PRESSURE CHANGES IN THE CEREBRO-SPINAL FLUID FOLLOWING INTRAVENOUS INJECTION OF SOLUTIONS OF VARIOUS CONCENTRATIONS

LEWIS H. WEED, Capt., Med. Corps

AND

PAUL S. MCKIBBEN, 1st Lt., San. Corps

From The Army Neuro-Surgical Laboratory, Johns Hopkins Medical School, Baltimore, Maryland

Received for publication March 22, 1919

In an attempt to determine whether, following intravenous injection of hypertonic solutions of sodium chloride, an increased amount of this salt could be detected in the cerebro-spinal fluid, it was noted that within a short time after the intravenous injection, cerebro-spinal fluid could not be obtained when the subarachnoid space was entered. This observation led at once to the attachment of a manometer to the puncture needle for the purpose of making continuous readings of the cerebro-spinal fluid pressure following the intravenous injection of hypertonic solutions of sodium chloride. It was soon found that the pressure of the cerebro-spinal fluid could be altered very rapidly and very definitely by intravenous injections of solutions of various concentrations.

METHOD

Cats were used entirely in these experiments and the subarachnoid space was entered by puncture with a needle through the occipito-atlantoid ligament. All animals were placed, lying on their sides, on a level board and kept thus throughout the pressure observations. As soon as a puncture was made a glass manometer was connected with the puncture needle by means of a metal elbow. For observations where previous experience made it certain that the pressure would remain above zero, a straight manometer was used, but for observations involving pressures below zero a U-shaped manometer, filled to zero with Ringer's solution, was connected with the puncture needle. The manometer was held in the vertical position throughout the exper-
CEREBRO-SPINAL FLUID PRESSURE

iment by a burette clamp. As soon as the manometer was attached, direct readings were begun and continued every half-minute for eighty or more minutes. Each reading was recorded as made and curves plotted at the end of each experiment. Our experience has shown that any manipulation of the puncture needle and of the manometer should be avoided if possible. After a good entry of the subarachnoid space uniform conditions are thus assured throughout the period of the experimentation. Sixteen to eighteen gauge puncture needles and manometers with a bore of 1 to 1.5 mm. were used in these observations.

Ether was chosen as the anesthetic largely because experience showed that the concentration of the anesthetic had to be regulated in accordance with the solution injected. It was necessary in many cases to diminish the amount administered for some minutes to avoid death of the animal, particularly when the initial injection was given too rapidly. Although with a non-volatile anesthetic a more even narcosis might be assumed, the disadvantages of this method were found to outweigh its advantages. In the early experiments ether was given by cone but in later observations a very even and satisfactory anesthesia was carried out by the well-known method of intratracheal insufflation. In many of the routine experiments a constant adjustment of the air and ether volume by this method was maintained throughout.

Variation in the temperature of the animals during these long observations under ether was found to affect the general condition of the animal and consequently the pressure of the cerebro-spinal fluid, so that an attempt was made to maintain the body temperature of the animals during the experiments by means of suitably adjusted electric lamps.

Injections of the solutions of different concentrations were all made intravenously. In the early experiments the injections were made with a syringe but owing to the difficulty of control the later injections were all given from a burette connected by rubber tubing with a venous cannula.

NORMAL PRESSURES

A number of readings of the normal pressure of the cerebro-spinal fluid were made in cats under ether anesthesia. At first these readings were isolated observations and as soon as the fluid in the manometer reached a fairly constant level, the record was made. Such observations were made on twenty cats, under routine experimental conditions
and an average pressure of 119 mm. of cerebro-spinal fluid was obtained. The maximal recorded pressure was 155 mm. and the minimal 90 mm.

But these observations were all made on animals which were immediately thereafter used for other purposes. The method of recording the pressure was imperfect in that a considerable dislocation of the cerebro-spinal fluid occurred; this dislocated fluid was required to fill the manometer to the initial level. Likewise the ether was administered by cone, a method which gave varying concentrations of the anesthetic. It was felt that the true pressure of the fluid could only be obtained after sufficient time had elapsed to permit any compensation for the dislocated fluid. In addition, in connection of the manometer to the needle, some fluid was very frequently lost; this loss gave a lower initial reading and necessitated further replacement. Hence experiments were undertaken, with the anesthetic administered by the intratracheal method, extending over a sufficient period of time to permit all physiological compensation for displacement and loss of fluid. For the most part such compensation was accomplished within the first fifteen minutes, as shown by the subsequent records.

In our observations the excursions of the column of cerebro-spinal fluid in the manometer, due to inspiration and expiration, were influenced by the method of anesthesia. With the administration of ether through the intratracheal tube the character and extent of the respiratory movements are altered. With an intratracheal tube of the proper size, sufficient space is left in the trachea and larynx to allow a free return to the exterior. Asphyxia seems to be wholly avoided by the proper regulation of the intratracheal blast. The respiratory movements may be controlled by the volume of the blast; in these experiments it was planned to maintain sufficient movement in inspiration and expiration to give to the column of fluid in the manometer connected with the subarachnoid space, well-marked excursions. Under these conditions these excursions varied from 1 mm. to 0 mm., usually being about 4 mm. in amplitude. These excursions were measured from the low point reached in inspiration to the high point reached in expiration. Pressure on the thorax in our experiments caused a rise of several centimeters in the fluid column in the manometer. Along with the respiratory excursions just noted, there also occur in the fluid column, pulsations due to the heart-beat. In our experiments these pulsations varied from 0.5 mm. to 2 mm. under certain conditions. The usual amplitude of these cardiac pulsations was 1 mm.
Under experimental conditions assuring constant anesthesia and constant body temperature, a number of continuous readings of the pressure of the cerebro-spinal fluid were made over a period of eighty minutes. Figure 1 is a composite constructed from seven such observations and shows the maintenance of a very uniform pressure throughout, though with a slight rise in the readings during the first fifty minutes.

![Composite curve showing normal pressure of cerebro-spinal fluid. Composite made from seven individual curves.](image_url)

Figure 2 shows a curve of normal pressure of a single cat. It will be noted that in the first five minutes of the observation there is a considerable rise in the pressure. This is quite characteristic in many of our observations and may be accounted for by two factors. First, following the release of the cerebro-spinal fluid by the puncture, dislocation of some of the fluid to fill the manometer was inevitable; second, in the connection of the manometer with the puncture needle the loss of at least one drop of cerebro-spinal fluid occurred in this observation. This initial rise then probably represents, partially at least, the restoration of the fluid displaced and lost in the connection of the manometer. The rise in the curve is unusually abrupt and the compensation seems complete as indicated by the maintenance for the remainder of the experiment (70 minutes) of a uniform pressure. Dur-
ing this observation, when the pressure readings were constantly at the same level, the respiratory excursions in the column of fluid in the manometer were 3 mm. and the arterial variations 0.5 to 2 mm. The uniformity of the pressure readings indicates that under the experimental conditions prevailing, reliable data were obtained.

In figure 1, the composite record of seven observations, it is indicated that the pressure of the cerebro-spinal fluid in the etherized cat was from 135 to 145 mm., with the rise occurring largely in the early part of the curve. Comparable values for the pressure of the cerebro-spinal fluid were obtained from many other cats, both as initial readings and as values of the pressure after the completion of the initial rise. In this series of sixty-five cats, which includes the twenty already mentioned, the initial pressure averaged 119 mm. of cerebro-spinal fluid; the subsequent pressure (after early compensation had occurred), as based on twenty-one animals, averaged 129 mm. of cerebro-spinal fluid. The interesting relationship of the lower value of the initial reading to the later more constant pressure is thereby indicated.

Analysis of the initial pressures of the cerebro-spinal fluid in these sixty-five cases shows that in only eight cats was the reading less than 100 mm. In several of these a loss of three or more drops of fluid, in connecting the manometer, was noted; one animal was obviously in poor
physical condition at the time of experimentation. Others of these eight cats had been subjected to previous experimental procedure in the laboratory. Thirty-six of the sixty-five cats gave initial readings between 100 and 120 mm., with an average of 110 mm., while seven cats fell between 120 and 140 mm. with an average of 131 mm. Fourteen cats showed an initial pressure of over 140 mm. with an average of 153 mm. Five of the fourteen had been previously used for experiments leading to the possible production of a chronic meningitis. In none of these fourteen was the fluid loss in the connection of the manometer more than one drop. Further, the cats which had not been subjected to previous experimentation gave the lower values in this series of fourteen.

The increased elaboration of the cerebro-spinal fluid under the influence of the volatile anesthetics (ether, chloroform) has been noted many times since Cappelletti (1) first described this phenomenon. Pettit and Girard (2), and later Dandy and Blackfan (3) and Dixon and Halliburton (4) have emphasized its importance. All the observations have dealt with an increased production of fluid as determined by the rate of flow from a needle or cannula in the subarachnoid space, the pressure of the cerebro-spinal fluid being determined by the capillary resistance to flow in the cannula. Although no attempt has been made in these experiments to study extensively the effects of variations in the concentration of the anesthetic on the pressure of the cerebro-spinal fluid, some data relating to the pressure of the fluid under these conditions have been obtained.

In our earlier observations, where ether was given by cone, it soon became apparent that variations in the concentration of the ether were sufficient to cause changes of appreciable magnitude in the pressure of the cerebro-spinal fluid as read in the manometer. Analysis of such experiments where there were changes in the pressure of the cerebro-spinal fluid due to variations in the ether supply, shows that the pressure will vary from 5 to 20 mm. with slight changes in the anesthetic during its routine administration by cone. Other, greater changes in the pressure have occurred in animals which were brought rather quickly from very light to full anesthesia or vice versa. Associated with the possible increase in the production of cerebro-spinal fluid due to the ether are other equally significant vascular readjustments; the combination of the two factors within the cranium determines the resulting pressure change in the spinal fluid. Similarly, exhaustion of the secreting cells of the choroid plexus by the anesthesia may present
an additional element which in the latter parts of the observation causes further alterations in the fluid pressure.

Such considerations lead to the view that the pressures recorded as normal in foregoing paragraphs are only relatively and not absolutely accurate. For the values are influenced by the displacement of fluid in the manometer, by loss of fluid in connecting the apparatus and by the anesthesia. The alterations in pressure referable to the anesthetic and associated asphyxia have been controlled throughout so that these factors are constant in all of our observations. Partial or complete compensation for dislocation or loss of fluid is quite uniform and occurs largely during the first few minutes of experimentation. Such relatively constant records of the pressure of the spinal fluid give a reasonable basis upon which further experimental data may be interpreted.

**RINGER’S SOLUTION**

Following the above observations in which the normal pressure has been plotted over periods of eighty minutes, the effects of various quantities of Ringer’s solution, injected intravenously, were considered. The formula for the Ringer’s solution used is as follows: NaCl, 0.9 per cent; KCl, 0.042 per cent; CaCl2, 0.025 per cent. In the experiments in which a relatively small amount of the solution (12 to 20 cc.) was injected, the curve showing the pressure of the cerebro-spinal fluid rises during the injection but falls on its completion to the level prevailing at the beginning of the experiment. This pressure is then maintained during the remainder of the observation. Such curves simulate very closely the normal except for the temporary rise during the injection. This initial rise is most marked when the intravenous injection is given very rapidly and with considerable pressure. It seemed apparent then that after the injection of small amounts of Ringer’s solution physiological readjustment of the volume of the blood took place very rapidly so that the pressure of the cerebro-spinal fluid was not essentially affected.

Other experiments were performed in which a large quantity (100 cc.) of Ringer’s solution was introduced intravenously in order to furnish control for observations (to be described later) in which 100 cc. of water were injected, and to determine if possible the effect on the pressure of the cerebro-spinal fluid of the intravenous introduction of this enormous volume of a solution isotonic with the blood. Figure 3 shows a record of the pressure of the cerebro-spinal fluid in such an
experiment. In this case the injection was made from a burette connected with a cannula in a fore-leg vein and lasted for twenty-six minutes, being given then at a rate of 3.85 cc. per minute. During the injection of the first 33 cc. the rate was rapid (6.6 cc. per minute); and for the next 17 cc. the rate was 4.25 cc. per minute. Reference to figure 3, in which the rapidity of the injection is indicated on the base line showing the period of injection, reveals the fact that when the rate of introduction of the fluid was high, at the beginning of the injection, the pressure of the cerebro-spinal fluid rose more abruptly and more rapidly than when the rate was decreased. The mechanical effect of a difference in the rate of intravenous injection, on the pressure of the cerebro-spinal fluid, is thus indicated. A further matter of interest brought out by our observation during the injection period in this experiment, is that the impact of the injection seems to have an effect on the pressure of the cerebro-spinal fluid which is independent of the effect produced by rapid injection. This has been noted in many of our experiments. During the latter part of the period of injection the rate was low and it can be seen from figure 3 that the pressure of the cerebro-spinal fluid had already begun to fall. This decrease in pressure continued gradually and uniformly during the remainder of the observation, the fall gradually becoming less rapid. Within thirty minutes after the completion of the injection the pressure had dropped to 138 mm., a point probably well within the normal pressure variation in this animal. During the last thirty minutes of the experiment the pressure, which was falling very gradually, was practically the same as that noted before the injection of the Ringer's solution.
It is apparent from the foregoing observation that the intravenous injection of a relatively large volume of fluid isotonic with the blood, although it increases the pressure of the cerebro-spinal fluid during the period of injection, does not bring about any material and lasting change in this pressure. The physiological adjustment to such a large volume is, however, a process requiring more time than is necessitated by the intravenous injection of smaller volumes. No ill-effects of this procedure are apparent in animals allowed to recover from the anesthetic.

HYPOTONIC SOLUTIONS

With the establishment of a curve of normal pressure of the cerebrospinal fluid under the experimental conditions adopted, intravenous injections of distilled water were given. A prompt and enduring rise in the pressure of the cerebro-spinal fluid was recorded in every instance, even after the introduction of relatively small volumes. The animals showed no respiratory or cardiac difficulties during or after the injection of this hypotonic solution; recovery from ether at the end of the experiment was prompt and no after-effects were observed.

Such a marked and enduring rise in the pressure of the cerebro-spinal fluid is shown in figure 4, following an intravenous injection of 20 cc. of distilled water. An abrupt rise in pressure during the period of injection is recorded; as soon as the injection was stopped a slight fall occurred, giving an obtuse peak in the curve. Within five minutes after the end of the injection the pressure of the fluid had again started to rise and this upward tendency was maintained throughout the period of observation.

An increase in the pressure of the cerebro-spinal fluid is the typical response to the intravenous injection of a hypotonic solution (distilled water). The initial peak in the curve during the injection seems to be partially at least a mechanical effect due to the rapid introduction of fluid into the venous system. It may be lessened or avoided by the very slow injection of the foreign solution, indicating that the resultant persisting change in the pressure of the cerebro-spinal fluid is not an immediate phenomenon but requires a varying interval of time for its fulfilment. This interpretation is supported by the curves in figures 4 and 5; in both of these animals, especially in the one receiving the smaller dose, the effect of the hypotonic solution is continued and is at its maximum at the end of the observation. That in the intravenous injection of even a large amount of distilled water, the initial
peak in the pressure curve may be avoided by giving the injection uniformly and gradually over a considerable period of time (26 minutes), is shown by figure 5. This curve may be compared

Fig. 4. Cat no. 1303. Pressure cerebro-spinal fluid with intravenous injection of 20 cc. sterile distilled water.

Fig. 5. Cat no. 1498. Pressure cerebro-spinal fluid with intravenous injection of 100 cc. sterile distilled water.
directly with figure 3, which represents the pressure of the cerebrospinal fluid after the intravenous injection of a similar amount of Ringer's solution. In figure 5 the rise in pressure begins abruptly, is maintained throughout the period of introduction of fluid and continues even after its completion. In this experiment the long period of injection may have sufficed to include within it the time necessary for the readjustment of pressure relations, so that any fall after the initial injection was avoided. In the early part of the curve, before the injection of water, is a fall due to ether; but the pressure was constant at 130 mm. before the injection was begun. In this experiment, as seen from figure 5, there is recorded a rise in the pressure of the cerebrospinal fluid from 130 to 285 mm. of this fluid.

These observations show definitely that the intravenous injection of a hypotonic solution (distilled water) causes a prompt and enduring rise in the pressure of the cerebrospinal fluid. The animals, subjected to such injections and allowed to recover from the ether, promptly become normal.

HYPERTONIC SOLUTIONS

Many experiments dealing with the effect of the intravenous injection of concentrated solutions of the common sodium salts (chloride, bicarbonate and sulphate) upon the pressure of the cerebro-spinal fluid have been carried on. In general, this procedure results in a temporary rise in the pressure of the fluid followed by a marked and enduring fall.

Sodium chloride. With sodium chloride in 30 per cent concentration, striking results have been obtained, with continuous readings of the pressure of the cerebro-spinal fluid during a period of eighty minutes. All curves plotted from data arising from these experiments show an abrupt initial rise in the pressure of the fluid, usually from 50 to 75 mm. This continues throughout the period of intravenous injection though it frequently forms a plateau in the curve in the latter part of the process. As soon as the injection is completed, the pressure of the cerebro-spinal fluid starts to fall and a rapid lowering is recorded during the next few minutes. The rate of fall then decreases shortly before the pressure reaches its lowest point. The maximum effect of the intravenous injection, i.e., the point of lowest pressure, is usually noted in from fifteen to twenty minutes after the completion of the injection.

Figure 6 shows the effect of a single intravenous injection of 12 cc. of a 30 per cent solution of sodium chloride upon the pressure of the
cerebro-spinal fluid. An initial rise of 80 mm. during the period of injection is recorded; following this a rapid and extreme lowering of the pressure occurred, the rate of fall decreasing only when the pressure went to below zero. The minimal pressure of the cerebro-spinal fluid recorded was minus 22 mm., a point reached eighteen minutes after the completion of the injection. The pressure then remained below zero for a period of twenty-six minutes. Subsequently it rose slowly to a pressure of 40 mm. above zero, which was reached at the end of the observation.

Fig. 6. Cat no. 1271. Pressure cerebro-spinal fluid with intravenous injection of 12 cc. 30 per cent sodium chloride.

It must not be assumed that the intravenous injection of concentrated solutions of sodium chloride inevitably brings about a lowering of the pressure of cerebro-spinal fluid to below zero. With various intravenous doses of this salt, roughly half of our experiments gave readings below zero. The maximum effect was obtained in one cat by repeated intravenous injections (total 22 cc.) of 30 per cent sodium chloride, when the pressure of the cerebro-spinal fluid was recorded as minus 55 mm.

In many other observations, the result of such injections of sodium chloride was a marked lowering of the pressure of the cerebro-spinal fluid (50 mm.) and the maintenance of this lowered pressure through-
out the period of record. This seems to be the phenomenon of chief physiological importance—a reduction of the pressure to a lower level. A curve showing the result of an experiment of this nature is given in figure 7. In this case the pressure dropped abruptly for a period of ten minutes after the intravenous injection; this lowered pressure was maintained with minimal change for at least forty minutes.

Sodium bicarbonate. Of the six cats given intravenous injections of saturated solutions of sodium bicarbonate (about 18 per cent), only one showed a lowering of the pressure of the cerebro-spinal fluid to below zero. This animal was given an intravenous injection of 10 cc. of the saturated solution. During the first part of the injection the

![Graph](image_url)

*Fig. 7. Cat no. 1305. Pressure cerebro-spinal fluid with intravenous injection of 10 cc. 30 per cent sodium chloride.*

pressure of the cerebro-spinal fluid rose 40 mm. but before the completion of the injection a rapid fall had begun. This break in the initial rise before the completion of injection is recorded in most of the curves with this salt. The marked fall continued abruptly in this case to 12 mm. below zero, a point reached in sixteen minutes after the end of the injection. This pressure remained at zero or below for a period of forty minutes and then slowly started upwards. This curve is reproduced in figure 8.
The more common response in the pressure of the cerebro-spinal fluid to intravenous injection of sodium bicarbonate is merely a lowering of 40 to 70 mm. The curves show typical peaks with breaks before

**Fig. 8.** Cat no. 1364. Pressure cerebro-spinal fluid with intravenous injection of 10 cc. saturated solution of sodium bicarbonate.

**Fig. 9.** Cat no. 1365. Pressure cerebro-spinal fluid with intravenous injection of 18 cc. saturated solution of sodium bicarbonate.
the completion of the injections. One of these typical curves with a lowering of the pressure of the cerebro-spinal fluid of approximately 40 mm. is given in figure 9. The injection in this case was 18 cc. of the saturated solution of the bicarbonate; the difference in reaction to a smaller dose in another animal is shown by comparison with figure 8. At the end of the period of observation some recovery toward the normal pressure is shown in figure 9.

Sodium sulphate. Four experiments with the intravenous injection of a 30 per cent solution of sodium sulphate were carried out. In all of these observations a reduction of pressure of the cerebro-spinal fluid was recorded, the fall being usually 50 to 80 mm. A typical initial rise in the pressure during the period of injection with formation of a peak is shown by all the curves, one of which is reproduced in figure 10. In this case an injection of 10 cc. of the 30 per cent solution of sodium sulphate was given; this gave an abrupt initial rise of 80 mm. which was promptly followed by a rapid fall to a point about 90 mm. below the pressure at the beginning of the experiment. Subsequently a low pressure (about 70 mm.) was maintained for thirty minutes with a gradual rise but incomplete recovery in pressure. Such a curve is typical of the series; none have shown pressures below zero.

![Fig. 10. Cat no. 1336. Pressure cerebro-spinal fluid with intravenous injection of 10 cc. 30 per cent sodium sulphate.](http://ajplegacy.physiology.org/Downloadedfrom)
Glucose. The observations in the foregoing paragraphs of this section have all been concerned with the lowering of the pressure of the cerebro-spinal fluid by the intravenous injection of concentrated solutions of electrolytes (common sodium salts). In an attempt to determine whether all crystalloids possess this power of bringing about a lowering of the pressure of the cerebro-spinal fluid, four experiments were undertaken in which intravenous injections of a concentrated solution of glucose were given. Large amounts of a 30 per cent solution were given and typical responses were obtained. The curves all show a marked abrupt initial rise followed quickly by a fall to a level lower than that prevailing at the beginning of the experiment. This lowering was not as marked as with the electrolytes but in two of the experiments the resultant level was 60 mm. below the initial pressure.

Toxicity and dosage of the sodium salts. It was early noticed that the intravenous injection of the concentrated solutions of sodium chloride was followed by severe respiratory and cardiac disturbances. It was often necessary to alter the anesthetic to avoid losing the animal. The ether was in these cases reduced and artificial respiration used, the intratracheal method of anesthesia making possible a nearly ideal artificial respiration. This toxicity of the sodium chloride was apparently not dependent upon the absolute amount injected but was frequently observed in the earliest intervals of the injection when only 1 to 2 cc. had been introduced. As soon as this initial toxicity was passed, further injection up to certain limits could be made with comparative safety in the same animal. Such early disturbances seem best explained on the basis of an alteration in the balance of the mineral salts in the blood.

In addition to the initial toxicity of the sodium chloride, another factor of importance in these experiments was variation in the tolerance of the individual animal. Some animals, showing no apparent disturbance on receiving relatively large intravenous injections, have given marked reactions in the pressure of the cerebro-spinal fluid following such injections. Other animals under similar conditions have exhibited but little reaction as indicated by a lowering of the pressure of the cerebro-spinal fluid. In still other animals where the toxic effects of the salt were marked, the lowering of the pressure of the cerebro-spinal fluid was definite and considerable. Thus an individual tolerance and reaction for each particular animal seems indicated, a tolerance and reaction which we have not been able to predict in our experiments.
Quite similar to these experiences with intravenous injections of sodium chloride were our findings with the bicarbonate and sulphate. It has already been pointed out that in one case the injection of 10 cc. of the saturated bicarbonate gave a far greater fall in the pressure of the cerebro-spinal fluid than an injection of 18 cc. of the same salt in another animal (cf. figs. 8 and 9). Such individual variations are common also with the sulphate, although the final toxicity of the salt used in our experiments seems much greater. Few animals have shown any disturbance during the injection of the sulphate solution but several have died, apparently from the toxic effect of the salt, before the completion of the observation.

Following the intravenous injection of these concentrated salts, then, the character of the resultant curve, as indicating the extent of the reaction producing the lowering of the pressure of the cerebro-spinal fluid, must be referred partially at least to the individual tolerance and reaction of the animal used in the experiment. The definite and marked lowering of the pressure by the intravenous injection of concentrated solutions of electrolytes is shown in all the curves, but the degree of reaction seems dependent, to some extent at least, on the individual animal. All of these animals, if allowed to recover from the ether, seem slow and quiet for a few hours; within twelve hours they become normal in every way.

DISCUSSION

In a foregoing part of this paper the results of the reading of the pressure of the cerebro-spinal fluid in sixty-five cats have been set forth. The average of the initial readings in these cases was 119 mm. but it was pointed out that if readings were taken a few minutes later, a higher value (129 mm.) was obtained. This higher value, as has already been indicated, is probably to be accounted for by replacement of fluid which follows the dislocation and loss due to the mechanical arrangement of the experiments. It seems reasonable to assume then, that, after sufficient time has elapsed to allow replacement of fluid which occurs after the puncture and connection of the manometer, we are dealing with a pressure of the cerebro-spinal fluid which is truer normal than would be obtained by readings taken immediately after puncture.

There are available in the literature records of observations on the pressure of the cerebro-spinal fluid which have been made on dogs.
under various anesthetics and by various methods. So far as is known to us, no observations of this sort have been made on cats. In general, our readings on cats agree fairly well with those recorded for dogs. They are somewhat lower than those given by Key and Retzius (5) (162 to 216 mm. of water in inspiration; 216 to 270 mm. of water in expiration—dogs under ether); higher than Bergmann’s first observations (6) (80 mm. of water, narcotized dogs) but agreeing fairly well with his later findings (7) (120 to 160 mm. salt solution, narcotized dogs). They coincide fairly accurately with the records of the work of Falkenheim and Naunyn (8) (100 to 150 mm. of water, dogs curarized), and while the conditions in Leyden’s experiments (9) are not comparable with those prevailing in ours, his results (80 to 150 mm. of water, 100 to 120 mm. of water, dogs under morphia) seem well in accord with ours. It is felt that the method of intratracheal anesthesia and the direct readings of the pressures in the manometer as practiced in our experiments give a better index of the normal than was obtained by Dixon and Halliburton using a graphic method and morphine-urethane anesthesia. Dixon and Halliburton (10) give a rough average of 40 to 70 mm. of salt solution as the normal pressure of the cerebrospinal fluid in the dog, but the extreme variations which they record have not been noted in our observations on control animals. Thus they record as typical variations of the normal pressure of the cerebrospinal fluid in the dog, the following values read at five-minute intervals: 95 – 25 – 30 – 35 – 55 – 25 – 80 – 65 – 65 – 75 – 70 – 60 – 55 – 50 – 80 – 90 mm. of 10 per cent sodium citrate solution. Compared to the curve reproduced in figure 2, in which the respiratory and cardiac excursions were well marked throughout, these variations recorded by Dixon and Halliburton seem extreme.

The logical physiological explanation of the alterations in the pressure of the cerebro-spinal fluid following the injection of hypertonic and hypotonic solutions, seems naturally to be concerned with the experimental change in the osmotic value of the blood. Thus an increase in the concentration of the fluids injected resulted in a fall in the pressure of the cerebro-spinal fluid while the injection of a hypotonic solution gave an enduring rise. Data regarding the relative or absolute osmotic values of the blood have not been obtained. It would appear that the alteration in the salt content of the blood produced experimentally can only be compensated by fluid readjustments within the tissues, for renal function is more or less impaired by the anesthesia. The individual reaction of the animal noted above may
therefore be referred to variation in the fluid interchange between blood and tissue, so that alterations in the pressure of the cerebrospinal fluid following intravenous injections of hypertonic and hypotonic solutions seem dependent on the osmotic readjustments within the tissues.

A number of observations have been made on the pressure of the cerebro-spinal fluid with simultaneous record of the arterial blood pressure, heart-rate and venous pressures. Further experiments of this kind are under way and will form the basis of a future report.

**SUMMARY**

1. The pressure of the cerebro-spinal fluid in the etherized cats has been found to average 119 mm. of this fluid, if read immediately after the connection of the manometer with a needle in the subarachnoid space; but this pressure, if read some minutes later, is somewhat higher, giving an average of 129 mm., this rise being due, partially at least, to the replacement of cerebro-spinal fluid displaced in the manometer or lost during its connection.

2. Intravenous injections of Ringer's solution cause no lasting change in the pressure of the cerebro-spinal fluid.

3. Intravenous injections of hypotonic solutions (distilled water) are followed by a marked and sustained rise in the pressure of the cerebro-spinal fluid.

4. Intravenous injections of hypertonic solutions (concentrated sodium chloride, sodium bicarbonate, sodium sulphate and glucose) cause initial rise in the pressure of the cerebro-spinal fluid followed immediately by marked fall in this pressure, often to below zero.

**BIBLIOGRAPHY**

(5) KEY AND RETZIUS: Anatomie des Nervensystems und des Bindegewebe, Stockholm, 1876.
(6) BERGMANN: Deutsch. Chirurgie, 1880, xxx, 266.
(7) BERGMANN: Arch. f. klin. Chirurgie, 1885, xxxii, 705.
(9) LEYDEN: Arch. f. path. Anat. u. Physiol., 1866, xxxvii, 519.
(10) DIXON AND HALLIBURTON: Journ. Physiol., 1914, xlviii, 128.