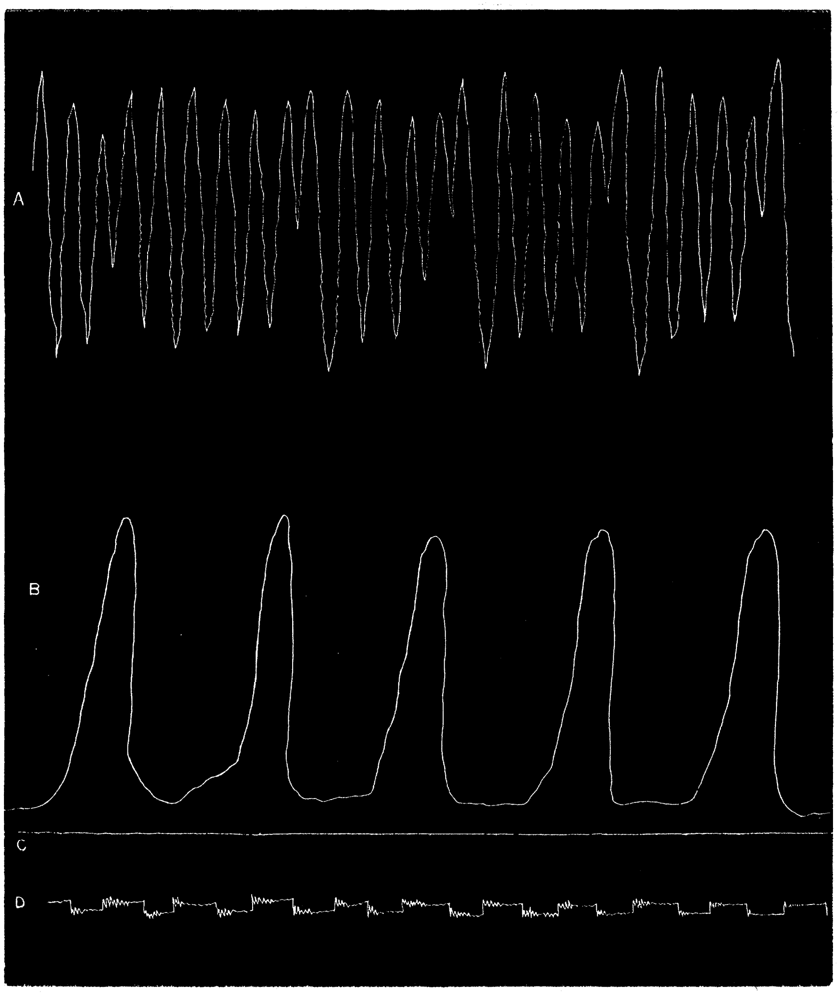
Secondary Effects.

(*a.*) *Rhythm.*—In the cases where artificial respiration was not resorted to, and

where consequently the animal speedily succumbed, the rate of the heart remained perfectly unaltered.

It was, however, quite otherwise when artificial respiration preserved the vitality of the nerve centres so as to lead to restoration of normal respiration, the exercise of which latter function permitted such effects to develop as of necessity follow the accumulation of blood extravasated within the skull. Should the bullet divide

Fig. 2.



Tracing showing vagus effect. The respirations had recovered after artificial respiration.
A = central femoral blood pressure. B = respirations. C = shot signal line. D = seconds trace.

several vessels and cause a considerable effusion of blood in its track, then, in spite of the fact that some of the fluid and pulped brain substance escapes from the aperture of entry, the intra-cranial tension commences to rise as soon as the bullet is within the cavity, as is shown by direct measurement, see p. 239, and then there begins a slowing of the heart rhythm. A good example of this is evidenced by Experiment No. 48, of which we append the following details, and by Experiment 9, see fig. 2.

	Rhythm.
Before the shot.	11 beats in 4 secs.
Shot.	——
10 seconds after shot.	7 beats in 4 secs.
1 minute after shot.	5·5 " " "
3 minutes after shot.	4·5 " " "
3 minutes after shot.	Both vagi divided.
7 minutes after shot.	11 beats in 4 secs.

Fig. 3.

Terminal phase of vagus effect, showing very slow heart rhythm and marked irregularity of respiration. Dog 9.

From this instance it is seen that the heart beats progressively slower in rate (for alteration in character *vide infra*), but that the original rhythm is restored as soon as the vagi are cut.

The phenomenon, therefore, is an example of the well-known effect (Leyden) produced through excitation of the vagus centre by raising the intra-cranial tension.

(*b.*) *Force.*—As regards the force of the heart beat, the amplitude of the excursions of the manometer column shows, on the whole, a steady increase parallel with the slowing of the rate until a well-marked "vagal" type of beat is produced. This parallelism is preserved so long as the blood-pressure is maintained. Should this latter fall, it is then noteworthy that the cardiac beats are also lessened in height, suggesting that the former phenomenon is due to the latter.

The amplitude of the "vagal" beats is sometimes enormous. We have measured such beats and found the mercury to execute excursions of 40 millims. in height with each ventricular systole. Section of both vagi causes, of course, the vagal character to entirely disappear. See the table on p. 230. We have often observed this vagal effect to develop in the complete absence of any primary change, thus establishing the truth of the view that it is evoked, not by the bullet, but by the secondary supervention of hemorrhage. When there is no vagal influence of the kind above described, and the heart gradually comes to a standstill, then the force of the ventricle steadily diminishes to the end of the experiment (see fig. 3).

C. *Vaso-motor Phenomena.*

Under this heading we propose to discuss the marked alterations we have observed to occur in the blood-pressure, and, in analysing the same, to indicate how far such variations may be attributed to the action of the heart or of the vaso-motor centre respectively. In nearly every case the pressure of the cardio-arterial trunk division of the vascular system was recorded by a cannula placed in the central end of the femoral artery, and in a few instances that of the common carotid.

To differentiate as far as possible the central vasomotor influence from that of the heart muscle, a cannula was in very many experiments also placed in the peripheral end of the opposite femoral artery; and in a few cases, as will be described later, a cannula was placed in the peripheral end of one carotid artery.

The phenomena observed appeared to us to be divisible into three stages, as follows:—

Stage 1. Fall of pressure at incidence of shot.

Stage 2. Recovery of pressure, and over-restoration of the same: "asphyxial rise," *vide infra.*

Stage 3. Variations in pressure between the occurrence of restoration of pressure and the end of the experiment.

Stage 1.—*Fall of Pressure at Incidence of Shot.*

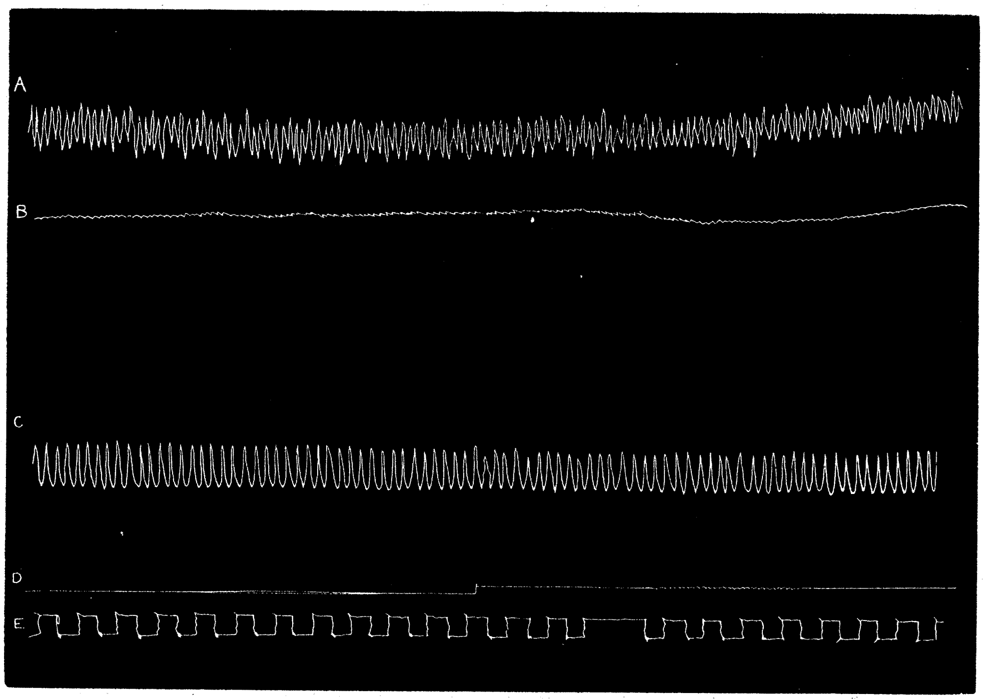
The moment of penetration of the skull is attended by a distinct fall in the blood pressure (see fig. 7 *et seq.*). The amount of this fall, however, is most inconstant;

we therefore placed together, in diagram form, tracings of the upper border, *i.e.*, uniting the systolic apices of the curves obtained by us in successive experiments, and analysed the combination of these curves.

The character of the fall is as follows :—There is a sudden interruption of the level of pressure, which then descends relatively rapidly (*i.e.*, in 10 to 15 seconds) to a minimal point, from which it as soon rises again.

The cause and mechanism of the fall are difficult to discover. In the first place, it is not dependent, as the respiratory arrest is, upon the penetration of the skull, for we

Fig. 4.



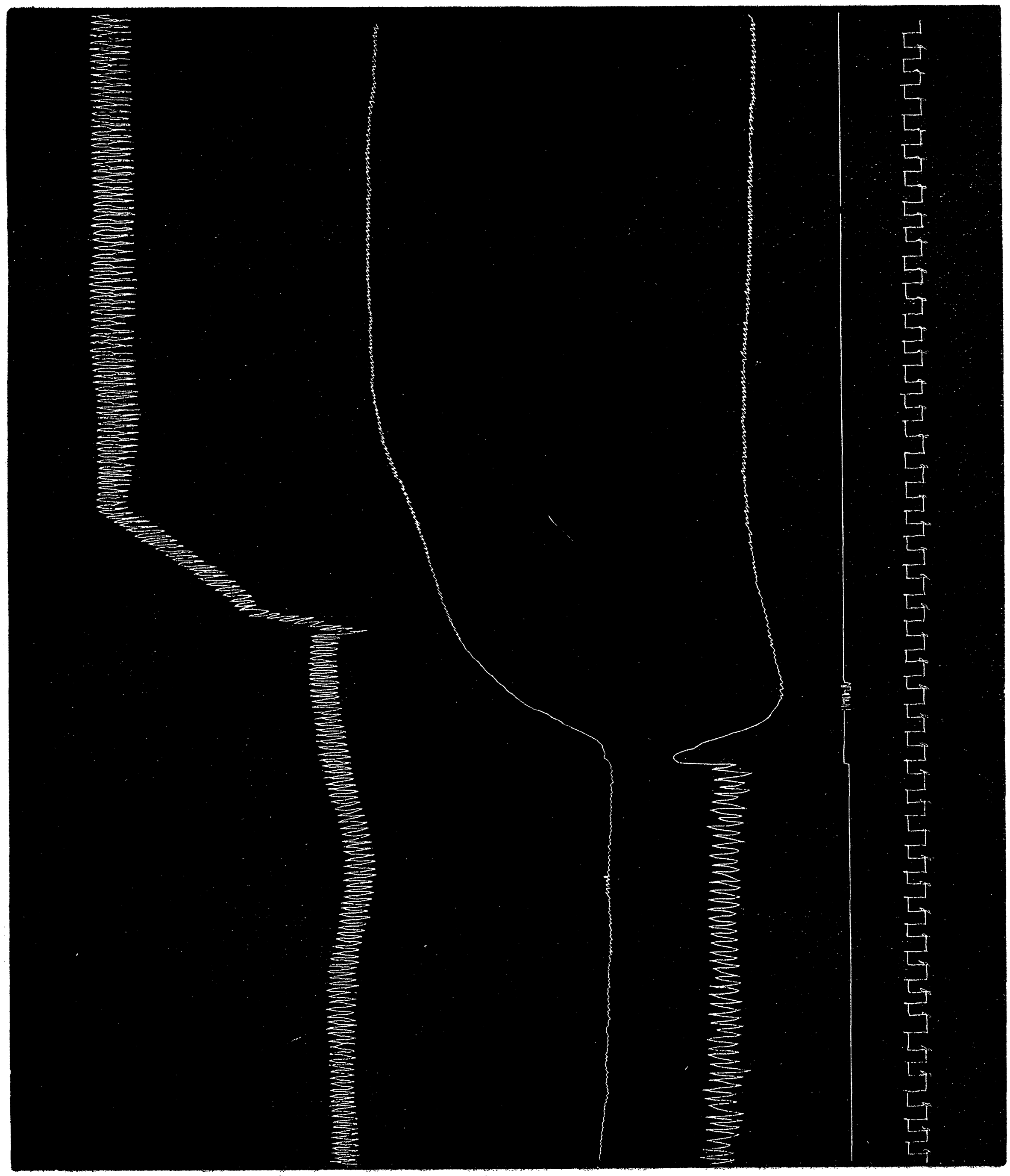
Tracing showing that there is little effect on the respiratory and circulatory system if the bullet glance from the surface of the skull without penetrating.
A = central femoral blood pressure. B = peripheral femoral pressure. C = respirations.
D = shot signal trace. E = seconds trace.

have sometimes observed it in cases where the bullet did not penetrate, but merely glanced from the convex surface of the skull, or where it caused but a slight depression of the same. As a general rule, a glancing shot caused no change (see fig. 4).

Further, when we removed the cranial vault (see page 242 and Experiment 67) to abolish, in great measure, the reflexion of the lateral pressures during the passage of the bullet, the fall was nevertheless well marked, and as fully developed as in cases where the skull was intact.

Finally, we obtained the same fall, even after both vagi and splanchnic nerves had been previously divided.

Fig. 5.



Tracing to show the correlation of the peripheral and central blood pressures with an unusually rapid rise of pressure (so-called asphyxial rise). Dog 49.

From consideration of the foregoing, we are compelled to believe that the initial fall is not due to a primary excitation of the vagal centre stimulated by the sudden increase of the intra-cranial tension. Under these circumstances, this depressor phenomenon appears to us to be a reflex effect on the heart, due to excitation of sensory nerves in the skin, muscles, bones, and dura, mechanically irritated by the bullet; because, whatever the arrangement of the experiment as above detailed, the penetration of one or more of these tissues was a constant feature.

Where the fall of blood pressure is most marked, the heart beats, as registered by the manometer (central, *i.e.*, cardiac, cannula), are much smaller in amplitude. This is what was to have been expected if the fall of pressure is brought about as explained above.

The final analysis of Stage 1, with the aid of the peripheral manometric observations (see below), will be found to completely confirm the foregoing conclusions.

Stage 2.—*Recovery of Pressure and Over-restoration of same* ("*Asphyxial Rise*").

In almost every case the blood pressure recovered itself after the preliminary fall just described, and regained its former level. Further, in all cases in which the respiration was arrested, and an asphyxial state thereby developed, the restoration of the blood pressure was continued as an asphyxial rise (see fig. 5 for a very marked effect). In those cases in which the respiration was not arrested, but in which nevertheless there was an initial fall, there was no over-compensation. So, too, where an apnœic condition existed the rise was less or not present (see fig. 6, p. 236). Wherever, on the other hand, respiration ceased, the over-compensation became very marked. The peripheral blood-pressure rose in exact parallelism with this "asphyxial rise" of Stage 2 (see also *infra*).

Stage 3.—*Variations in Pressure between the Restoration of the same and the End of the Experiment.*

After the blood-pressure had returned to its former level in cases where the asphyxial arrest of the respiration did not occur, it tended to fall gradually, and this slow fall was marked by the occurrence of sundry small variations in height, producing curves of a TRAUBE-HERING character.

The same curves may also be seen developed in imperfect parallelism on the record obtained from the peripheral end of the femoral artery, and are therefore doubtless truly of central vaso-motor origin (see Experiment 49).

Results obtained by the use of the Peripheral Manometer.

We have employed peripheral manometric observations in two ways, by fixing the cannula, firstly, in the peripheral end of the femoral artery, and, secondly, in the

peripheral end of the common carotid artery. As the distribution of the latter is intracranial, we place the results obtained therefrom in a separate paragraph.

(A.) *Peripheral Femoral Observations.*

The results obtained from the femoral artery prove distinctly the following conclusions :—

(1.) That the pressure in the peripheral arterioles after the shot, follows in a strikingly parallel manner the variations of pressure in the cardiac arterial trunks, though later and in a more gradual manner (see fig. 7).

(2.) That the initial fall described as occurring in Stage 1, *i.e.*, immediately upon the bullet perforating the skull, is, in the majority of cases, similarly exhibited in a (later) parallel fall of pressure in the peripheral femoral arterioles. In two instances out of fifteen experiments made on this point, however, there was no fall recorded on the peripheral trace. It is therefore clear that the initial fall in the central blood pressure, is certainly not a vaso-motor phenomenon, a conclusion already arrived at on page 234 from other considerations, and to which latter may be now added the fact that the effect is produced within the brief period of time required for a single reflex act, and not a period sufficient for an excitation of the vaso-motor centre to evidence itself by its usual curve of reaction.

(3.) That the ratio between the central, *i.e.*, cardiac blood-pressure and the pressure observed in the femoral arterioles is little altered by the effect of the shot, and the figures obtained show only the fact that the cardiac or arterial trunk pressure is lowered before the peripheral.

The average ratios obtained are as follows :—

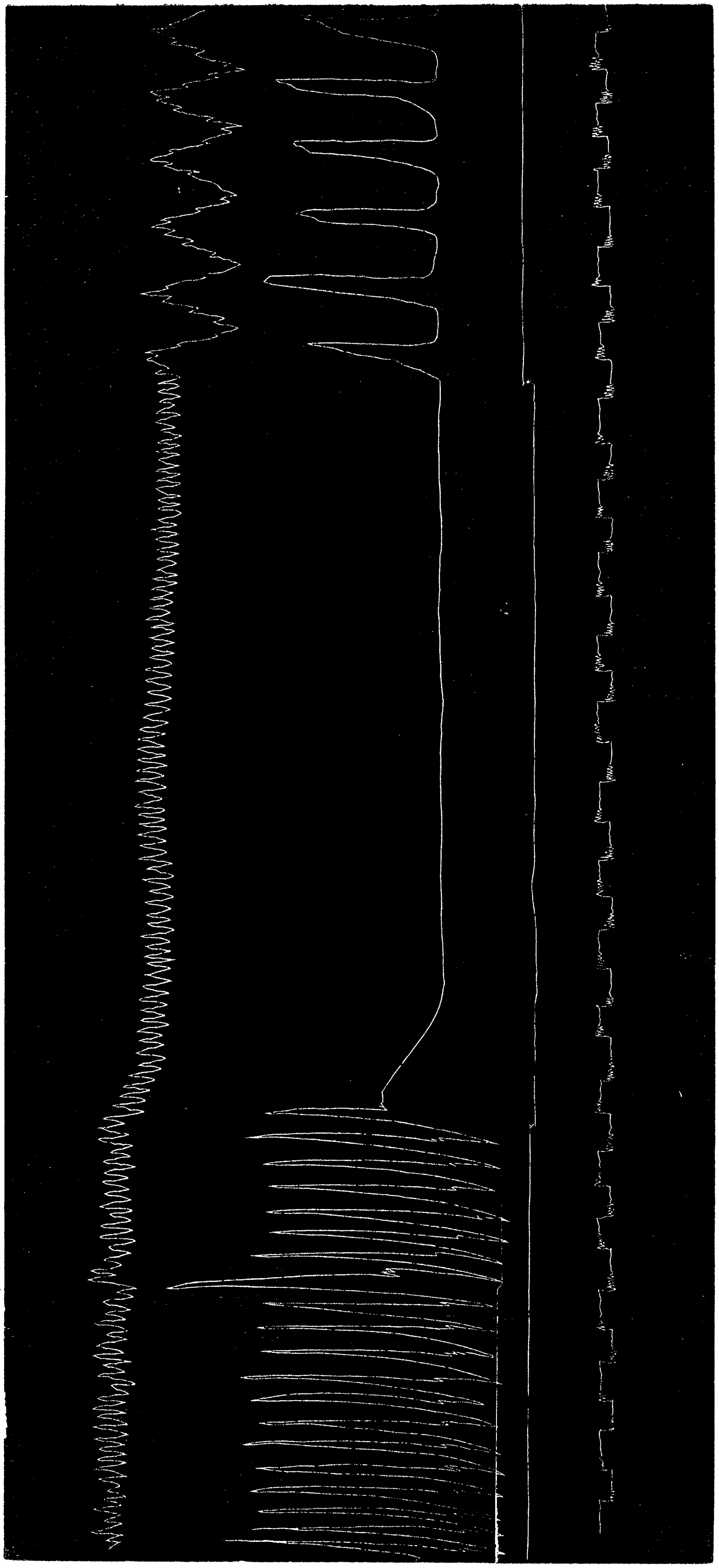
	A. Before the shot.	B. 2 mins. after shot.	C. Later but variable periods, 6–20 mins. after shot.
Cardiac pressure. / Peripheral pressure.	$\frac{2\cdot8}{1}$	$\frac{2\cdot25}{1}$	$\frac{2\cdot2}{1}$

The general effect indicated by these ratios is that already described from examination of the tracings. From these facts we are led to believe that the vaso-motor nerve apparatus is, if at all, very slightly primarily affected by a bullet wounding the cerebral hemisphere.

(B.) *Peripheral Carotid Observations.*

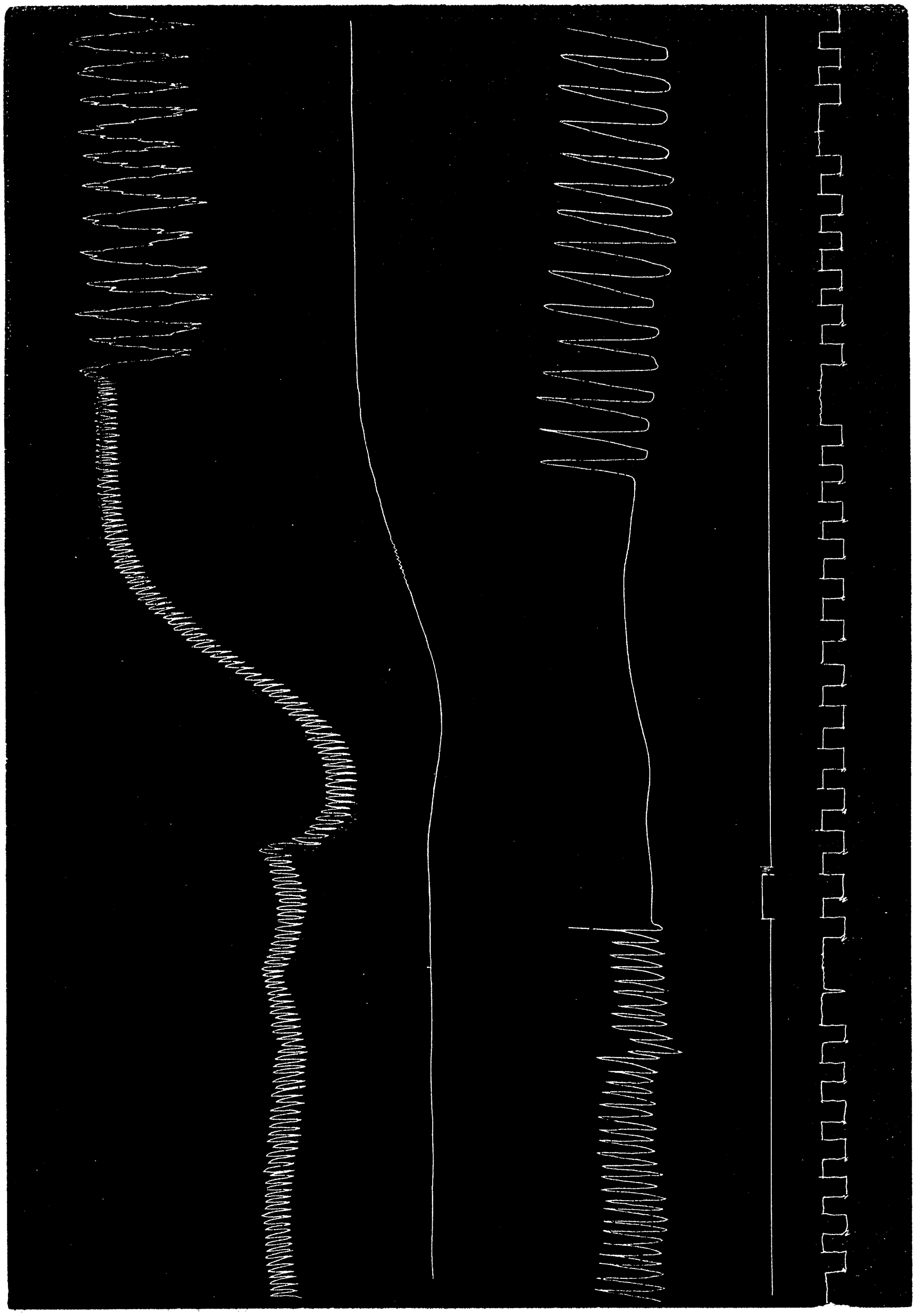
In considering the changes produced in the pressure within the distribution area of

Fig. 6.



Tracing of simple case, but in which there was no rise of blood pressure of asphyxial kind. Note great depth of respiratory movements before shot. Dog 9.

Fig. 7.



Tracing to show the character of the rise of blood pressure in the peripheral end of the femoral artery; and the correlation with the central femoral pressure curve. Dog 40.

the carotid two preliminary facts have first to be remembered, viz.: (*a.*) That the bullet cuts open numerous branches of the artery. (*b.*) That the intra-cranial hemorrhage gradually brings about compression of the artery and its branches. It is clear at the same time that these two facts tend to neutralise one another in time, *i.e.*, as the blood continues to be extravasated. Further, not only at the incidence of the shot, but also later, it is not unlikely that the cannula in the peripheral end of the carotid may act in part as that of an intra-cranial manometer.

The results actually obtained are as follows :—

The fall of pressure in the peripheral carotid cannula is very sharp (see fig. 8, p. 240), and markedly contrasts with the slow and imperfect fall in the peripheral end of the femoral artery. See Experiments 42, 52.

After the shot the pressure rises and subsequently exhibits a tendency to parallelism, but not so markedly as in the case of the femoral.

On examining the ratio between the central and peripheral pressures, we find the following averages :—

	Before shot.	After shot, 2–6 mins.
Cardiac pressure. / Peripheral carotid pressure.	$\frac{1{\cdot}76}{1}$	$\frac{2{\cdot}53}{1}$

This establishes the fact, above described as being elicited from inspection of the tracings, that the fall in the peripheral pressure is greater than that of the central, whereas, in the case of the peripheral femoral, this was not the case. The general character of the carotid fall, especially the suddenness, suggests strongly to us that it is in part due to the simple effect of the bullet opening the skull, and also to the wounding of the branches of the carotid.

D. *Muscular System.*

With the object of finding whether the mechanical effect of the passing bullet also caused in reality an excitation of such fibres, etc., as are sensitive to mechanical stimuli, we investigated the condition of the muscles. To ordinary attentive observation, the muscles of the limbs and trunk are easily seen to twitch at the moment of shot. For the purpose of recording such phenomena we attached the freed patellar tendon of the rectus femoris muscle to a Fick spring myograph. Fig. 9 is a good example of what occurs.

As the bullet traverses the hemisphere the rectus sharply contracts and the contraction then gradually relaxes. That this is a genuine excitation effect exerted

upon the encephalon (possibly on the fibres of the corona radiata) we proved in several experiments by dividing the spinal cord in the mid-dorsal region before shooting, in which case the muscular phenomenon was absent from the muscles supplied below the level of the section.

From the foregoing description it is evident that a very marked and remarkably constant series of phenomena are evoked by the passage of the projectile. It now remains for us to point out how the various events are produced, and to show that in all probability they occur in consequence of the medulla oblongata being subjected to the shock of considerable pressure suddenly applied.

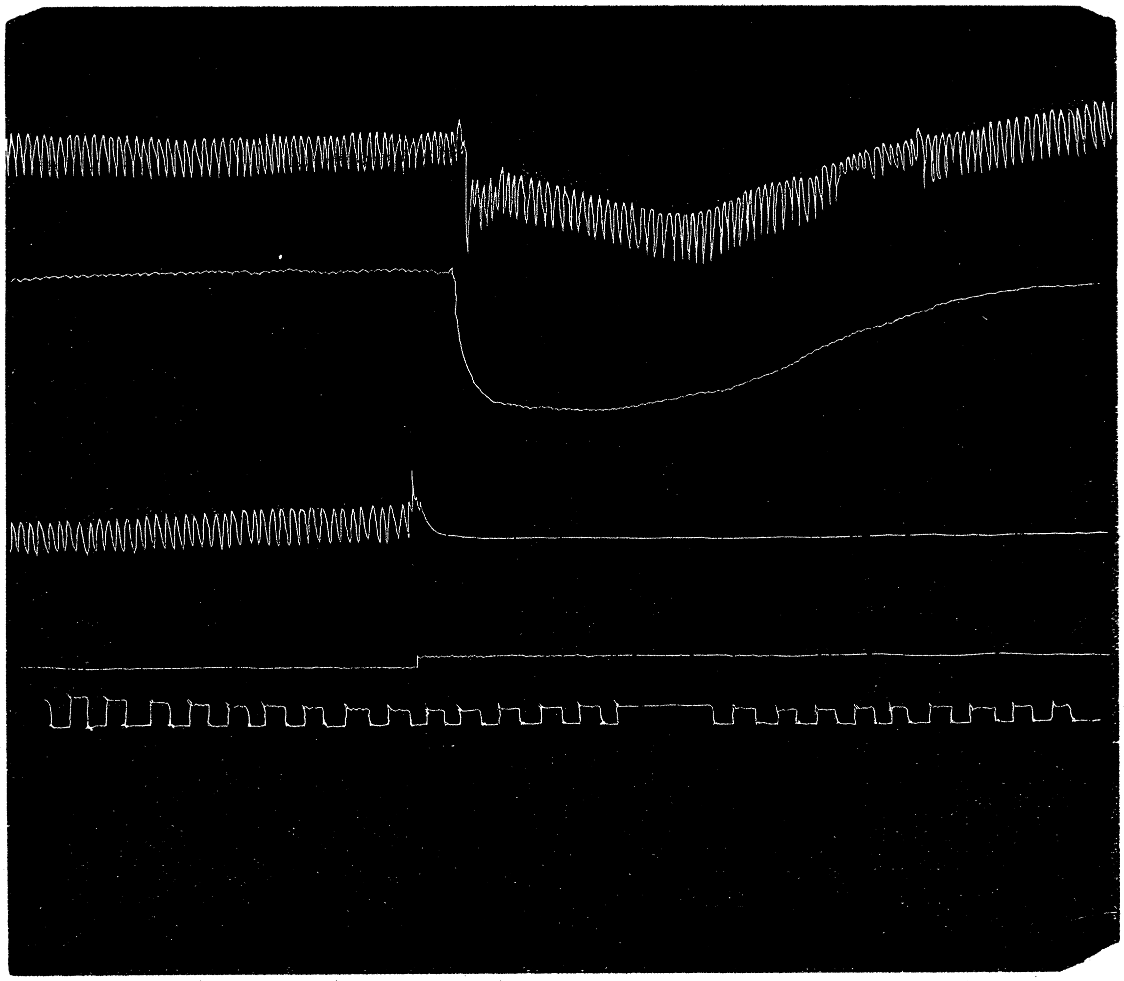
Physical Considerations upon the Causation and Mode of Production of the above described Phenomena.

For the purpose of this paper the skull may be considered as a rigid capsule filled with soft solid and fluid contents. The projectile may be considered as a cone driven with great velocity. The "active" force exerted by a cone at any given point, driven into a rigid mass, varies directly as its momentum and the angle of the inclination of its surface. By far the largest factor is, of course, the momentum, and variations of this would practically produce all the variations of the effective force exerted by the bullet during its passage through the brain. We may consider that lines of force operate from every point on the surface of the bullet in directions perpendicular to the particular part of the surface considered. Owing to the soft solid and fluid state of the contents of the skull, such forces would be transmitted without much diminution to the surface of the brain. On arriving at the unyielding skull they would be reflected back from every point of its inner surface, so that the active force of the bullet would immediately become a "compressing" force operating on the general intracranial contents. This conclusion, drawn from general theoretical physical considerations, is borne out by the phenomena related above, since the effects we have described are really those of severe acute cerebral compression, as stated by SPENCER and HORSLEY* to follow noteworthy elevation of intracranial tension. To record the chronology of these events, and especially the rise of tension more accurately, we employed the method described on page 225 for marking the moment and nature of changes in the intracranial tension. The graphic records obtained by this method are well instanced by fig. 10, p. 244, in which it is seen that there is a very sudden increase of the intracranial tensions at the incidence of the bullet, and that the tension continues to increase after the initial rise until an equilibrium is arrived at, this increase being clearly due to the secondary supervention of hemorrhage within the skull. The extent of the damage, and the inevitably fatal effect (by the respiratory centre being unable to recover its function) of the

* 'Phil. Trans.,' B, 1891.

larger bullet we used in our experiments is now fully explained. These positive considerations have been fully confirmed by negative experiments, in which it has occasionally happened, when employing the pistol, that through faulty cartridges, &c., the velocity of the bullet was so reduced that it was only just able to penetrate the skull. In such cases, the phenomena were proportionately less developed, so much

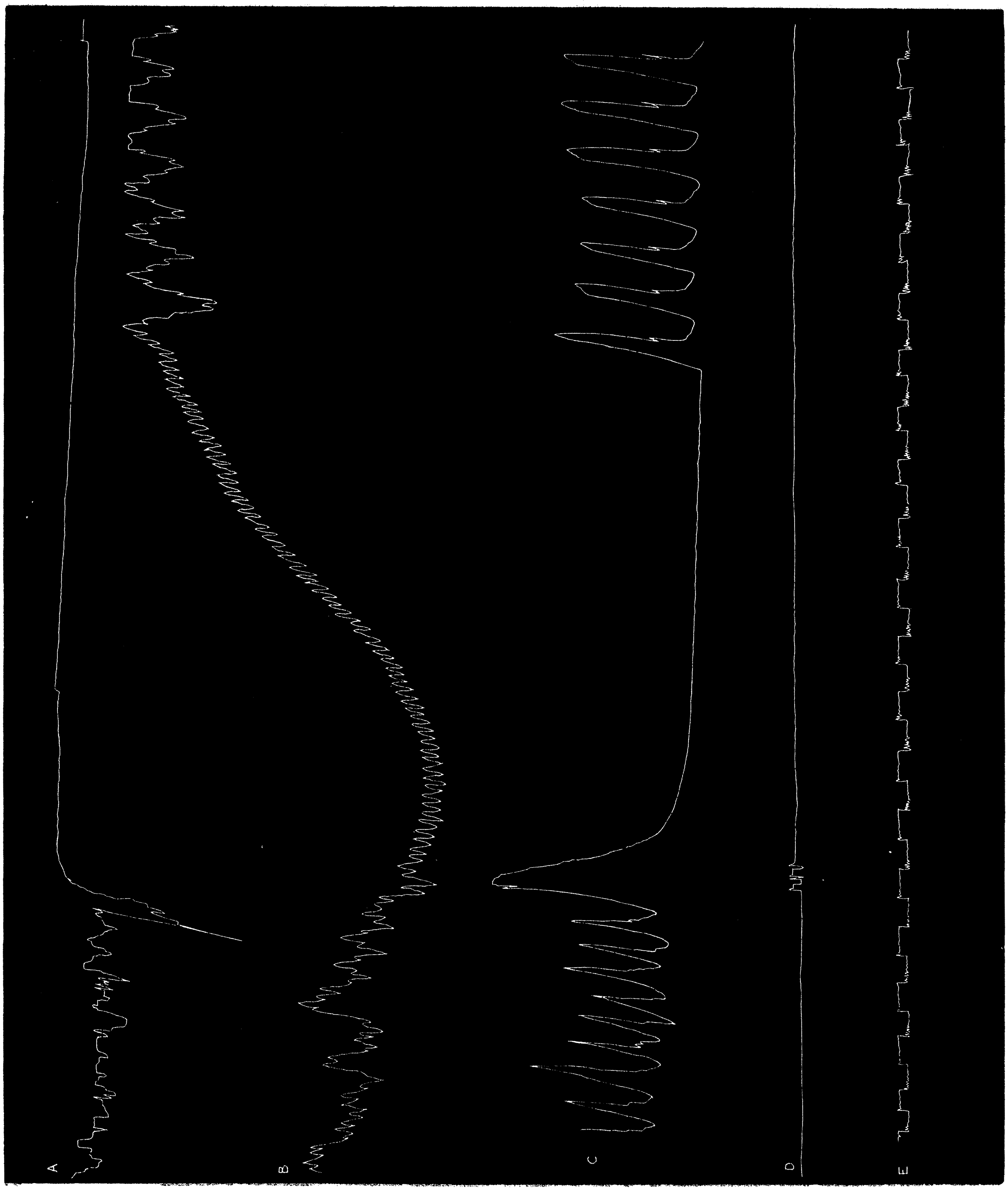
Fig. 8.



Cannula in the peripheral end of the left carotid artery. Note the suddenness of the fall of pressure. Dog 42.

so indeed that in one instance (1 out of 75 experiments) the respiration, though extremely depressed, was not absolutely arrested, notwithstanding the fact that the track of the bullet occupied the same region as in other cases in which the force was greater. The last series of our experiments were directed towards this very point, and are, we think, conclusive in demonstration of the truth of the explanation we have given above. The design for these experiments was as follows:—

Fig. 9.



Tracing showing the sudden contraction of the rectus femoris muscle at the moment of shot. Note the tremor in the muscle due to etherisation (ether clonus so-called) before the shot.

A = tracing from myograph lever. B = central femoral pressure. C = respiratory trace. D = shot signal trace. E = seconds trace.

Supposing the above stated physical considerations to be true, it seemed to us that if part of the rigid wall of the skull were removed and the dura mater opened, that the lines of force could not be reflected, and that, consequently, the forces which exerted the unfavourable effect upon the respiratory centre when the skull was intact, would be dissipated in projecting the brain peripherally, *i.e.*, through the opening. In an experiment of this kind a certain portion of the occipital lobe is seen to be forced at the moment of shot through an opening in the parietal bone. (See fig. 3, of Plate 3.) This expulsion of the cranial contents would be contributed to, of course, by reflection from such points of the cranial surface as remained. In a certain number of experiments, therefore, to test these conclusions, the skull and dura mater were very freely taken away, the entire parietal and occipital lobes being exposed, and the animal was then shot through the frontal bone and region of the brain.

Under these circumstances almost the entire hemisphere was torn off by the bullet and scattered on objects around. Although such very extensive injury was inflicted on the cerebrum, no respiratory arrest occurred (see fig. 11), for the reason suggested, that in consequence of the rigid capsule of the skull being in great measure removed, the medulla oblongata was no longer subjected to the severe compressing forces above discussed.

We now pass to the further consideration of the physical conditions which underlie the development of the disruptive lateral forces just referred to. The idea that some of the so-called explosive effects produced by bullets passing through soft and moist structures, were due to hydrodynamic forces, arose apparently with HUGUIER, who made a number of experiments relating to the effect of bullets upon hard and soft structures, and in which he speaks distinctly of the lateral pressure of a projectile striking a moist object as throwing to a distance fragments with the contained liquid; and further, in describing the effects upon parenchymatous organs, *e.g.*, the brain, he says: "Il semblerait que le liquide abondant que renferment tous ces organes parenchymateux, projeté au loin par l'action latérale de la balle, aît entrainé avec lui des portions de ces viscères."*

But perhaps the most light has been shed on this subject by the researches of Professor KOCHER.

In the first place as regards direct hydrodynamic effect upon the skull, KOCHER found that if the foramina in a dried skull were plugged with plaster of Paris, and the cranial cavity then filled with water, that the passage of a bullet (Vetterli rifle) through the preparation, burst the skull into pieces, the rending beginning in some places in the sutures. To investigate the influence of water interstitially present in substances, he fired numerous bullets through tin-plate canisters, open and closed, filled with dry and wet substances respectively. Whereas the dry filled canisters were

* 'Bulletin de l'Académie Nationale de Médecine,' tome 14, 1848–49.

merely perforated by the projectile, those filled with wet substances were burst explosively when penetrated by the bullet.

KOCHER also* showed that a projectile with less propulsive force produced much less bursting effect.

The conclusion he arrived at was that the "explosive" effects of bullets through the brain were due to the lateral pressures in wet substances being hydrodynamic in character.

REGER† from his earliest experiments in 1882 confirmed the hydrodynamic view so firmly grounded by KOCHER.

In his second paper he shows very definitely the extent of the error that has been made in many observations on tissues that are dead, and consequently more rigid. We have ourselves in this respect established a striking contrast as regards the effect of the bullet on the brain, by first firing a bullet through it in the living condition, then hardening the brain in MÜLLER'S fluid, and again shooting it in another region. In the former case the bullet tears a large funnel-shaped passage, with much bruising. In the second case it simply bores a hole with one or two lateral diverging cracks.

BRUNS,‡ in a paper descriptive of the surgical aspect of gunshot wounds, describes a large series of experiments made by him on the effect of the small calibre rifle bullet on tissues, &c. From a direct manometric observation of the pressure set up by the bullet's passage, he describes a rise of pressure equivalent to that of fifteen atmospheres.

In all cases the most "explosive" effect was observed in the case of the brain in the skull, the control being evidenced by the simple perforations of skulls emptied of their contents.

A general survey of the results obtained by BRUNS shows that the bursting effect is in proportion to the velocity of the projectile; and we have repeated KOCHER'S experiments, and have in every respect completely confirmed them. In view of the fact that, so far as we are aware, no illustrations of such experiments have been published, we append photographs of some of our own results.

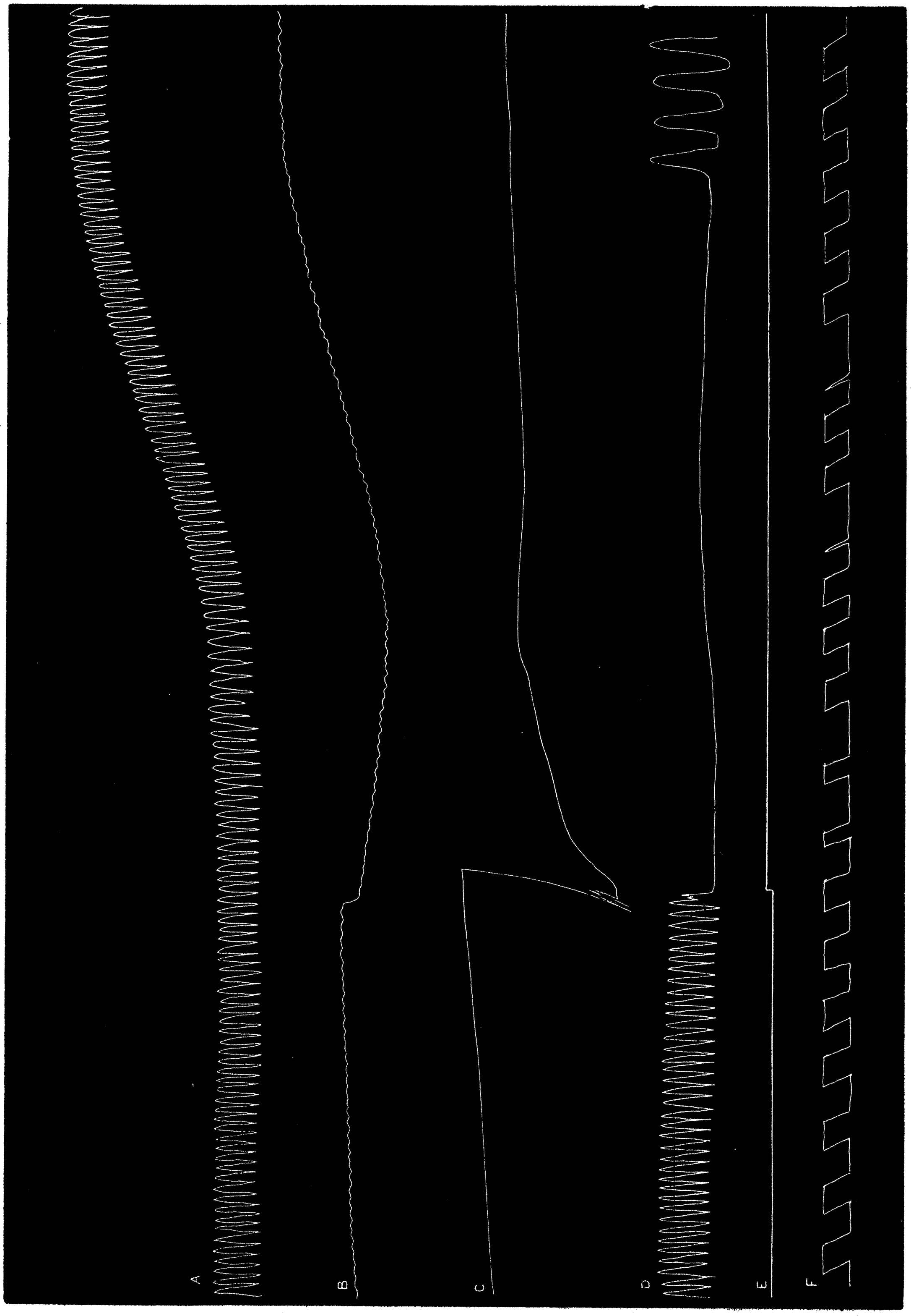
Plate 3, fig. 4, shows photographs of two dried dogs' skulls of similar strength. The skull shown as intact was fired at with a saloon pistol 22 cal., and merely perforated, as is shown in the photograph. The other skull, which had been cleaned in precisely the same way, was fired at with the same pistol after the cranial cavity had been filled with water and all the foramina closed with modeller's wax. The rending effect of the water, starting the sutures, &c., is particularly well shown. It may be

* 'Correspondenz-Blatt für Schweizer Aerzte,' 1875, p. 3; 1879, p. 65.

† 'Gewehrschusswunden der Neuzeit,' 1884; 'Verhandlungen der Deutschen Gesellschaft für Chirurgie,' Berlin, 1892.

‡ 'Verhandlungen der Deutschen Gesellschaft für Chirurgie,' 1892, p. 1.

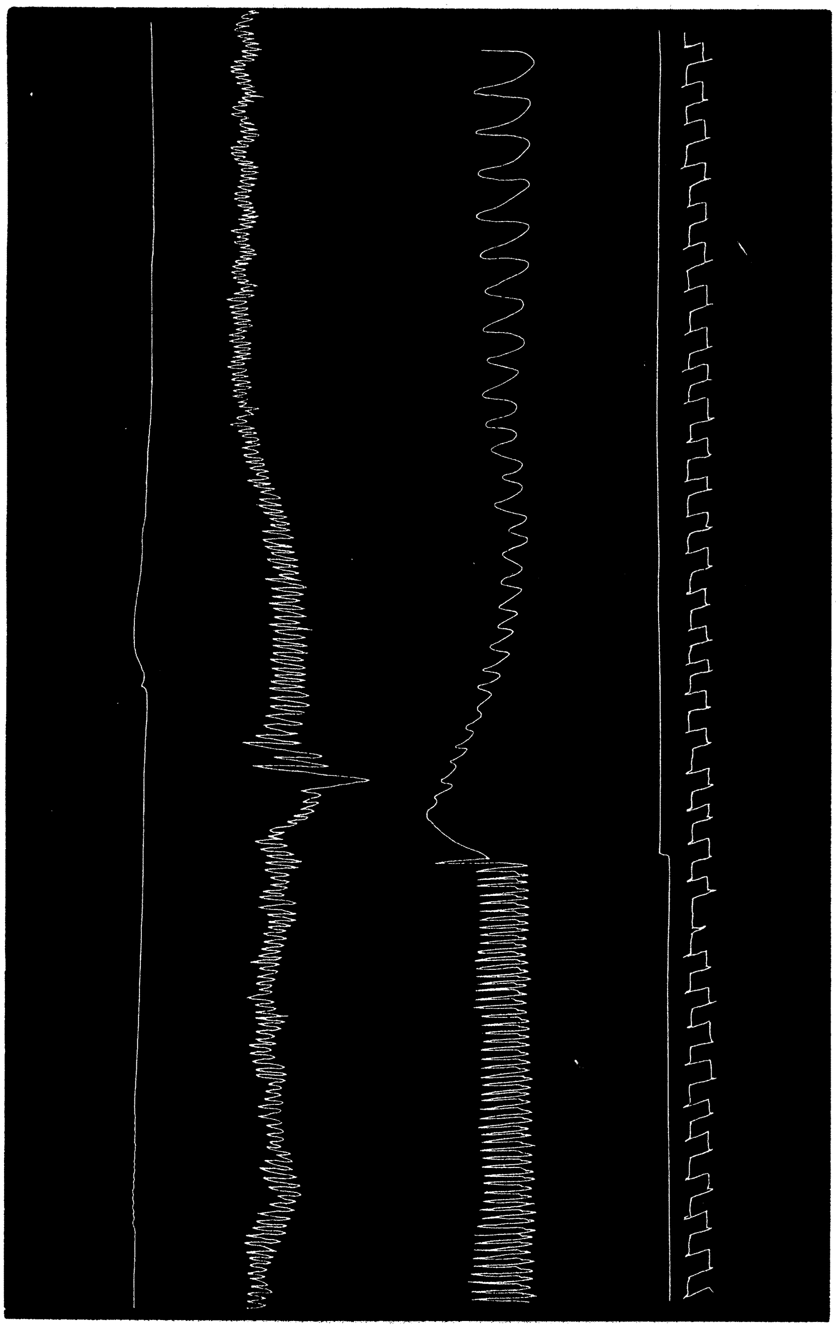
Fig. 10.



Tracing showing the rise of intracranial tension at moment of shot. Dog 60.

A. Central femoral blood pressure. B. Peripheral femoral blood pressure. C. Intracranial tension. D. Respirations. **E. Shot signal.** F. Seconds.

Fig. 11.



Cranium opened freely before the shot. Respiration not arrested, though inspiratory spasm produced, and diminution of movements.

noted, too, that the effect is greatest on the side of entry of the bullet (*vide* p. 248). Precisely the same influence is seen in a very marked degree when the ·38 cal. bullet passes through a similar skull containing the brain in the living state. Finally, we have observed the same difference between the effect of the bullet on a canister full of dry lint and one filled with very wet lint, as originally described by Professor KOCHER.

A ·38 cal. bullet was first fired through the dry canister, and merely perforated it, whereas when a similar bullet was fired into the wet one, it completely blew it up, projecting the contained lint even on the top of a tall wooden block placed behind the canister to prevent the bullet injuring the wall.

On the further question, what is the quantitative character of the hydrodynamic effect produced on water at different points after entering the fluid, it occurred to us that the bullet might be made to automatically record the disturbance it produces, and as follows. A tinplate box 12 in. by 10 in. by 8 in. was taken and filled with water coloured strongly with methylene blue. A white unglazed paper screen was then fixed longitudinally, the bottom part touching the surface. The bullet was then placed so that it travelled through the water just in front of and parallel to the bottom of the screen, and at a depth of 2 centims. The effect was that a wave of water was thrown up by the bullet and against the white screen, which was consequently stained blue by the wave. A number of such experiments produced a good series of such records. In these it is seen that the disturbance of the water is greater almost immediately after the bullet enters the water, and then falls gradually to the end of the bullet's trajectory.

In the course of these experiments we found that the disturbing effect of the bullet was, as may be supposed, greatest in the immediate neighbourhood of the trajectory, but we were not prepared to find that when the bullet was fired through a weak, *i.e.*, a wooden box, close to (2 centims. distance) one side, that that side was alone burst out. It is interesting to observe that the water surface in all these experiments was only subject to the atmospheric pressure. So, too, on *post mortem* examination of the skulls experimented upon, in those cases where the bullet did not penetrate the further side of the cranium, the proximal side was the more severely rent. (*Cf.* also fig. 4, Plate 3.)

It may, perhaps, be useful to refer here to the theory first formulated by HAGENBACH,* contested by BODYNSKI,† and re-asserted by HAGENBACH,‡ namely, that a bullet coming into contact with a rigid body loses a certain proportion (27 grams. from a bullet weighing 40 grams., moving while 100 paces from the firing point with

* POGGENDORFF'S 'Annalen der Physik und Chemie,' vol. 140, 1870, p. 486.

† POGGENDORFF'S 'Annalen der Physik und Chemie,' vol. 141, p. 594.

‡ POGGENDORFF'S 'Annalen der Physik und Chemie,' vol. 143, p. 153.

a velocity of 320 metres per second) of its substance by melting, and so produces additional destruction. This notion of fusion of the bullet received much clinical support from SOCIN,* who made, in conjunction with HAGENBACH, experiments of deformation and loss of substance of projectiles striking hard substances. In no case, however, was it proved that the condition of the bullets was due to melting. Although much discussed by them, curiously enough none of these authors seem to have adopted the course of testing the matter by actual experiment.

The matter remained in this unsatisfactory state until VON BECK† adopted a rough calorimetric experiment, from which it was obvious that HAGENBACH's theoretical position was unsound.

A very conclusive research negativing the heating of the bullet at least by friction in its course is that of MESSNER.‡ He fired small-bore bullets through canisters filled with sterilised meat peptone gelatine, the bullets in some cases being clean (control experiments), in others infected with cultures (micrococcus prodigiosus, green pus, staphylococcus pyogenes being used) and also (when clean) caused to pass through a layer of flannel on which a culture had been spread before entering the canister. The results invariably showed that the bullet carried in the organisms, and that the latter were in nowise destroyed by the heat supposed to be developed.

By many authors, *e.g.*, BUSCH,§ the fact that fluid fat sometimes oozed from the wound was taken to mean that it was melted by the heat of the bullet. This is put forward without recognition that fluid fat always escapes from adipose tissue if this latter be cut, lacerated, or contused. Against the view that any part of the bullet is fused, is the incontrovertible and finally decisive fact, that fired bullets often show the marks of the rifling of the barrel, and scratches on their surfaces as perfectly sharp. In one case we noted, as VON BECK had previously, that the bullet had enclosed a hair in its course, which hair was quite uninjured. Finally, no part of the wound is in the slightest degree charred, even superficially.

* 'Chirurgische und Pathologisch-Anatomische Beiträge zur Kriegsheilkunde.' Leipzig, 1872, p. 10.

† *Loc. cit.*

‡ MESSNER. "Wird das Geschoss durch die im Gehirnlauf stattfindende Erhitzung sterilisirt?' 'Münchener Medicinisches Wochenschrift.' No. 23. 1892.

§ 'Archiv für Klinische Chirurgie,' Bd. 16, 1874, p. 22.

Destructive Effect of the Bullet on the Encephalon.

The destruction caused by the bullet may be described under two divisions, viz., (1) immediate effects, (2) remote effects.

1. *Immediate Effects.*

The local destruction caused by the bullet in the brain is well shown in all our specimens. As Hoppner and Garfinkel* have demonstrated, the track of the missile is a funnel-shaped tube, the wide end of the funnel corresponding with the aperture of entry. We find that in the case of the pistol bullet the aperture of entry is a round, depressed, and lacerated opening, with blood extravased into the pia mater around for a distance varying from 5 to 15 millims. The canal of the bullet is a rounded tube with ecchymosed pulpified walls, the softening extending through the substance of the hemisphere for about 1 centim. on each side. The aperture of exit is a ragged and bruised opening. The bullet named (No. 3) frequently did not penetrate the encephalon completely. Under these circumstances the bullet was found resting at the end of a canal which exhibited progressively less and less bruising. Such diminution of the bruising effect is well described by Klebs, who showed that with the cessation of the movement of the bullet the track of the bullet was simply represented by a canal showing loss of substance.

In every case the canal contained fragments of bone which were often found on the proximal side of the aperture of exit, having been driven through the encephalon, and in several cases a disc formed from the squamous bone, and rather larger than the bullet, was forced half-way into the hemisphere opposite to the side fired at.

The laceration of the canal must thus in part be attributed to the movement of these fragments of bone, but the pulpy state of the walls can only be due to the lateral thrusting forces of the bullet referred to on page 242, &c., and which were described by Muron † as producing like effects at a distance in other soft tissues, *e.g.*, muscle and marrow of bone. (*Cf.* Busch. ‡)

Wahl§ also points out that the particles of the tissues at the point struck are thrust aside into the neighbouring structure, so destroying these. On this point Delorme‖ has urged that the lacerating effect seen so markedly when a bullet traverses a book is due to the bullet driving in front of it *débris* of the leaves struck first. That this is so will admit of no doubt in the mind of anyone who repeats the experiment. The punching action of the bullet leads to its driving in front of it

* 'Centralblatt fur Chirurgie,' 14 and 15, 1874.

† 'Comptes Rendus des Séances et Mémoires de la Société de Biologie,' 1871.

‡ 'Verbandlungen der Deutschen Gesellschaft für Chirurgie.'

§ 'Archiv für Klinische Chirurgie,' vol. 17, Berlin, 1874, p. 56.

‖ 'Traité de Chirurgie Militaire.'

particles of increasing diameter, and these by being hurried forward cause much destruction. Although in consequence of the difference in density analogy may easily be strained in transferring such results as these to explain the condition of the bullet tract through the brain, still relatively similar conditions must be present also in the latter case.

A further point which requires brief consideration is the suggestion of BUSCH* that the rotation of the projectile causes molecular disruption of the walls of the wound. So long as the bullet remains smooth the rotation of its surface cannot produce an appreciable effect even if such rotation were complete. But, further, the rotation exists during the intra-cranial passage of the bullet only to the extent of a fraction of the circumference of the latter. We may add that the rotation of the projectile is not regarded as a factor by practical artillerists in considering the disruption of penetration. So, too, KOCHER† shows that the only influence of the rotation would be to cause the particles to fly sideways from the front of the bullet.

In reference to the disruption of the walls of the bullet track allusion must be made here to the view frequently put forward, namely, that part of the effect is due to air carried forward by the projectile. The first allegation that the compressed air so beautifully shown in the photographs of the ·303 bullet *in transitu,* made by Mr. BOYS,‡ is in great measure the source of the energetic action of the bullet on soft tissues was made by MELSENS.§ Before him, the notion that projectiles cause lateral shocks and disruptive vibration by virtue of the wave of compressed air they produce, prevailed, of course, as a long-standing tradition. It was, nevertheless, already completely disposed of by the very accurate measurements made of the displacements, caused by such waves by GROSSMAN and PELIKAN,|| who demonstrated that the air displaced laterally by a forty-pound cannon shot scarcely influenced a light registering apparatus, and had no effect on an animal even when the projectile passed quite close to its body. Moreover, from the point of view of pure physics, MORIN,¶ in the discussion on MELSENS' paper, objected that the greater density of the object penetrated by the bullet would cause such reflection of the waves of compressed air as to preclude the possibility of their assisting to break up the object fired at. In Professor BOYS' photographs the reflection of such waves from the surface of hard substances, *e.g.*, glass plate, is well seen. In our experiments the conditions were very parallel, for before the bullet entered the brain it had to traverse the hard bony wall of the skull as well as tough aponeurotic membranes. As far as the direct entry (*i.e.*, no screen

* 'Archiv für Klinische Chirurgie,' vol. 16, 1874, p. 56.

† *Loc. cit.*

‡ 'Nature,' March, 1893.

§ 'Comptes Rendus de l'Académie des Sciences,' vol. 65, 1867, pp. 564.

|| SCHMIDT'S 'Jahrbücher,' 1859 and 1869. "Note sur les plaies produites par les armes à feu." 'Journal de la Société Royale des Sciences Médicales et Naturelles,' Bruxelles, 1872, p. 53.

¶ See first reference to MELSENS, p. 568.

intervening) of bodies projected with a certain velocity into fluid is concerned, that is, of course, another matter. MAGNUS* having shown that a large quantity of air was entangled behind the projected body, and thus carried into the fluid, LAROQUE,† by a very ingenious experiment of a long falling body which would not entirely sink, found that some air was certainly driven into the fluid in front of the projectile. MORIN's objection, however, seems to us to completely nullify MELSENS' conclusions so far as the conditions of our present research might be supposed to be affected by such air. WAHL‡ believed that such air might enter a vein, and thus cause sudden death, but this belief, unsupported by any physical demonstration, must fall to the ground for the same reason as MELSENS' hypothesis.

2. *Remote Effects.*

The remoter destructive effects of the bullet are extremely important, as to them are unquestionably due the secondary occurrence of general death, when the primary source, viz., the arrest of respiration, has been successfully met by the employment of artificial breathing.

The first and most important is the entry of blood into the lateral ventricles, and its passage thence by the aqueduct of Sylvius into the fourth ventricle. In cases where this occurred the respiratory centre could not be restored into activity. It is therefore well to consider the cause of this injection, as it were, of the ventricles with blood.

In the first place it is of course essential that the integrity of the ventricle should be interrupted by the bullet. It is, however, not sufficient for the production of this fatal result that the bullet should only open the ventricular cavity. The passage of the blood downwards is due to the pressure under which blood is extravasated into the intracranial cavity. Under ordinary circumstances, as we have shown, the intracranial tension rises very markedly at the moment of shot, and continues to rise as the secondary extravasation occurs. That this rise is the cause of the blood finding its way downwards is shown by the fact that in the experiments in which the cranial vault was removed, this passage of blood to the fourth ventricle did not occur, although the lateral ventricles were opened by the bullet. Besides, in many instances of excision of portions of the hemispheres, the ventricle is freely opened without harm, both in man and the lower animals. The influence of pressure, however, in these cases may produce the fatal injection just described, as one of us has witnessed.

Relief of the intracranial tension, if prompt, will permit of this formidable danger being excluded.

* POGGENDORFF's 'Annalen der Physik und Chemie,' vol. 80, p. 1, and especially vol. 95, p. 49.

† 'Comptes Rendus de l'Académie des Sciences,' vol. 65, 1867, p. 796.

‡ 'Archiv für Klinische Chirurgie,' vol. 16, 1874, p. 533.

The second remote effect is one which if not so dangerous is as interesting. It consists in more or less extensive hemorrhage at the base of the brain, the extravasated blood filling the sub-arachnoidal space and the sheaths of the cranial nerves. We noticed early in the research that the basal extravasation was not immediately connected with the hemorrhage around the openings of the canal made by the bullet, consequently it was not due to a mere trickling of blood to the base from the vessels torn by the missile. It could therefore only be due to the direct compression at the base at the moment of shot, and produced in the manner discussed on p. 239. That this is so we established by the following experiments. The usual arrangement of the recording apparatus having been made, an abdominal opening was prepared so that, the shot having been fired, a further opening was instantly made in the diaphragm, and the arch of the aorta immediately clamped so as to arrest at a blow the encephalic hemorrhage. The skull was quickly opened and the brain removed. It showed local ecchymosis confined to the track of the bullet and well-marked basal extravasation. Hence, the latter must have been produced at the moment of shot, and in the manner we have indicated.

The sub-arachnoidal hemorrhage just described (especially if combined with intraventricular bleeding) very usually produces oozing of blood, which finds its way down the meninges of the cord, even to the level of the fourth dorsal vertebra. In passing down the cord the blood travels along each side of the ligamentum denticulatum.

Further evidence of the diffuse crushing effect of the missile is afforded by the presence of punctiform hemorrhages in the cortex of the brain, especially where the occipital lobes rest on the bony tentorium, and even where, as on the mesial surfaces of the hemisphere, the brain has been thrust against the falx cerebri. Similar hemorrhages we have observed in the pons, and in various regions of the corona radiata far from the track of the bullet. Such effects are well shown in Fig. 14. Occasionally some hemorrhage may be found in the pia mater and choroid plexus of the fourth ventricle, and this without any hemorrhage into the lumen of the ventricle.

The mechanism of the production of the intraventricular hemorrhages is probably that first described by DURET as "choc céphalo-rachidien," and which consists in the fact that the cerebro-spinal fluid (being incompressible) of necessity transmits directly to the structures of the fourth ventricle any pressure applied to it in the cerebral hemispheres. In the present instance the motion of the bullet produces a direct effect by the energy it imparts to the cerebro-spinal fluid.

CONCLUSIONS.

The following conclusions may be drawn from our experimental results :—

1. That a bullet passing through the cerebral hemispheres immediately produces a

severe elevation of the intracranial tension inducing the state commonly termed compression of the brain.

2. That the primary cause of death in such cases is due not to the failure of the heart, but to arrest of the function of the respiratory centre.

3. That the secondary cause of death is due to hemorrhage and consequently to further elevation of the intra-cranial tension.

4. That the primary cause of death can frequently be removed by the employment of artificial respiration.

5. That the physical influence of the bullet on the encephalic contents is a hydrodynamic one.

Appendix.

List of Experiments Showing the Path taken by the Bullet.

Experiment.	Bullet.	Path.
1	·38 cal.	Junction of pons and bulb; pons and cerebellum destroyed. Much bruising of upper surface of hemisphere.
2	·38 cal.	Both pre-frontal lobes destroyed. Hemorrhage at base and on 4th ventricle and substance of cerebellar cortex.
3	·38 cal.	Junction of parietal with occipital lobe, and part of cerebellum bruised and left anterior corpus quadrigeminum destroyed.
4	·38 cal.	Left temporo-sphenoidal lobe destroyed and graze of base of brain. No hemorrhage in 4th ventricle. Hemorrhage downwards below 5th cervical nerve.
5	·38 cal.	Entire mesencephalon destroyed. Right lateral lobe of cerebellum shattered. In the pons, cerebellum, and bulb numerous large hemorrhages.
6	·38 cal.	Entire base destroyed. Great laceration of left hemisphere. Bruising of the cerebellum both in its substance and on its surface.
7	·38 cal.	Base and temporo-sphenoidal lobes destroyed. Hemorrhage in membranes of 4th ventricle.
8	·38 cal.	Lower five-sixths of both frontal lobes destroyed. Much bruising of tentorial aspect of cortex. Blood in all the ventricles.
9	·38 cal.	Bullet passed under the left sigmoid gyrus, and destroyed the whole left frontal lobe and sigmoid gyrus. Ventricles free from blood.
10	·22 cal.	Graze of the base of the brain, just anterior to the commencement of the sylvian fissure and of the anterior perforated spot. Blood passed downwards beyond the 7th cervical nerve. None in the ventricle.
11	·22 cal.	Graze of base of brain, just anterior to the sylvian fissure. Both olfactory tracts were destroyed. Much bruising of the cortex at the upper end of the Sylvian fissure. Blood in all the ventricles.
12	·38 cal.	The tips of the frontal lobes and of the olfactory bulbs were destroyed. No blood in the ventricles but hemorrhage in the ependyma of the 4th ventricle.

LIST of Experiments Showing the Path taken by the Bullet—(continued).

Experiment.	Bullet.	Path.
13	·22 cal.	The right frontal lobe, and the sigmoid gyrus, and the left frontal lobe in front of the latter point were destroyed. The olfactory tracts were left. There was notable bruising of the cerebellum and no blood in the 4th ventricle.
14	·38 cal.	The bullet passed through the junction of the frontal and parietal lobes: the former were destroyed.
15	·22 cal.	The bullet track passed through the anterior limit of both occipital lobes, through the corpus callosum and the pineal gland. There was no blood in the aqueduct, but bruising of the 4th ventricle.
16	·22 cal.	The frontal lobes were traversed by the bullet.
17	Saloon pistol, ·22	The bullet passed through the surface of the frontal lobe of the left side only. There was no blood nor bruising.
18	Saloon pistol, ·22	The bullet passed through the parietal lobe just anterior to the Sylvian fissure, *i.e.*, and just below the floor of the lateral ventricle on both sides.
19	Saloon pistol, ·22	The bullet passed through both hemispheres immediately in front of the crucial sulcus, through the coronal sulcus and the corpus callosum.
21	Saloon pistol, ·22	The bullet passed through the parietal portion of the hemisphere just anterior to the plane of the external auditory meatus, *i.e.*, exactly through the upper end of the Sylvian fissure. There was much hemorrhage at the base, and none in the ventricles.
22	Saloon pistol, ·22	The olfactory lobes and tracts were destroyed. There was hemorrhage around the cord, and slight bruising in the 4th ventricle.
23	Saloon pistol, ·22	The aperture of entry was opposite the left crucial sulcus: the aperture of exit was 1·5 centims. behind the Sylvian fissure. The track of the bullet was immediately above the corpus callosum.
24	Saloon pistol, ·22	The bullet passed through the brain just below the outer extremity of the crucial sulcus, through the coronal sulcus, through both hemispheres obliquely forward, and so through the corona radiata, just in front of the ventricles. There was much hemorrhage at the base.
25	Saloon pistol, ·22	The bullet passed both parietal lobes, entering on the left side, just in front of the upper end of the Sylvian fissure. The exit was through the upper border of the coronal gyrus in the plane of the crucial sulcus. There was a minute bruise on the left side of the 4th ventricle. There was no blood in the 4th ventricle, but some in the lateral ventricle.
26	Saloon pistol, ·22	A grooving shot through the centre of the upper fifth of both hemispheres, far above the corpus callosum. There was no blood in the ventricle, but bruising in the lateral lobe of the cerebellum and 4th ventricle, especially on the right side.
27	Saloon pistol, ·22	The left cortex was grooved along the pre-crucial gyrus, and the right post-crucial gyrus was just grazed. There was slight symmetrical bruising in the lateral lobe of the cerebellum and none in the ventricles. There was blood in the meninges on the side of the left hemisphere but none at the base.
28	Saloon pistol, ·22	The bullet entered the left hemisphere just at the outer end of the crucial sulcus, passing out anteriorly and inferiorly to the sigmoid gyrus on the right side, through the prorean sulcus. There was slight hemorrhage round the medulla, and under and around the cerebellum and mesencephalon, none in the 4th ventricle, and very slight at the base.

List of Experiments Showing the Path taken by the Bullet—(continued).

Experiment.	Bullet.	Path.
30	Saloon pistol, ·22	The bullet passed through the olfactory lobe. There was much hemorrhage at the base of the pons, and posteriorly over the right occipital lobe and the surface of the cerebellum. There was none in the ventricle, though great hemorrhage round the medulla.
31	Saloon pistol, ·22	The entry was just in front of the Sylvian fissure. The corpus callosum was traversed. There was no blood in the aqueduct but great hemorrhage round the medulla.
32	Saloon pistol, ·22	The bullet passed through the olfactory lobes. There was scarcely any bruising externally, except slight along the optic tracts, elsewhere there was none.
33	Saloon pistol, ·22	The bullet passed through the hemispheres in the plane of the Sylvian fissure. There was much bruising of the vertex of the left hemisphere, but little of the right. There was no hemorrhage in the ventricles, but they were all bruised, while there was slight basal hemorrhage.
34	Saloon pistol, ·22	The passage of the bullet was through the parietal lobes, just in front of the left Sylvian fissure, and through the upper end of the right Sylvian fissure. There was much basilar hemorrhage in the arachnoid and round the bulb. There was no hemorrhage in the posterior cornu of the lateral ventricle, but great bruising and hemorrhage of the fissure of Bichat, and in the lower half of the 4th ventricle. There were also hemorrhages in the lateral lobe of the cerebellum.
35	Saloon pistol, ·22	The bullet entered at the outer extremity of the left crucial sulcus, and passed diagonally through the brain, leaving the hemispheres through the temporal lobe. There was notable bruising but no hemorrhage in the 4th ventricle, and there was but slight basilar hemorrhage.
36	Saloon pistol, ·22	The bullet passed through both olfactory tracts and tips of the frontal lobes. The ventricles were free from blood, but there was slight bruising throughout the left hemisphere, though none in the right.
38	Saloon pistol, ·22	The bullet passed through the fronto-temporal suture, *i.e.*, just in front of the Sylvian fissure, through the right Sylvian fissure. There was hemorrhage at the exit in the meninges, and hemorrhage and bruising in the lateral ventricle.
39	Saloon pistol, ·22	The first shot caused a slightly depressed fracture of the coronal suture, with slight bruising of the brain beneath. The second bullet traversed the left occipital lobe, the corpora quadrigemina, and the fissure of Bichat.
40	Saloon pistol, ·22	The bullet entered the coronal sulcus just below the post-crucial gyrus. Bruising present in the 4th ventricle, but no hemorrhage, although much had occurred at the base of the bulb.
41	Saloon pistol, ·22	The bullet entered just below and behind the left crucial sulcus, between it and the upper end of the Sylvian fissure, and passed through the brain by an exit through the right temporal lobe just below and behind the Sylvian fissure. There was slight hemorrhage at the base of the left side and notable bruising, but no hemorrhage in the 4th ventricle.
42	Saloon pistol, ·22	The bullet passed through the brain just behind the sigmoid gyrus, and on a level with the corpus callosum. There was much bruising in the left lateral ventricle and well marked in the 4th ventricle. There was moderate hemorrhage at the base.
43	Saloon pistol, ·22	The bullet just penetrated the dura, bruising the brain immediately in front of the crucial sulcus, the bone being driven into the hemisphere. There was no other lesion.

List of Experiments Showing the Path taken by the Bullet—(continued).

Experiment.	Bullet.	Path.
44	Saloon pistol, ·22	The bullet passed through both hemispheres just below and behind the sigmoid gyrus, opening both lateral ventricles. Much general bruising of the vertices, moderate bruising at the base, and bruising of the left half of the aqueduct and of the passage of the 4th ventricle.
45	Saloon pistol, ·22	The bullet entered the left hemisphere just below and posterior to the left sigmoid gyrus, cutting the corpus callosum.
46	Saloon pistol, ·22	The bullet entered just through the foot of the pre-central gyrus, and passed downwards with an exit through the right Sylvian fissure. There was moderate hemorrhage at the base, but not in the 4th ventricle, nor in the longitudinal fissure.
47	Saloon pistol, ·22	The first shot did not penetrate, and only caused a small very superficial bruise, 1 centim. below the outer margin of the left gyrus. The second shot passed through the hemispheres on a level with the upper end of the left Sylvian fissure, and the lower end of the right Sylvian fissure. There was bruising and hemorrhage of both ventricles. Very slight bruising of the 4th ventricle, and moderate hemorrhage on the left side of the base.
48	Saloon pistol, ·22	The bullet penetrated the base of the brain close to the optic chiasma. There was no hemorrhage in the rest of the base and only slight bruising of the 4th ventricle.
49	Saloon pistol, ·22	The bullet perforated both hemispheres through the posterior angle of the sigmoid gyrus. The brain was large and there was no effect in the ventricle or the base.
50	Saloon pistol, ·22	The bullet entered the left hemisphere through the cornu sulcus, opposite the crucial sulcus, through the top of the right Sylvian fissure 1 centim. below the point of entry. There was moderate hemorrhage at the base chiefly on the left side. Nothing in the 4th ventricle.
51	Saloon pistol, ·22	The bullet passed through the hemisphere immediately between the sigmoid gyrus and the top of the Sylvian fissure passing above the corpus callosum. There was moderate hemorrhage under the bulb.
52	Saloon pistol, ·22	The bullet passed through the left occipital lobe just behind the upper end of the Sylvian fissure. It left by the fissure of Bichat, grooving the right occipital lobe. There was slight hemorrhage at the base.
53	Saloon pistol, ·22	Both anterior lobes totally destroyed.
54	Saloon pistol, ·22	Both occipital tracts and bulbs destroyed. Much hemorrhage and laceration at the base. Much bruising in the 4th ventricle and lateral ventricle, but not hemorrhage.
59	Saloon pistol, ·22	The bullet entered between the sigmoid gyrus and the upper end of the Sylvian fissure and traversed both hemispheres, causing some bruising of the 4th ventricle and hemorrhage and bruising of the lateral ventricles.
60	Saloon pistol, ·22	The bullet traversed both Sylvian fissures. There was much hemorrhage at the base and round the medulla. There was also much bruising in the ventricle, and hemorrhage only in the track.
61	Saloon pistol, ·22	The bullet was found lying on the velum just behind the foramen of Munro. There was no hemorrhage in the ventricles but some slight bruising.
62	Saloon pistol, ·22	The bullet passed through both hemispheres just behind the top of the Sylvian fissure. There was slight hemorrhage at the base and much bruising in the ventricles but no hemorrhage.

List of Experiments Showing the Path taken by the Bullet—(continued).

Experiment.	Bullet.	Path.
63	Saloon pistol, ·22	The bullet passed through the left cerebral hemisphere, just in front of the upper end of the Sylvian fissure and out just behind the upper end of the same. There was slight hemorrhage at the base, also much bruising in the lateral ventricles, especially the left, and very slight hemorrhage in the 4th ventricle.
64	Saloon pistol, ·22	The first shot penetrated both marginal gyri. In the second shot the bullet passed through a point 2 centims. below the former.
65	Saloon pistol, ·22	Cortex of right hemisphere completely destroyed.
66	Saloon pistol, ·22	The skull was opened. The bullet entered through the left occipital lobe, and passed diagonally downwards through the cerebellum.
67	Saloon pistol, ·22	The skull was opened. The first shot passed through the frontal bone and lobe. The second shot passed through the exposed occipital lobe, and the third shot through the 4th ventricle.

Description of Plate 3.

Fig. 1. Ammunition employed; actual size.

Fig. 2. Photo. of brain (Experiment 2). The bullet traversed the præfrontal region, but nevertheless caused extensive bruising of the tentorial surface of the occipito-temporal region of both hemispheres, of the cerebellar hemispheres, and in the membranes of the 4th ventricle.

Fig. 3. Photo. of preparation showing longitudinal expulsion of brain through an opening in the skull by bullet passing at right angles to longitudinal axis of cranial cavity. *a*, aperture of entry of bullet; *b*, thick edge of opening in bone; *c*, finger-like portion of occipital lobe forced 1·8 centim. out of the opening (which in this case was 1 centim. in diameter).

Fig. 4. Example of Kocher's experiment.

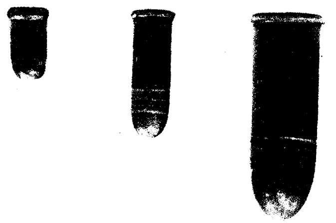


Fig. 1.

Fig 2.

Fig. 3.

Fig. 4.

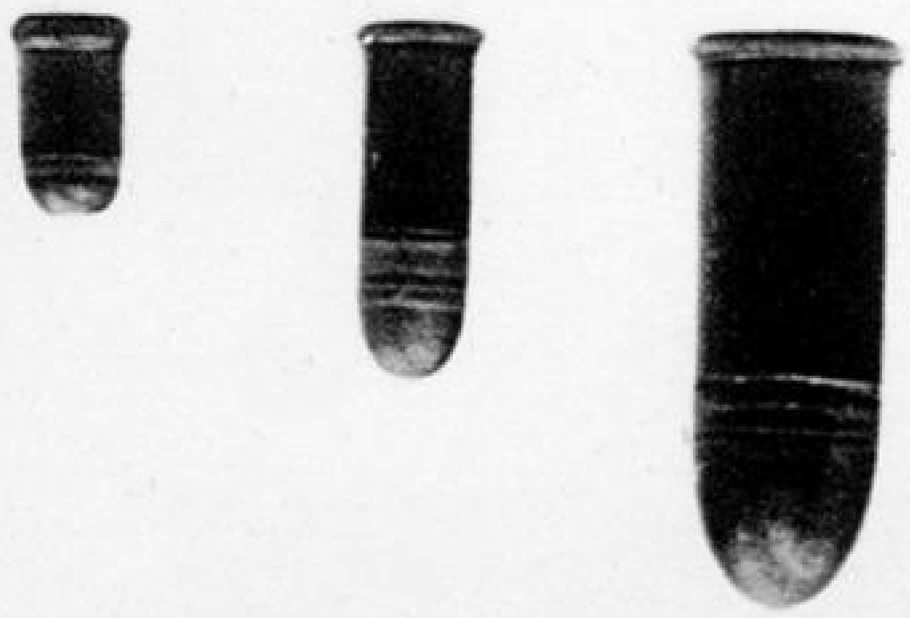
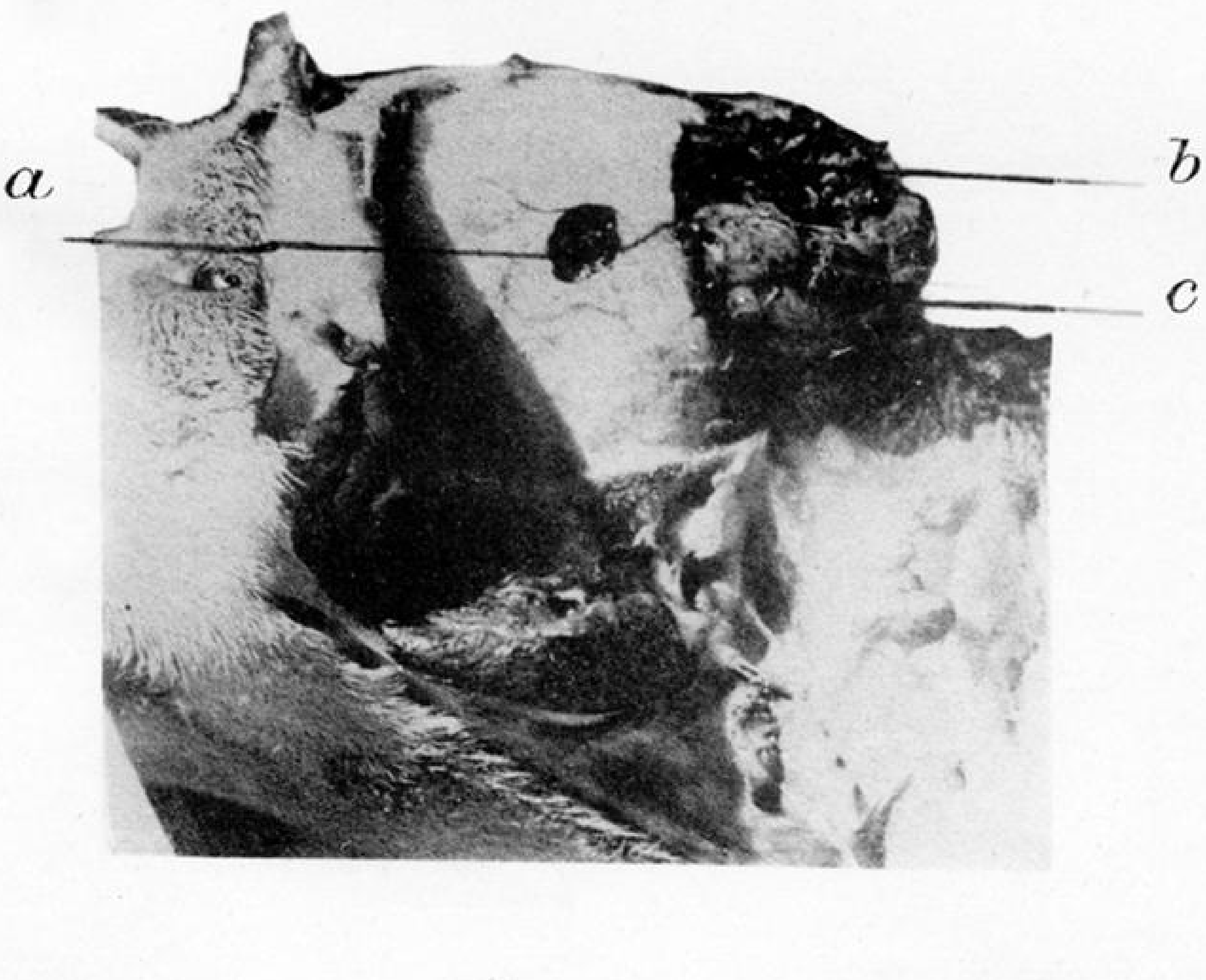


Fig. 1.

Fig 2.



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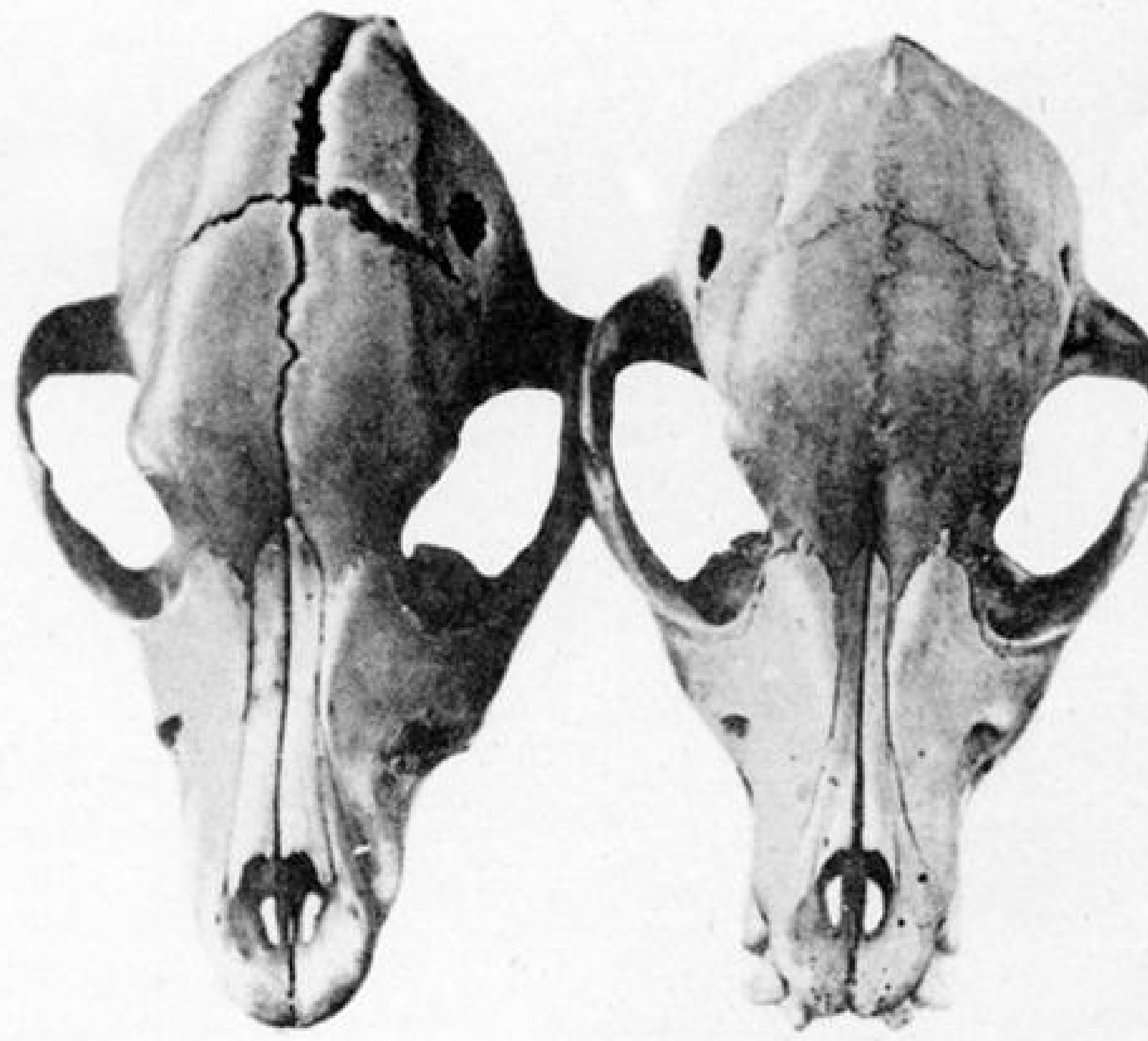

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