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"Cerebral Circulation"

Thesis. June. 1889
The selection of "Central Circulation" as the subject of a thesis may seem ambitious but the remarks and suggestions offered do not pretend to contain much that is either new or very critical. With the selection made, it may appear inconsistent to say that the numerous subjects which presented themselves to our mind, were consecutively dismissed as being beyond us, but here at least the views held are well defined and distinctly opposed, and our object is an attempt, though futile, at reconciliation rather than to deal in a comprehensive manner with such an admittedly abstract question.

The man who is engaged in scientific research is, we believe, if not others, the most desirous of truth, frequently sacrificing his cherished hopes and beliefs in its pursuit. He does not place himself at the top of creation endeavouring, with prejudiced mind, to reconcile everything to preconceived ideas. He may have theories but they remain as such and are only adhered to so far as the inductive method of observation will permit. We ought then to accept that man actually see, or believe they see, what is described in experimental investigations and endeavour. The results are contradictory to find out, but fallacies may be introduced. In attempting this our difficulty is much increased by a certain consciousness of the falseness of our grasp on physics and the other collateral sciences, and we crave indulgence in the many instances in which this must necessarily become so painfully obvious.
The following pages may be further preceded by
shortly enumerating the two main points to be considered:-
Firsty: Subsidence of intracranial blood after death (probably
affected without its place being taken by any other fluid)
with constancy in amount of the intracranial contents during

Judging from the appendix of Dr. Caffin's book
on the "Causes of Sleep" (from which alone most of our data
must be drawn) one would think that after all there is but
one opinion as to the relation which the cerebral contents bear
to their immediate environment, that the disagreement has
resulted from the ambiguity of terms and ignorance as to
the distinction between "red blood" and "serous effusion".

That the cranial cavity is Qclosed in one, which
practically communicates with the external pressure through the
blood vessels only, is evident. Dr. Helli says: "It does not
appear conceivable how any portion of the circulating fluid can
be withdrawn from within the cranium without being
simultaneously occupied by some equivalent, or how anything
new or enhancerent can be introduced without an equivalent
displacement" (Causes of Sleep page 135) and this is supported
by experiments on animals and by occurrences and accidents
in human life. Dr. Burrow, opposing this view, performs
experiments which show contrary results and asserts that
the principle of subsidence of fluids after death operates
on the parts contained within the cranium as well as on those
situated in the thorax or abdomen; and he points to the
numerous foramina in the skull as a means by which
the atmospheric pressure may be communicated to the interior and thereby allow escape of its contents. The theory that the cranial contents cannot be materially increased or diminished is one which appeals to our common sense and induces us to look for an explanation of the discrepancies above referred to. St. Cappie says that subsidence of fluid can only be explained by supposing that the skull of the rabbit cannot resist the atmospheric pressure and by the gravitation of the red blood corpuscles towards the dependent parts of the body, and he thus dismisses the question.

(Exposition of Sleep, p. 164-7)

I quote from Sir Thos. Watson (Principles and Practice of Med, Sect. XVI) Dr. Burnand's experiments were as follows:

I. Two well-grown rabbits were killed, the one (A) by opening the jugular vein and carotid artery on one side of the throat, the other (B) by strangulation. Round the throat of the first as soon as it was dead, a ligature was tightly drawn to prevent any further escape of blood from the vessels of the head. The contrast between the two brains in point of vascularity, both on the surface and in the interior was most marked. In the one searching the trace of a blood vessel could be seen; in the other every vessel was tinged with blood.

II. Two full-grown rabbits were killed with brassie acid, and while their hearts were still beating, the one (C) was suspended by the ears; the other (D) by the hind legs. They were kept suspended twenty-four hours; and before they were taken down for examination a tight ligature was placed round the throat of each rabbit to prevent, as effectually as it was possible, any further flow of blood to or from the head, after

* See quotations, though lengthy, seem necessary.
"They were removed from their respective positions.

"In rabbit D the external parts of the head, the ears, eyeballs etc. were turgid, livid and congested. The muscles and bones of the cranium were of a dark hue and gorged with blood which at some parts appeared extravasated. Upon opening the cranium the membranes and vessels were dark and turgid with livid blood; the superficial veins were prominent, the longitudinal and lateral sinuses were gorged with dark and there was staining of the tissues, if not extravasation of blood into the membranes. The substance of the brain was uniformly dark and congested to a remarkable extent.

Dr. Kelbie's experiments, as given by Cogge (in "Cause of Slack", page 145) were as follows: "One sheep was bled from the carotid artery alone, another from the jugular vein ---- A dog was bled from both femoral arteries, another from the carotids, and a third from both jugular veins. Then, to afford examples of brain not depleted by previous hemorrhage, he tied both carotids in two dogs and allowed them to die, and a third dog was poisoned with Prussic acid.

In the majority of cases of bleeding to death the brain did not appear to be seriously depleted; in no case was it all en- sanguinised like the other parts of the body, but the appearance as indicated by the presence of red blood varied somewhat. In the sheep were the carotids were tied and the jugulars were opened, death did not occur till twenty-three minutes after the veins had been wounded, and for a time the blood flowed slowly and by occasional drops only. Here the sinuses of the head were in their usual state; those of the
...of the brain contained less blood than we have hitherto found in them, and the veins on the hemisphere of the brain were less filled; the choroid plexuses were pale and empty; the vessels on the basis of the cerebrum were better filled; those ramifying on the basis cereblli were minutely injected. There was a slight but very decided effusion within the ventricles.

In this dog poisoned with prussic acid, the brain was very much turgid with blood. The veins and sinuses were loaded and congested and it was quite evident that the brain contained, by all and all doubt or dispute, a much larger quantity of blood than the brains of any of the other animals which had been brought to death. The summary is, that though we cannot by any means of general adhesion entirely or nearly empty the vascular system of the brain, so we can the other parts of the body it is yet possible by profuse haemorrhage to drain it of a sensible portion of its "red blood": that the place of its application seems to be supplied both by extra- and intra-vascular serum and that watery effusion within the head is a pretty constant concomitant or consequence of great sanguinous adhesion. Dr. Kelli completes his experiments by trephining the skull. Then all the blood is seen to escape—so very little is left behind. Whilst the brain itself subsides.

Looking at the above it is most apparent how much more thorough the experiments of Dr. Burrows were than those of Dr. Kelli. The former certainly took care "to exclude every conceivable source of fallacy." If Dr. Burrows' statements can be trusted, what can we wish for more than "the brain substance..."
and membranes were pulled - anaemic beyond my expectation - but scarcely the trace of a blood vessel could be seen! And again - vessels dark and turgid - sinuses gorged with blood - the substance of the brain uniformly dark and congested to a remarkable extent. The red corpuscles, in the course of depletion, must have gone somewhere out of the cranium and the liquor sanguinii left the blood vessels. The question then arises, where and how? Cappio shows impatience at the result of his experiments, or at least at the conclusions drawn from them (Causation of Sleep, page 167); and it seems his assertion that fluid can only proceed from the cranium after death by the skull being unable to resist the atmospheric pressure is unfortunate; his remark that the red blood corpuscles may have settled down to the dependent parts of the body is equally so, for there is the liquor sanguinii? If the corpuscles had proceeded alone the vessel would still be at least partially; but says Dr. Burrows, "the vessels can scarcely be traced." Has its place then been taken by an increase in the amount of ventricular fluid? Dr. Burrows in his experiments is silent on this point, but considering his attention to details, we may take for granted he would have stated the fact had it been so. No increase was apparently observed. And again in the instance were the carotid arteries of the sheep were tied and the jugular veins opened, Dr. Kilbi affirms that "the sinuses of the head were in their usual state; those of the base of the brain contained less blood; etc. but there was a slight though very decided effusion within the ventricles" (Causation of Sleep, page 167). Now, in the experiment near all forward pressure which would normally be communicated to the brain.
through the blood vessels is cut off by their ligatures, and the blood flowing from the divided veins must, if there be any effect whatever, produce negative pressure within the cranium. Here an increase of ventricular fluid is associated with diminished pressure! To quote Dr Copper on this very subject, ("Causation of Sleep," page 139) where he refutes this theory put forward by Mr Durham, he says "in such circumstances do we actually find an accumulation of serous fluid within the cranium? Is it not in those cases in which we can with confidence predicate increased pressure within the vessels or diminished support outside of them? and as on to the end of page 190, referring to the pressure of inflammation, exposure to cold, hydrocephalus, and the atrophy of old age. "Diminished support outside" must refer to this last condition. In oldage pressure must be some must be kept up so long as circulation is maintained. The tissue of the brain atrophy, tending to produce a vacuum, and their place is taken by fluid passing through the walls of the blood vessels. Here there is certainly an absolute diminution in support, but it is equally correct to say there is relating increased pressure; and in this particular instance I fail to see the need for any such distinction. Is there effusion then must be increased pressure, absolute or relative. If the cut-off arteries be ligatured and the jugular veins cut then must be negative pressure within the cranium and therefore no effusion. In speaking of the amount of ventricular fluid, which in man varies so much normally, it cannot be considered satisfactory to find "light" or "decided" within the limits of one short sentence. Something else then must take the place of the blood which subsides from
within the cranium in profuse haemorrhage. But leaving this for a time let us observe the explanation offered by Dr Burrow.

It is asserted by Dr Burrow (Watson’s Lectures, page 324) that "the principle of subsidence of fluid up to death, operates on the parts contained in the cranium as well as upon those situated in the thorax or abdomen," and he supports this by saying that "the numerous foramina do away with the idea of the cranium being a perfect sphere like a glass globe," suggesting that the mechanism here is sufficient to permit of the brain being depleted through the atmospheric pressure.

It is conceivable that these foramina may allow of some slight subsidence of fluid, for when the blood was flowing from rabbit A in Dr Burrow’s experiment, "the eyeballs were seen to shrink within the sockets," which must have been due to the withdrawal of blood from the soft tissues behind the eyeballs, and if so why not from the tissues in the optic foramen, its place being immediately taken by a slight re-creation of the optic nerve, ophthalmic artery, and connective tissue, due to the atmospheric pressure? The same may be said for the other foramina at the base of the skull, although the amount should be measured by drops rather than suppose it could explain the anaemia described. This, however, should not be overlooked in explaining the gorged appearance in the contrary experiments.

Another point to note is the influence of the cerebrospinal fluid, to which we shall refer more fully later on. If fluid be put into a syphon tube it will flow towards which ever end there is the heavier column; and, consequently, if an animal be suspended by the ears and
the blood vessels undivided, it is possible that the
gravitating blood may along raise the spinal fluid.
But the case would be altered if the blood vessels were divided
for the column of blood would then be very materially
diminished. These remarks however, seem superfluous
for, as a matter of fact, no increase of ventricular or sub-
arachnoid fluid was observed in St. Burrows' most searching
experiments, and the blood vessels could scarcely be traced,
showing that even the liquor sanguinis had disappeared.
But, taking for granted, in the mean time, that
the subarachnoid fluid is sufficient to permit of the intra-
cranial blood outwinding; and that the effect of the
atmospheric pressure through the cranial foramina is
trifling, what other medium is there by which this may be
affected? Cappio, Burrows, Watson, Abercrombie etc. all
agree in stating that the cranial contents consist of brain-
mass, blood and cerebral fluid; but, in this enumeration,
there seems to be an important item omitted; and that
the idea may appear absurd we will, before mentioning
it, make a short quotation from Foster's physiology:
Referring to the effect of changes in pressure of the air
breathed he says "in sudden diminution, death results
from the liberation of gases within the blood vessels and
the consequent mechanical interference with the circulation.
The gas found in the blood vessels on examination after
death consists chiefly of nitrogen." It will be apparent
from the above that the fourth factor referred to is the
gases of the blood and that we look to for an ex-
planation of the complete anaemia described by St. Burrows.
Carbonic acid is the only gas in the blood sufficient in amount. Nitrogen is contained in small quantities, whilst oxygen must practically be absent from the blood of dead animals. Yet, "nitrogen is the chief gas found after death." It must be admitted, however, that under diminished pressure Carbonic Acid is given off and that when the pressure is restored it re-enters the blood more rapidly than Nitrogen. For the latter is simply held in solution and will therefore be more slowly absorbed by the blood than Carbonic Acid, while in addition possesses an affinity for the carbonic ferrous Compound. And as the presence of Oxygen through the blood is supposed to favour dissociation of this Compound so its absence will favour its formation.

Of the 20 cubic inches of gas given off at each inspiration 14 percent consists of Carbonic acid; that is 0.8 cubic inches, most of which comes from the pulmonary blood. We have no means of accurately estimating the amount of blood in the lungs, and much less from what portion of it this is given off, but in Foster's Physiology (page 35) a table shows that 22.76 percent of the whole blood is contained in the heart, lungs, and great vessels; and seeing that the latter (especially the veins) usually contain a large proportion of blood after death, it may be supposed that the lungs alone contain only 10 percent. In the same table the blood of the brain and the cord is estimated at 1.24 percent; and deducting 0.24 for the cord, leaves 1.0 for the brain. Then the formula

10 : 1 : 0.8 (cubic inches) : C02 will give the amount
of Carbonic acid which may be supposed to be given off from the cerebral blood, during each act of inspiration, were it exposed to similar conditions as the pulmonary blood; that is, about 1/2 cubic inch of carbonic acid would be given off from the brain of a rabbit every 1/9 part of a minute. But this is a low estimate as, "in the rabbit, 1/3 to be the amount of blood contained in the head at a given moment relatively to the total bulk of the blood in the system," (B.M.J. 1858; page 503) and Carpenter's Physiology (page 529) states that 1/3 of the whole blood in a healthy man constitutes the supply to the encephalon. But the Carbonic acid given off from the cerebral blood, were it exposed to the air like that of the lungs, is not what is given up in 1/9 of a minute but all that accumulates in it, not only till the heart stops, but till the animal is removed from its hanging posture: for if the disintegration of vital function has ceased, that of the dead tissue must still be going on. By simply holding the breath Becher found the percentage of Carbonic acid more than doubled—from 3.6 to 7.5 (Juter 308); and so it may be supposed that the Carbonic acid gas, before and after death, tends to accumulate and supersaturate the encephalic blood and interstitial lymph, ready to escape the moment the intracranial pressure becomes negative.

The brain is certainly not exposed to the influence of atmospheric pressure in the same sense that other organs of the body are, but we believe that its environment is not less favourable for its thorough depletion than if (the animal being decapitated) part of
the skull were removed, as we shall endeavour to show.

If a rabbit be poisoned with prussic acid and suspended by the ears, as soon as the heart stops beating, the main compressing force acting on the brain is removed; and the blood generally, as it gravitates towards the dependent parts, must act on that contained within the cranium, exiting its force through the carotid arteries, jugular veins and other vessels, and thus produces a tendency to the formation of a vacuum; and if the carbonic acid be in excess it must be liberated. It escapes by diffusion chiefly from the pulmonary blood without any tendency to the formation of a vacuum and why not from the brain under these more favorable circumstances? and, being poisoned with prussic acid the blood will remain fluid and thus favour the continuation of this process.

How far then can this theory be applied in explaining the phenomena associated with some of the accidents and occurrences in human life?

In "hanging," even if very little blood were pressed on after the drop, the gorged appearance of the face would be caused by compression of the superficial veins, associated with the natural contraction and emptying of the arteries after death, and more as if a certain amount of blood escaped from the intra-cranial vessels. Venous congestion is what one might naturally expect, but I cannot see why we should specially look for a gorged condition of the intra-cranial vessels; for if the carotid arteries be compressed by the cord, then the main blood supply is cut off and the chance of congestion minimized. If on the
other hand, the cerebral arteries be patent then what extra blood we might expect to have been forced into the intracranial vessels (if any) whilst the heart was still beating will tend to drain off through the patent cerebral arteries after the heart has ceased. Watson, in his lecture (page 325) states that the appearances in the brain in such cases vary considerably, and that on the whole there is even less blood than normal or not unnaturally full. This is what we would expect, for if depletion depends on the liberation of gases consequent upon the backward pressure exerted on the intracranial contents through the gravitating column of blood, then the amount of gas liberated must depend on the size of the blood column. If the large vessels be closed by the rope the backward pressure must be little, and the depletion slight in proportion. If the larger channels be left patent, then there will be a greater tendency to form a vacuum; more gases will be liberated and there will be greater depletion. In hanging all the vessels are not cut off: the vertebral sinuses are always patent (Watson's lecture, page 325) and therefore the "not un-naturally full" condition is consistent. Each case must necessitate very directly with the size of the blood column tending to escape. The same may also be said of Kellet's experiments where the vessels were opened. The anæmia was comparatively slight as the blood column necessarily was short. So also in decapitation.

If we now go on to ask why the gas does not become more obvious and show its presence in the vessels
and tissues: and the answer may be more difficult than we suppose. As far as the arteries and arterials are concerned it may be said they will contract on it and compress it; but even if so the tendency to form a vacuum is not done away with and it may be supposed that the gas passes on into the inter-epithelial spaces and capillaries. And certainly the veins and venous sinuses, which are not contractile, provide ample room for its accommodation. But whenever it may collect its absence on examination is easily explained, for, as the gas is liberated under diminished pressure, it must necessarily be compressed into smaller bulk; this moment the atmospheric pressure is allowed to act upon the intra cranial contents by the slightest opening being made into the skull. The lymph and blood which, hitherto not drained away will re-absorb part; and should the gas possess the least degree of tension it will escape from the venous sinuses and meningeal veins by those veins which connect the latter with the venous channels in the diaphragm (Gray's Anat. p. 432), for when the skull-cap is remov'd those veins must be divided, leaving the sinuvas in direct communication with the air. No emphysemaatus condition of the brain tissues nor distortion of its vessels could be expected under those circumstances; and it appears that the phenomena observed by Dr. Burrows with regard to depletion are consistent with physiology and probably with the facts of physiology as well.

We shall now return to the rabbit suspended by the hind legs; and it may here be remarked that though the pallor just referred to could only be caused by
great depletion, yet a comparatively slight addition to the
normal amount of blood may produce a gorged appearance.

The engorgement observed in the animals experimented on does not seem to have excited much
surprise either in Dr. Kellie or Dr. Cappin. Both seem to
have devoted their energies to explain the absence of
"red blood." For instance, referring to the dog poisoned with
Prussian acid, Dr. Kellie says "the brain was very clearly
furred with blood. The veins and sinuses were loaded
and congested; and it was quite evident that the brain
contained, beyond all doubt or dispute, a much larger
quantity of 'red blood' than the brains of any of the
animals which had been killed to death." The words here
are almost as strong as those employed by Dr. Burrow
in describing the congestion of the brain of the rabbit
suspended by the hind legs. Dr. Kellie only emphasizes
the expression "red blood," evidently meaning that it had
 usurped the place of a certain amount of extraneou
intra-vascular serum. No explanation is offered as to
how this is effected. "Settling of the red corpuscles" will
not afford a solution; neither can we suppose that the
extra-vascular serum (not including the cerebral fluid)
has diminished. For the increased pressure must lead
to effusion rather than otherwise, yet some thing must
have yielded.

In discussing Mr. Duchams Theory of Sleep
Dr. Cappin strongly opposes the idea of the cerebral fluid
rising and falling in the spinal column, and more as
the transfer from the ventricles to the base of the brain.
His argument are convincing and we must agree with him concerning that takes place in the living body, but the case may be altered when the cadaver is suspended for twenty-four hours. There is free communication between the subarachnoid fluid of the brain and that of the cord, and the continuity indicates that variations of some time or other may be looked for. Then an animal is suspended by the hind legs all the fluid of the body will tend to gravitate towards the head, the most dependent part. The gravitating fluids are the blood and the cerebrospinal fluid; each struggling to supplant the other within the cranium. That these two fluids try to displace the other is evident; for the blood, in its attempt to enter the cranium will tend to expand the brain and its superficial vessels, while the efflux of the spinal fluid must be to compress these. Other things being equal it is evident then, that the fluid which exerts the greater pressure will displace the other; and as the amount of blood is nothing that of the spinal fluid it is not difficult to decide which will give way. But on the other hand there is the fact that the cavity of the spinal column is a closed-in one, and any attempt to form more fluid in must be resisted. The probability seems to be that the blood does not enter at the expense of the cerebrospinal fluid.

One other explanation can be offered. It must be observed that before removing the rabbit Dr. Burrow ties a cord lightly round the neck to prevent any further draining from the head or entrance into it. The animal has hung for twenty-four hours previous to this,
and the soft parts about the head and neck must consequently be enormously engorged. The carotid arteries and jugular veins must be distended with blood trying to force its way into the cranium. The ligature must prevent any backward flow, and therefore the pressure must be kept up. An incision is now made through the scalp, and part of the skull removed upon which the pent-up blood in the vessels will, from the atmospheric pressure on it, and from the diminished resistance to brain expansion, force itself into the sinuses, veins and arteries of the encephalon. Whilst at the same time it is a physical impossibility for any to escape. The blood may even be expected to escape from the temporal scalp through the veins if the deslave into the meningeal veins of sinuses. This transfer of blood must go on from the moment the slightest entrance is made, and during all the time the skull-cap is being removed. In this way it may be fairly assumed that, on examination, a state of over-fullness may be found without menacing displacement of the cerebro-spinal fluid.

In experiments of this sort then, Dr. Burrow's statement that both engorgement and depletion (subsidence of fluid) do take place, according to circumstances, is not surprising. Munks may fill his glass globe with water and Dr. Lippin a skull-elfin covered by the scalp etc., and not a drop may escape; but if either be filled with venous blood similar results can not be expected.

But though it may be correct that fluids sub...
in these experiments, it must be remembered that in their chief bearing they are performed on dead animals, and, with regard to the living, any theory founded upon them must be accepted with caution. Because the brain of an animal can be drained of its blood after death, under extreme circumstances, are we to infer that any thing analogous may take place in the living? Consistent with life, how can there be backward pressure produced in the ear-vidge to any degree whatever, much less to cause the eye-ball to shrink, the spinal fluid to be raised or the gases of the blood to escape - the latter being inevitably accompanied by "gas embolism" and death. In cases of painting from diminished supply of blood to the head it is probable that the calamity is prevented by the recumbent posture which nature imposes, the intracranial pressure being thereby kept up. The "Edinburgh Agama" then is applied to the living subject, but if the heart is possibly in Considered demolished. Any further remarks as to its bearing on cerebral pathology and the movement of the cerebrospinal fluid will be introduced in the consideration of the normal cerebral circulation.

If we bear in mind the supposed powers of the tissues in attracting blood, which is doubtful (lest by Prof. Pachurford), the general circulation of the body is carried on by the heart propelling the blood into the large arteries, the latter by their recoil after systole, driving it on through the arterioles and capillaries into the veins. And though the cerebral circulation is stated to be so peculiar, it would be...
strange indeed if it varied in the slightest in these points. Accordingly, we shall endeavour to show that, though subject to restrictions, it is essentially the same as that in other parts of the body. In tracing the circulation as above, we find that the heart throws the blood into the cerebral vessels during systole only or else where and not continually. The large cerebral arteries must then cause the blood to circulate through the arteries and capillaries and empty it into the veins. But here the difficulty arises. The veins must be filled gradually; there must be a continuous flow into them, and we would naturally suppose a continuous flow out of them. But how is this consistent with the sudden propulsion of blood into the cranium (its contents being a constant quantity) during systole only? It is beyond reason to suppose that the blood is forced directly through the cerebral arteries into the veins, causing venous pulsation. This only occurs in less highly organized structures when in a condition that might be considered pathological, with extreme relaxation of the arteries. But again, another apparent contradiction is the fact that the jugular veins do pulsate. Dr. Broadbent says: "The movement of the blood in the internal jugular has been shown to be pulsatile." (B.M.J. 1867, page 764). On the same page he states: "It can not be supposed that the brain substance is compressed into smaller compartments at each pulsation of its vessels." He further goes on to show the impossibility of the intracranial fluid being able to afford accommodation by its movement; but still there is no explanation offered of the phenomenon of venous pulsation.
There are two dissentient views," says Mr. McKibb (B.M.J. 1888 p. 505) as to the mode in which provision is made for the variations in central circulation. One, supported by Majendie, Carpenter, etc., is that the movement of the cerebrospinal fluid is sufficient to account for these variations: the other, held by Forster, Capfin and Frank, is that the venous system inside the cranium explains it. The variations permitted in health (B.M.J. 1888, p. 504) must include those occurring during normal circulation, and consequently those who believe that it depends on the backward movement of the cerebrospinal fluid have to admit that the same amount must be displaced as that which enters with each cardiac contraction: and to effect this, accommodation must be provided in the spinal canal for the same amount. That is, in 1/3 of a second about an ounce of fluid is forced out of the spinal canal (vide infra). The time thus allowed for the transmission of blood from inside the canal is simply incredible, however large the veins of its meninges and of the bodies of the vertebral may be.

The amount of blood sent to the head at each cardiac contraction is not definitely known, but even that the heart throws out this ounce each time and that in the healthy man the head contains 1/3 of the whole mass of blood (Burkfield's physiology, page 529) it must receive, as shown by a simple calculation (1/3 = 0.333... etc.)/ X = X = 0 X 5 = 1.667) about one ounce each time the heart contracts. Now, the cerebrospinal fluid varies from two to ten ounces" (Gray's Anat. ed. VII, page 449) and two ounces being apparently the smallest amount consistent with health, only one ounce therefore...
in 1753, "yet the chief use of this fluid is probably to afford mechanical protection to the nervous centres and to prevent the effects of concussion from without" (Gray's Anat. Ed. VIII, p. 472).

But even granting it possible for the fluid to be forced into the spinal canal, there is no means by which it could be raised suddenly as to account for regular pulsation; pulsation would indeed be inconsistent, because the fluid being forced out by the sudden expansion of the arteries it must necessarily return slowly during diastole; while the latter are emptied of their contents, and the venous flow must therefore be continuous: yet, pulsation has been demonstrated. If venous pulsation could be produced at all by the returning endospirinal fluid, it must in point of time be diastolic and be the result of pressure applied directly to the venous system inside the cranium.

Lastly, the view is untenable because, first, the veins in the spinal canal must have sufficient tone to provide for the blood supply of the cord alone; second, we should expect that the arterial pressure in canal would counteract the pressure exerted on its fluid from above; and third, if cerebral circulation is only to be explained by pressure through the medium of the endospirinal fluid on veins, why look for those veins in the spinal canal when they are to be found within the cranial sinus itself?

In the face of the anatomical difficulties as clearly put forward by Dr Cappin ("Causes of Sh糊", page 181) it is difficult to understand how a logical mind like that of the late Dr Moore could so fully accept this endospirinal fluid theory. He says "there is a wider and finer passage for it than
"In the blood which passes through the capillary arteries of the brain, and, if the circulation be perfect, the heart may drive the blood less forcibly to the tissues of the brain than the venous pressure of the canal drives the cerebrospinal fluid into its cavities, so that when the head is raised, the venous blood falls away more rapidly from the skull and the cerebrospinal fluid outstrips the arterial blood in its race to supply its place and the ventricles may tend to fill more quickly with water than the substance of the brain with blood and so the person feels giddy" (B.M.J. 1881, page 492). This explanation of momentary dizziness, the result of raising the head, involves almost as free movement as that which we have just been disputing; but the facts at our command, as far as we are able to use them, lead us to the conclusion that no variation in quantity does take place except by the more gradual process of secretion and absorption.

The cavity of the cranium then is a closed-in one whose contents are a constant quantity; the amount of cerebrospinal fluid inside the cranium does not vary during the period of a single cardiac cycle: as the blood enters suddenly or must it must be sudden; and therefore, in trying to explain the events which take place inside the cranium during a single cardiac cycle, it will be allowable to make use of an illustration which involves the above principle and then endeavour to see whether there be any analogy.

A glass globe then is filled with a substance corresponding to the brain mass and put in line with an hydraulic apparatus. Outside the globe there is the propelling apparatus
explain the superfluous application, may appear difficult or impossible in many cases. The attempt to apply the admission of air to the action of the pump is difficult, and the result is not satisfactory. The admission of air to the action of the pump is difficult, and the result is not satisfactory. The admission of air to the action of the pump is difficult, and the result is not satisfactory.
The brain is a rich source of potential energy, but this energy is not used efficiently. The blood vessels are not fully utilized. The brain's energy consumption is higher than expected, even in rest. The brain's energy demands far exceed its capacity to supply it. This is why the brain is constantly at work, even when it is not actively using it.

The brain's energy consumption is directly proportional to its mass. The brain is the most energy-intensive organ in the body. It consumes about 20% of the body's total energy, even when it is at rest. This high energy consumption is necessary to maintain the brain's constant activity, even when it is not actively using it.

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and transfer their contents gradually into the capillaries, the contents of the capillaries being pushed on into the venous system, the venous system (having been emptied by the cardiac systole) being filled in proportion as the arteries are emptied and simultaneously with that event... But can this transfer of blood from one part of the intracranial contents to another be shown to be effected without undue disturbance to the brain substance? Considering the difficulties experienced in trying to grasp the relation which the brain mass, cerebral fluid, and blood vessels bear to each other, it will not be surprising if we go far astray, but it may be worth while to indicate a few of the more obvious points bearing on the above. Two questions may be put first, is the venous system compressible? And second, what are the means causing and permitting much compression? To answer these separately would involve much repetition, and besides, all that we have to say may conveniently be put together.

The venous sinuses are defined as incompressible and inextensible channels, tunnelled out in the dura-mater of the brain (Essays in Medical Science, page 66) and it does not seem necessary to dispute this. Then the top of the skull is removed, they certainly can be flattened by pressure, numerous veins being there by made invisible by blood pouring out (Ellis pract. and, page 10) but suppose we could exert pressure on them from within, the skull being intact, then the tough fibrous, stretching from the anterior to the posterior parts of the skull, would necessarily resist such pressure, and no doubt successfully all that could be exerted through the
cranial contents. But even through compressible, they are certainly not sufficiently distensible to accommodate a great surce of venous blood; and besides, the veins may be considered sufficient for our purpose. The latter too are numerous, equally distributed and thin-walled, and therefore more fully under the influence of widespread pressure and more easily distended.

Though the pressure within the cranium may correctly be said to be the same at all parts of its contents, yet it cannot be asserted that the effects are the same. The parts which are stiff will yield more and become altered in shape to a greater extent than those that are firmer, if there be any difference in consistence. More especially will this be the case with the fluid parts - the blood contained in the vessels and part of the cerebrospinal fluid. Now, the blood vessels and the subarachnoidal fluid, being placed between the unyielding bone on the one hand and the comparatively resisting brain on the other, will reasonably be subject to a greater amount of displacement than any of the other parts of the intracranial contents - more so than the ventricular fluid which must receive some support from the brain substance. The blood vessels and subarachnoidal fluid are therefore placed in that part of the cranial cavity where the effects of varying pressure will be most marked - where the vessels can be most rapidly emptied and, the pressure being relaxed, most quickly repilled.

Suppose the blood vessels be made to penetrate the brain, acting and uning together as in many instances else where, how the continuity of its structure could be considerably
pressure on them from within
marginal. This tunnelling of the brain substance, however, would be the least of the evils, for with each contraction of the heart the brain would be rendered liable to a simultaneous separation and compression of its substance which we believe, being widespread, might seriously interfere with its function. Even if expansion were allowed by the cerebrospinal fluid having as free outlet as some suppose, still this injurious effect would not be diminished to any great extent for there would still be the tendency to separation and laceration of its elements. Not only this, but the circulation could not possibly be carried on satisfactorily for the expanding artery would at once compress the vein and lead to interrupted circulation incompatible with the maintenance of normal cerebral function.

Again, suppose the arteries placed mainly outside the brain, and the veins, having emerged from the brain substance, opening directly into the sinuses which are incompressible; then, as the cerebrospinal fluid cannot escape from this, these must yield when the arteries are distended with blood forced in by the heart. Here there is evidently nothing that can yield only the veins penetrating the brain mass, and to effect compression of those would entail alteration of the brain in shape or rather a total diminution in bulk, which is not of reason.

From these considerations it is evident that the large blood vessels and veins of the brain are placed in the only possible position for them to be in, consistent with normal circulation in an organ situated in a closed cavity. In all other positions there would be imperfect circulation and disordered function.
Varying pressure (intra cranial) is demonstrated in every healthy child, and so in acute febrile affections where the rise and fall of the fontanelle shows that it varies directly with the propelling force of the heart. It is said, "the brain would pulsate if it could" (McKibb, O.M.J. 1888) but the term pulsate is objectionable for, according to the definition which Broadbent gives, pulsation indicates a change of shape in the wall of the artery from the flattened to the circular form (O.M.J. 26.3.1887) and therefore if the brain pulsates we must assume that the vessels penetrating it increase in size and expand the brain at each cardiac systole; but this cannot be admitted for the following reasons:

The "cortical" branches as well as the "central" (going to the gyri and of the brain) arising from the circle of Willis are not large arteries but minute twigs, all but capillary in size and the flow of blood through them must be continuous during the complete cardiac cycle and not pulsatile. And further, the fact that the cortical branches, seen dipping into the substance of the brain from the pia mater, are not actually capillaries but minute arteries, excludes entirely the possibility of pulsation for, according to physiologists, an important function of the arteries is their role as stopcocks for the prevention of pulsation. Under the microscope the blood is seen to pass "in a continuous stream from the small arteries through the capillaries into the veins". Therefore, in the central circulation in this respect differs from that in the body generally, or is in a continuous pathological
condition, pulsation of the intra-cranial vessels is an impossibility and systolic expansion of the brain as well. Gradual expansion during functional activity, or expansion and contraction associated with sleep, it is needless to attempt denying; this is stated as a simple fact by Landor Brunton in his "Therapeutics." But besides, if pulsation occurred in these minute vessels, the circulation would be obstructed as previously indicated.

It would seem then, that the compressing force exerted through the heart must mainly take effect, not on the brain itself, but on the more yielding structures outside, namely on the veins through the medium of the subarachnoid fluid.

However ridiculous this view may appear to superior intelligence, this much at least may be said for its favour that it is not as "round-about" as the theory put forward by so many authorities, that the blood pressure during systole is communicated to the cerebro-spinal fluid, forcing the latter into the spinal canal and thus displacing venous blood for its accommodation. For this it is admitted there is pressure exerted on the cerebro-spinal fluid but its effect on the cerebral veins is ignored. As before stated, why should we fall back on the veins in the spinal canal when the cerebral veins are at hand ready to be acted upon? Pressure on the former can not explain jugular pulsation; on the latter it does.

But there are numerous difficulties to be encountered here which we can do little more than hint at; difficulties in connection with the quantity...
Of the intracranial fluid, its distribution on the cerebral surface, and its behaviour under special circumstances. Anatomists and surgeons are both the same detail, in a way which is only equalled by the contempt of the physiologist for cerebral circulation as a whole.

In "Ellis' practical Anat. and the more recent edition of Gray" the quantity is not referred to, but if the brain theory be tenable, it must be at least equal in amount to the quantity of blood expelled at each cardiac contraction. If less or absent, the result must be a predisposition to, or an actual diseased condition, though no doubt the circulation would be carried on by some compensating effort on the part of nature. If absent, as in hypertrophy of the brain, then it cannot be admitted that the large arteries at the base of the brain alter much in calibre during the cardiac cycle. The continuous flow of blood cannot be kept up by their contraction but by the general tension in the vessels outside the skull; and under such circumstances there would be no regular pulsation within certain limits the circulation would be normal, but a pathological state would be more readily induced than with a due amount of fluid.

As to distribution, it is most plentiful at the base of the brain (Ellis' pract. Anat. page 177) which is consistent for if the arteries at the base of the brain receive as much blood as is forced out of the veins on the cerebral surface, as we have suggested, then there is as much fluid displaced from the limited part of the base as is forced on to the more extensive surface, and consequently the subarachnoid space at the base must
be larger. The contracted state of the arteries after death would, to some extent, resemble the condition of affairs immediately before systole: the fluid would be more plentiful then at the base than immediately after systole.

But in cases of tranquilizing the results are contrary to what we should expect. If pressure be exerted on the subarachnoid fluid, why does it not escape when the dura mate with the arachnoid membrane has been opened into? But the question comes with equal force if we accept the other view that the subarachnoid fluid is forced into the spinal canal. In operation on the brain I have not been able to bring any reference, in textbooks, to the escape of fluid and the natural conclusion is that it does not occur, or very slightly. If this is so, the explanation may be that when the bone is removed the atmospheric pressure possibly may allow the brain to subside in the cranium so that the arteries may have room to expand without raising the fluid. On the other hand it is said that the substance of the brain often bulges out into the opening. In fraction of the bone however, there is an escape of fluid through not pulsatile — its non-pulsatile character being due probably to the minuteness of the pressure combined with its distance from the arterial system.

Lastly, that the pressure exerted through the arteries is sufficient to empty the veins is obvious, for the force which expands the arteries must be enough to empty the veins to which it is equally communicated through the medium of the subarachnoid fluid.
A would be presumptuous to speculate on the nature of convulsions, but when so many different views are held of a particular disease, the mind naturally leans towards some one or other; and that which seems to us most reasonable is to hold the belief that it is an affection of the whole encephalon, and that the exciting cause is in most instances high arterial pressure.

[B.M. J. 1887, page 790, Broadbent]

If the cerebral veins are normally subjected to pressure, what is more natural than to suppose that this physiological process may, like so many others, be carried to an extreme and become pathological. The brain circulation must be more readily obstructed if compression of the veins is an essential feature in its maintenance than if it were carried on by the movement of the embrocephalic fluid, for the latter would tend much to be more or less expelled from the cranium before the venous outlet could be obstructed.

The statement that "No fits are the decay of the system, and that underlying them there is no essential disease which can exist without independent of them" (Hilton Fogg, page 679) leaves the mind unsatisfied. That it is simply "the dissipation of a accumulated energy" (page 689) does not seem probable, for how then can the "status epilepticus" continue for hours without intermission and end in death, pure from energy stored up? and that, under conditions which cannot be replaced. To interrupted attack it might be applicable.

To the "centre" theory we can only state that no centre has yet been found, the moderate stimulation of which produces convulsions; whilst, on the other
hand there is scarcely a centre which, if powerfully stimulated, does not produce convulsions. Matter is then in any special centre or set of centres associated with the loss of consciousness, the essential phenomenon in Epilepsy. The loss of consciousness points to a general affection of the grey matter and the "status epilepticus" indicates the existence of an irritant or exciting cause continuous. Applied, and both these may be accounted for by high arterial pressure, either compressing the centre (Droeshout) or interfering with its blood supply. A predisposition to convulsions is insisted on and no doubt rightly, but what is the predisposition in the previously healthy man? Here, a depressed fracture of the skull, lice, and becomes epileptic? And what is the exciting cause? The depressed bone is not the exciting cause for it is always present, without variation, yet the fits are not continuous. Does it not rather appear that the depressed bone is the predisposing cause which provokes alternation in the general arterial circulation, the exciting cause being high arterial tension in the body generally, whether induced by the

I have seen only one case of convulsions. J. G., aged 12, had scarlet fever, followed by nephritis. Attended by my principles, convulsions setting in one day and on my arrival the boy had been unconscious for one hour, but the convulsive movements had almost ceased, and in 2 or 3 hours there were signs of returning sensibility. The pulse was extremely stiff though rapid and I felt that the case of least aid not borne by the

pressure theory. A week later I again saw him. The lesion was then as high as it had previously been low. Was the low tension then the result of nature attempting to throw off the attack, and an indication for a specific line of treatment? The Nitrites and bromides of sodium were prescribed.