(12)

THE RELATION

OF

THE CRANIAL CONTENTS

TO THE

PRESSURE OF THE ATMOSPHERE.

BY

JAMES CAPPIE, M.D.

(*Read before the Medico-Chirurgical Society of Edinburgh, 4th February.*)

EDINBURGH: OLIVER AND BOYD, TWEEDDALE COURT.

MDCCCLXXIV.

Reprinted from the Edinburgh Medical Journal for August 1874.

THE RELATION OF
THE CRANIAL CONTENTS TO THE PRESSURE OF THE ATMOSPHERE.

A general knowledge of the facts concerning the pressure of the atmosphere on the surface of the body is sufficiently familiar. Its enormous aggregate amount, and the reason why such a weight does not injure the most delicate of organic structures, are well known. Bearing with a ratio of nearly fifteen pounds to every square inch of surface, an equal and contrary pressure of the fluids within serves to preserve an equilibrium so nice that no sensible result need be noticed from its presence. This, of course, is simply analogous to what is observed in the world of physics. When the air is still, its weight does not seem to interfere with the mobility of the magnetic needle, nor will it break the finest film of glass. The pressure of fluids being exerted in all directions, the opposing pressure below is equal to that above or at the sides. But the presence of a great energy is at once shown on the occurrence of any change in the balance of resistance. Thus, in nature, the destructive effects of the hurricane bear witness to its potency; and, in art, the workman can contrive by its aid to suck up water to the height of thirty feet above its previous level; and the surgeon can produce the once familiar effects of cupping, or the more recent results of aspiration.

It cannot be without interest to ascertain whether that force is made to subserve the attainment of required ends in the animal economy. In the construction of the body there is not only the adaptation of one structure or function to other structures and functions, but there is also an adaptation of structures and organs to the outward physical forces of nature. Thus, the mechanism of the eye enables us to recognise the subtle undulations of the ether as light, and through that of the ear the undulations of air are converted into sound. It was therefore to be expected that some mechanism would be found in animal bodies to make the weight of the atmosphere useful, and I shall allude to some of the contrivances for this purpose, before speaking of the special relation which is the subject of the present paper.

"There is an effect of the atmospheric pressure on the living body which is rarely thought of, although of much importance, viz., its keeping all the parts about the joints firmly together by an action similar to that of the Magdeburg hemispheres. The broad surfaces of bone forming the knee-joint, for instance, even if not held together by ligaments, could not be separated by a force of less than about a hundred pounds while the capsule surrounding the joint remained air-tight. In the loose joint of the shoulder this support is of greater consequence. When the shoulder or other joint is dislocated, there is no empty space left, as might be supposed, but the soft parts from around are pressed in to fill up the natural place of the bone. When a thigh-bone is dislocated, the deep socket called the acetabulum instantly becomes like a cupping-glass, and is filled partly with fluid and partly with the soft solids. In all joints it is the atmospheric pressure which keeps the bones in such steady contact that they work smoothly and without noise."[1]

A function in which the atmospheric pressure has long been recognised as taking an important part is that of respiration. "Distension of the pulmonary cavities is entirely accomplished by the action of the muscles external to the thorax, or partly forming its parietes. The lung completely fills the cavity of the pleura, in the healthy state at least; so that when this is enlarged, a vacuum would be produced, if it were not occupied by a corresponding enlargement of the lung; and to effect this the air rushes down the trachea, and thence passes into the entire substance of the lung, which it fills out in every direction. The complete dependence of the expansion of the lungs upon the enlargement of the cavity of the chest is well shown by the effect of admission of air into the pleural cavity. When an aperture is made on either side, so that the air rushes in at each inspiratory movement, the expansion of the lung on that side is diminished or entirely prevented, in proportion to the size of the aperture. If the air can enter through it more readily than through the trachea, an entire collapse of the lung takes place; and by making such an aperture in each side, complete asphyxia is produced."[2]

In assisting the action of the heart, the pressure of the atmosphere takes an important part. "The heart," says Dr Pettigrew, "has the power of forcibly expanding itself, as it has of forcibly closing itself. It can therefore, in virtue of its rhythmic movements, alternately suck in and eject blood—the auricles attracting it while the ventricles are repelling it, and *vice versa*."[3] The pressure bearing on the surface of the body thus becomes an essential auxiliary to the whole circulation. It is evident that no dilatation of any of the heart's chambers can take place without the pressure on the inner surface of their walls being sustained. That is to say, the muscular force would not succeed in forming an absolute vacuum. The filling of the cavity must be simultaneous with its dilatation, and in securing the former part of the process, the weight of the air becomes a necessary agent.

[1] Arnott's Elements of Physics, p. 327.
[2] Carpenter's Physiology.
[3] Edinburgh Medical Journal, Feb. 1873.

In the abdomen, if its mode of operation is less obvious, the action of the atmospheric pressure is still very important. How it may make the walls of the cavity adjust themselves to the change of bulk which so frequently occurs in the contents of the intestinal canal is sufficiently obvious, but this is only a small part of the use it subserves here. It also affords positive support to the weighty abdominal viscera. As the liver and stomach (the latter perhaps loaded with food) lie at the upper part of the cavity, they would tend strongly to gravitate towards the pelvis, if only supported by their respective attachments. The support of the mobile intestines would go for very little if any communication existed with the external air above the liver. Many facts seem to prove, however, not only that there is no dragging of the attachments of the abdominal viscera, but that there is a decided tendency to upward suction in the cavity.[1] Here the pressure of the atmosphere, bearing on the pliable parietes, is likely to be the potential agent, and its energy will be kept in active play by the movements of respiration. These movements involve a constant change not only in the shape of the thorax, but also in that of the abdominal cavity. They do not necessarily affect the cubic capacity of the latter, for the bulk of its contents may for a period remain without alteration. If the cavity expands or relaxes in one direction, it must contract in another. During inspiration, which is a purely muscular act, the diaphragm descends and the upper part of the cavity flattens out. In expiration, the lung contracts from the elasticity of its own tissue, aided by the rebound of the ribs, and by a muscular effort in which the muscles of the abdomen take a share. The simple act of resilience in the lung, tending to form a vacuum in the pleural cavity, will, of course, produce a suction effort towards the diaphragm as well as towards the ribs. If any response is to be made from the former direction, the resilience will require as its complement the pressure of the air on the pliable wall of the abdomen. That pressure will urge the viscera in the direction of the receding diaphragm. The upward movement of the liver will also be assisted by the elastic rebound of the ribs which form the lower third of the thorax. Then, as the liver is comparatively a solid organ, and as it extends across the whole upper part of the cavity, it cannot move upwards without tending to form a vacuum beneath it. An adspiratory effort is thus produced, the effect of which may be communicated to any part of the cavity on which the atmosphere can bear, and such effort must accompany every act of expiration.[2] Thus, not only is efficient support afforded to the abdominal viscera, but, as Dr Duncan has pointed out, the accomplishment of other ends, such as the return of

[1] See Dr Matthews Duncan's Essay on "The Retentive Power of the Abdomen."—*Researches in Obstetrics.*

[2] It should be mentioned, however, that Dr Duncan supposes that "greater adspiratory power in the abdomen" exists with the "*in*spiratory effort." Op. cit., p. 429.

venous blood from the lower extremities, is at the same time promoted.

Coming now to the cavity in which the most important organ of the body is lodged, we find that the contents of the cranium have a relation to the pressure of the atmosphere very different from what we have found in the other cavities of the body. Whatever be the changes that go on in its interior, direct pressure from without cannot affect them. The compact bony wall cannot expand and contract like the walls of the thorax, or like those of the heart or abdomen. Yet here, too, we shall find a mechanism specially fitted to cause the outward pressure to subserve the attainment of important physiological ends.

We do not require to consider whether the cranium could resist the weight of the atmosphere if a complete vacuum were created within it; nor need we even discuss whether an infinitesimal amount of change may not be accomplished by moderate physical means. The relief afforded in certain forms of headache by tying a handkerchief tightly round the head, would seem to show that internal support may be modified by outward pressure. Still, it will be admitted that any such change must be extremely small, and that even in the cranium of an infant we have an amount of resistance of which we have no example in any other cavity of the body except the spine.

I need hardly say, however, that pressure bearing on the general surface of the body will be readily directed to the interior of the skull through the bloodvessels which enter and make their exit from its cavity. Any active impulse to which liquids are subjected is communicated equally in all directions, and therefore, by means of the blood, the whole interior of the skull, and the whole contents of the cavity, are brought completely and equally under the potential energy of the atmospheric pressure.

If such be the case, then we may assume, without any argument, that here, as in other parts of the body, an equilibrium must at all times be preserved between the pressure on the surface and that within the skull. In any other case the circulation of blood through it would be impossible. The conditions of this equilibrium being preserved involve, 1st, absolute fulness of the cranial cavity; and, 2d, this peculiarity—that for any quantity of blood made to enter the cavity, an exactly equal quantity should at the same moment be discharged from the venous sinuses.

Our further object in this paper will be to illustrate these points in the first place, and then to show how certain forces are at work whose tendency it is to disturb the equilibrium of the internal circulation, and therefore of the internal pressure, and to point out the modes in which an equilibrium may be preserved or rectified.

I may remind you that the discussion of some of these questions here is not new. It was before this Society, and indeed in the first session of its existence, that Dr Kellie of Leith read the celebrated essay which has since given rise to so much discussion.

The full title of Dr Kellie's paper was,—"An Account of the Appearances observed in the Dissection of two of three Individuals, presumed to have perished in the Storm of the 3d, and whose Bodies were discovered in the Vicinity of Leith on the Morning of the 4th Nov. 1821; with some Reflections on the Pathology of the Brain."[1] It was read in two parts,—the first on 6th Feb., and the second on 20th March, 1822. To give an adequate analysis of this essay, to point out its immediate effect on cerebral pathology, and then to trace the origin of misconceptions as to the views expressed in it, and the consequent misrepresentation of these which has been persistently indulged in during the last thirty years, would require a whole evening to itself. Had it earlier been thought of, such a theme would have afforded no unworthy subject for discussion in connexion with the jubilee of this Society,[2] which happened two years ago; but at present I shall attempt nothing more than a short analysis of the paper itself.

The general impression among recent writers seems to be, that Dr Kellie believed, and that he performed his celebrated experiments to prove, that the amount of blood within the skull must continue invariable. Now it so happens that the very occasion for Dr Kellie investigating his subject was the circumstance that, in the post-mortem examination of two individuals who had died from the effects of cold, he found from three to four ounces of serous fluid in the ventricles and at the base of the brain; and his reflections on the probable production of this quantity of fluid within a few hours led him to the conclusion that an amount of blood equivalent in bulk to the serous fluid had been pressed out of the cerebral vessels. "When the cavity of the cranium," he says, "is actually encroached upon by the depression of its own walls, or by an effusion of fluid within its cavity, one of two things it is obvious must follow,—either the compression of its previous contents into less space, or the displacement and removal of an equivalent bulk of their contents." He then gives reasons why he thinks it "highly improbable that in the course of a few short hours from three to four ounces of brain could be wasted or removed by absorption," and continues: "It seems more probable that in most cases of intrusion on the brain, compensation may be made at the expense of the circulating fluid within the head; or that less blood is then admitted and circulated within the brain than before such encroachment on its capacity has been effected."[3]

It thus appears that, so far from thinking that the amount of blood within the skull must remain constantly uniform, the admission of its decrease as a probable fact was actually the starting-point of Dr Kellie's investigations!

But then comes another question:—Supposing there is no oppor-

[1] Transactions of the Medico-Chirurgical Society of Edinburgh, vol. i.

[2] This was written before the delivery of Dr Handyside's elaborate valedictory address.

[3] Op. cit., pp. 98, 99.

tunity for effusion to take place,—supposing the other contents to continue unchanged, can the quantity of blood within the skull be lessened? The inference he makes is that such an event is improbable, and the following is his line of argument:—

"The circulation within the head is in truth of a very peculiar description. The brain itself, little compressible, is contained within a firm and unyielding case of bone, which it exactly fills, and by which it is defended from the weight and pressure of the atmosphere—a force constantly acting on every other part of the system—a force therefore which must be constantly operating to maintain the plenitude of the vascular system within the head.

"If these premises be true, it does not then appear very conceivable how any portion of the circulating fluid can ever be withdrawn from within the cranium without its place being simultaneously occupied by some equivalent; or how anything new or exuberant can be intruded without an equivalent displacement.

"One of my oldest physiological recollections, indeed, is of this doctrine having been inculcated by my illustrious preceptor in anatomy, the second Monro—a doctrine which he used to illustrate by exhibiting a hollow glass ball, filled with water, and desiring his pupils to remark that not a drop of fluid escaped when inverted with its aperture downwards."[1]

To test the correctness of this doctrine he undertook his experiments, and made an examination of the different pathological conditions that might, *a priori*, be expected to produce depletion on the one hand, or overfulness on the other.

His first query was:—"Is it then true and consistent with experience that we cannot lessen to any considerable extent the quantity of blood within the cranium by arteriotomy and venesection?" To determine this, he bled several animals to death in a variety of ways, and afterwards carefully examined the brains. For example, a sheep was killed in the ordinary way by the butcher, another was bled from the carotid artery alone, and a third from the jugular veins. In one case he tied both carotids, and four minutes afterwards opened the jugular veins; and in another he tied the jugular veins, and five minutes thereafter opened the right carotid. A dog was bled from both femoral arteries. Then, "to afford examples of brain not depleted by previous hæmorrhagy," he tied both carotids (including the pneumogastric nerves) in two dogs, and allowed them to die, and a third dog was poisoned with prussic acid. The general belief seems to be, that Dr Kellie thought he had proved that bleeding to death does not affect the amount of blood left in the vessels within the cranium. This, however, is a mistake. For example, in speaking of the last three cases, he says, "These comparative experiments afforded us the most satisfactory proofs that the other brains had really been depleted by bleeding, and the vessels drained of a very sensible proportion of the red blood

[1] Op. cit., p. 102.

usually contained in them."—P. 115. Still, the results on the whole came near to what he expected, and, with a guarded carefulness of expression which runs through the whole essay, he was satisfied that it had been "found nearly true that there are such obstacles as the hypothesis supposes to the free depletion of the vascular system within the head." In no case was the brain found at all exsanguined, and where there appeared to be a loss, it was probably caused by the proportion of the red corpuscles in the blood being reduced.

"The summary of these observations," he says, "in so far as they apply to our present subject of inquiry, may be thus stated,—that although we cannot by any means of general depletion entirely or nearly empty the vascular system of the brain as we can the vessels of the other parts of the body, it is yet possible, by profuse hæmorrhagies, to drain it of a sensible portion of its red blood; that the place of this spoliation 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 sanguineous depletion."—P. 116.

Proceeding, then, with his argument, he remarks, that "if the obstacle to the free depletion of its vessels depends mainly on the cerebral system being defended from the weight and pressure of the atmosphere by the solid and unyielding cranium, it seemed probable that, by removing a portion of the skull, and allowing the atmosphere to gravitate upon the brain, we should succeed in producing a much greater depletion of its vessels by general bloodletting than can be otherwise effected."—P. 124.

To ascertain this point, he made other three experiments on dogs by removing a portion of the cranium with the trephine, and the animals were then bled to death. On afterwards examining the brains, the contrast in appearance to that of the former cases was very striking. Thus, in one of them "the vessels on its surface were reduced to mere hairs, the brain was remarkably pale, and the choroid plexus bloodless."

"Comparing, then, these with the observations made on animals bled to death by simple hæmorrhage, it appears that when the head is entire, the brain still contains a considerable quantity of blood,—when previously perforated, very little; the brain continues to fill the cranium in the one case, and subsides within it in the other."—P. 126.

Our author then remarks that "the same causes which maintain the plenitude of the cranium and oppose the depletion of the vessels of the brain may be presumed to present also natural and constant obstacles to the repletion of those vessels. To prove his case still further, therefore, he proceeds to an elaborate examination of some of those "occurrences and accidents in human life, and some diseases also incident to man, which bear on the question of repletion with all the force of direct experiment."—P. 127. He investigates the results on the brain circulation of death from suspension, suffocation, and drowning; the effects of stooping and other low positions of the head; the effects of some diseases of the heart and of its larger vessels; and, lastly, the effects of ligatures and tumours compressing the vessels of the neck so as to impede the free return of blood from the head. In concluding, he says, "I have thus passed in review the most important of those circumstances which, from the earliest era of medicine, have been presumed to have a powerful and undoubted tendency to force blood into, or to confine it within, the vessels of the brain, and so to produce dangerous morbid congestion of that viscus,—circumstances which accordingly have very generally been enumerated by systematic physicians as the principal exciting causes of comatose diseases; and although I am aware of many objections—though I know but too well the unlucky *pour* and *contre* which embarrass us in almost every subject of medical inquiry—I think a case has fairly been made out, proving that the agency of such causes has been greatly overrated; that nature has guarded with peculiar care the brain and its membranes against such accidents from repletion and depletion, as they must otherwise have been constantly exposed to; and that while the structure of this organ remains *healthy* and *unchanged* and its *vessels sound*, those causes are little capable of occasioning plethora, congestion, effusions, or comatose diseases."—P. 168.

I have thus fully referred to the observations of Dr Kellie, because it is on their assumed correctness that my future argument is founded. I have also been influenced by a wish to assist in reviving the scientific reputation of one of the eminent founders of this Society, by representing fairly, though inadequately, the doctrines he attempted to establish. Accepting his conclusions, therefore, as on the whole a safe starting-point for further inquiry, I proceed to notice with more detail the mechanism through which the atmospheric pressure affects the interior of the skull, and by which it may exert an influence on the physiology of the brain. I am not aware that any attempt has been made to differentiate further on this subject than was done by Abercrombie and Kellie. Indeed, the tendency has rather been to question the correctness of even such a general view as they took. As it would lead me far beyond the limits of a paper like the present to treat my subject in a controversial manner, I content myself with the single remark, that I know of no fact or argument that seriously affects the soundness of their conclusions. The exceptional cases of an infant, and of an adult who has lost part of the skull, will be afterwards alluded to, and shown to belong to that useful class of exceptions whose peculiarities "prove the rule."

In attempting, then, to determine with greater detail how the atmospheric pressure can affect the interior of the cranium, we require, in the first place, to distinguish between its mode of acting on the arterial and on the venous vessels. It will be found, I think, that this distinction is not unimportant. In the one case it acts in the direction of the current of the circulation, and in the other it is opposed to the current. In the one case, therefore, it assists the action of the heart, and in the other it opposes the return of blood from the head. Whatever influence the outward pressure may exert on the one system of vessels or on the other, it will be facilitated by the fact that "the terminations of the great veins or sinuses, or ends of the lateral sinuses, are not contiguous to the trunks of the corresponding arteries, as is observed in most other parts of the body, but pass through different holes in the cranium."[1]

At first sight it may be thought that the distinction I have made of a pressure on the arteries and on the veins is unnecessary, for, so far as the general circulation to and from the head is concerned, these forces must balance one another. The amount of pressure is the same in both sets of vessels, and thus, notwithstanding the potential weight of one atmosphere opposing the exit of blood from the venous sinuses, no interruption whatever takes place in its movement. The cavity being full, the internal pressure is as great as that on the surface, and the amount of blood making its exit depends simply and entirely on the amount that is made to enter the intracranial arteries. It will be convenient therefore to regard the atmospheric pressure as a constant quantity. It of course varies with the barometric pressure, but this variation will affect both systems alike. For example, its increase does not impede further the exit from the veins, because a forward pressure in the arterial vessels is increased to exactly the same extent. Thus, no disturbance in the encephalic circulation is occasioned by the rise and fall of the barometer.

To see how energy so potential as that of the atmospheric pressure can be converted into an energy that shall produce sensible results within the skull, we require to discover one or more factors whose varying value will qualify the result, and therefore have to be taken into account in determining what the ultimate product is to be.

Such a factor we may find in the greater or less activity of certain dynamic forces within the skull itself; and, as a co-factor, in the peculiar arrangement of the bloodvessels of the brain.

I allude, in the first place, to the molecular changes in the brain, nd their effect on the capillary circulation; and, in the second place, to the fact that the circulation of the brain itself is almost entirely capillary, and that its principal bloodvessels, both arterial and venous, are supported on its external surface in the pia mater.

In surveying the relation which these conditions hold to one another, we shall, I think, find a field where a constant struggle may be supposed to go on between the forces propelling the blood onwards and the force tending to keep it back; where at one time the forward impulse is the more energetic, or produces

[1] Monro, "Observations on the Nervous System."

greater results, and at another time the backward pressure prevails; and where momentous results are determined according as success is inclined to one side or the other.

The molecular changes in the tissues constitute a force which exerts an influence on the circulation in all parts of the body. It is assisted by the ganglionic nerves regulating the minute arteries, but is not essentially dependent on these, and its activity and power of modifying the local circulation have no direct relation to the force of the heart's action. The blood itself does not flow passively, or only under the influence of the latter. In the capillaries it both acts and is acted on. It attracts to itself certain elements of the tissue, and the latter attracts certain elements from the blood, and a constant interchange goes on. The amount and rapidity of this interchange greatly modify the facility with which the blood passes through the capillaries. When more active, the circulation is brisker, and the pressure within the vessels is increased; when less active, the movement of the blood is more sluggish, and its pressure within the vessels is lessened. While it continues, the blood moves onwards although the *vis a tergo* has failed; if it ceases, the blood becomes stagnant although the action of the heart may continue strong.

The constant energy directed on the encephalic circulation by the molecular forces would tend to keep the vessels of the brain full, even though its mass were exposed to the unimpeded weight of the atmosphere on its surface; and, in fact, it keeps them full when such exposure is partial. It has been urged that serious disturbance should be expected on the removal of part of the skull, if it be true that in the natural state of the parts the brain is altogether withdrawn from such exposure. But, in making this objection, the existence and energy of the molecular forces have been overlooked, and the fact that these are as active in the brain of a child with an open fontanelle as in the adult with a close skull. Indeed, when part of the latter is removed by injury, it is the protrusion of the brain, or the preponderance of internal pressure, that is probably the more prominent phenomenon. Instead of collapse we have over-distension.

As is well known, however, vascular disturbances within the head are more readily produced in the child, and the direction of the disturbance can often be readily observed on the surface. When there is an actively congestive tendency within, the scalp at the open fontanelle is raised and has the appearance of a tense throbbing tumour. On the other hand, in atrophy of the brain, or where there has been a rapid drain on the fluids of the body, as in choleraic diarrhœa, the internal pressure being lessened, the surface sinks, and not unfrequently the shape of the fontanelle is defined with great sharpness by the scalp falling in abruptly and tightly at the edge of the bones.

It is not necessary for me to say anything as to the nature of the molecular changes which constitute the nutrition, or are involved in the functional activity of the brain. I assume that even when the organ is quiescent they are subtle and unceasing, but that their amount, rapidity and energy are greatly increased when its function is in active exercise. This being the case, the tissue of the brain will have a more powerful attraction for the blood during the period of wakefulness than when the mental functions are suspended. The force with which that fluid bears against the internal surface of the arterial and capillary vessels, and, consequently, the fulness and tension of the whole organ, will then be also greater.

That there is such a tendency to increased fulness in the vessels of the brain during activity of function, is a matter of observation when the organ is exposed from injury of the skull. In the latter case, however, it may be urged that the appearance of increased fulness is simply the result of the larger space that has been gained. The problem to be solved is, how to permit increased vascularity in the brain without augmenting the blood within the skull. The difficulty may, to some extent, be removed by remembering the arrangement and size of the veins in the pia mater. These vessels are so numerous and so large and tortuous, that they seem specially fitted to become the receptacles of a varying amount of blood. It is possible, therefore, that an increase may take place in the brain-tissue by the proportion in the veins being lessened. We will be in a better condition, however, to judge whether such an occurrence is probable when our argument is further advanced.

Assuming, then, that in determining the intensity of the intra-cranial circulation, the molecular changes in the brain-tissue are the dominant factor, we have now to ascertain what relation the pressure of the atmosphere holds to their greater or less activity.

I have already hinted that, in supplying blood to the brain, the action of the heart may be assisted by the atmospheric pressure. When the body is in the erect posture, which it usually is when the brain is most active, and when it is of the greatest consequence that the supply be full and uninterrupted, the influence of gravitation is directly opposed to the free determination of blood to the head. Considering what a mass of this fluid is sent to the vessels within the skull, it is obvious that were the brain exposed to the unimpeded weight of the air on its surface, serious draining of its vessels would inevitably result on the head being raised; and to induce syncope, it would be sufficient to rise from a recumbent to the erect posture.

In some of the lower animals we see even greater necessity for some means being provided to counteract the effects of gravitation on the circulation of the brain. For example, the giraffe may at one moment be sipping water from a pool, and the next be nibbling leaves from a branch perhaps fifteen or eighteen feet above the ground! Here the construction of the skull serves not only to prevent the vessels of the brain from becoming too full when the head is low, but also from becoming emptied when the head is raised.

But that is not all. The forces acting on the capillaries, we assume, are not simply permissive,—they exert positive energy in attracting blood from one direction, and urging it onwards in another. If this be so, then, acting in a chamber which excludes all pressure from without, except what comes through the blood, these forces must exert an active suction power on the blood in the carotids. That is to say, they must tend to form a vacuum behind them; and to prevent this, the weight of the atmosphere, transmitted through the soft parts, will assist, not simply in sustaining, but also in actively directing the necessary amount of blood to the head, and thus an important, if not an essential, aid is afforded to the action of the heart.

It is, however, to the effect of the atmospheric pressure on the blood in the encephalic veins that I have especially to request attention. The tendency of that pressure here is to keep back the blood within the head. As resistance to the movement of a fluid reacts with energy on the fluid itself, and therefore on the channel through which it flows, that tendency will have effect on the internal surface of the veins through their whole extent, and thus, too, the brain itself is brought under the influence of a simple physical agency. Whatever be the impulse a fluid within a tube is subjected to, it will tend to dilate the vessel just as powerfully as to move the fluid onwards. Thus, the lateral pressure on the walls of the veins will be simply in proportion to the amount of propelling or opposing force that may be acting on the blood itself. In considering, therefore, how the backward pressure may be balanced or overcome, we have to take into account not only the force that moves the blood onwards, but also the support afforded to the walls of the veins by the solid brain-mass. The flow of blood will go on smoothly only so long as that support is stable and uniform.

We have seen that the dynamic forces within the brain-tissue vary greatly in energy, and that according to their energy the pressure of the blood within the capillaries is more or less strong. The circulation is fullest, and the whole organ is most expanded, when its function is in active exercise. A certain amount of pressure is then directed against the external surface of all the veins of the pia mater. Now, what will happen when that external support is lessened? This, of course, must occur, when the dynamic forces acting at the capillaries become weakened. If the blood is to circulate at all, a balance must be preserved between the pressure on the surface of the body and that within the skull; but at one point we find that the internal pressure is wanting in energy. The cranial wall cannot contract to keep up the necessary amount of support; the pia mater cannot leave the inner surface of the dura mater; the cerebro-spinal fluid cannot at once be augmented. The most likely result—or rather, I would say, the necessary result—

will be that the lateral pressure within the veins will now bear with greater effect in dilating the vessels. The flow of blood will be retarded, and until a stable equilibrium is again reached, more blood will enter the veins than will be discharged from the sinuses. The brain is thus allowed to become less vascular, and yet the whole pressure within the skull remains nearly the same. The mass of blood continues the same as before,—its mode of distribution alone is altered. A less proportion remains within the arterial and capillary vessels, while an increase is made in the veins of the pia mater.

Perhaps this argument may become a little clearer if I remind you for a moment of the distinction that is usually made by scientists between potential and actual energy. A stone lying on an elevated platform presses towards the earth with a force proportioned to its mass, but if the support be sufficiently strong, no immediate effect is perceptible. Lying on the platform the stone simply presents such properties of inertia as it would exhibit on the solid ground. But if the support be withdrawn, it falls to the earth with a force proportioned to the height of its descent. The momentum with which it reaches the earth constitutes the actual energy exerted, and it also constitutes the potential energy which, in virtue of its position, the stone possessed all the time it was lying on the platform. Now, the weight of the atmosphere bearing on the blood in the encephalic veins is a form of potential energy. When the brain is active, and its circulation is brisk, a certain balance of pressure exists, and the weight of the air, tending to keep back the blood within the head, produces no sensible effect. The lateral pressure within the vein is balanced by the support on its external surface, and the movement of blood within it is steady and easy. But let the external support be diminished, and an opportunity is then afforded for the potential to be converted into actual energy. Either the walls of the vessel must be sufficiently rigid to resist the weight of the atmosphere, or the vessel itself must yield to the lateral pressure, and become more distended by the flow of blood being retarded. Here there is no opportunity for the forward pressure in the arteries to bear with effect. The conditions for its activity have become unfavourable, and it must now await its turn of increased energy in the renewed activity of the molecular changes.

If it be admitted that in certain conditions of the brain the balance of the encephalic circulation is altered, the next stêp that should naturally be taken would be to show that no such change can take place without at the same time altering the balance of pressure in and on the brain.[1] As illustrating certain pathological

[1] In the July number of this Journal, there is a paper "On the Non-existence of Pressure on, or Compression of, the Brain," by Mr Neil M'Leod. He remarks, "The brain is subjected to pressure between, on the one hand, the force of the blood; on the other, the resistance offered by the rigid bony wall of the cranium—an example of action and reaction. This wall, being rigid, cannot exercise *active* force on the surface of the brain; but force is

conditions, this principle was long ago insisted on by Dr Abercrombie, but, except by Professor Bennett, its significance seems to have been overlooked by recent biologists. "As far as the explanation of morbid phenomena is concerned," says Dr Bennett, "the terms, 'changed circulation within the cranium,' and 'pressure on the brain,' are synonymous, as the one cannot take place without the other."[2] As this principle, however, is the necessary result of the fixed capacity and absolute fulness of the cranial cavity, it must equally apply to the phenomena of health. The energy exerted by a fluid does not depend alone on the impulse that is given to it, but also on the extent of area over which the impulse extends. In proportion, therefore, as a bloodvessel is increased in calibre, is the pressure of blood within it increased. Thus, if the area of brain-tissue in contact with a particular vein be doubled by the increase of the vessel, the pressure exerted by that vein, or rather by its contained fluid, will, in accordance with the law of equality of pressure in all directions, be also doubled. Of course, the pressure in some other vessels within the skull must be lessened to the same extent. On this tempting part of the subject, however, I cannot now enter. I have already made an attempt to apply the principle toward explaining the phenomena of sleep,[3] but I have no intention to inflict a résumé of that argument on you here. I cannot conclude, however, without saying that whether or not I be wrong in the views I have now ventured to submit, or in the application of these I have elsewhere attempted, I am confident not only that they refer to a subject which deserves to be studied, but that in forsaking the track so well entered on and prosecuted by the Scottish triumvirate—Monro, Kellie, and Abercrombie—biologists have been neglecting a field of inquiry which is not more interesting than it is certain to be fruitful.

always called into action in the form of resistance, which it offers to increased force from within." Throughout his paper, the author overlooks the fact, that there is a pressure of blood on the surface of the brain as well as through its substance. It must be remembered that the vessels of the pia mater are entirely outside of the nervous structures, and that they are being constantly flushed with rapidly-moving blood. Now, a fluid in motion must of necessity exert *active* pressure. If the distending impulse within the brain should, by any possibility, be sufficient to obliterate the layer of fluid which exists between the organ and its rigid envelope, instant insensibility must result. The cerebral circulation would be completely checked! I believe that some forms of epileptic seizure may be due to such an accident taking place over part of the brain's surface. The subject, however, is too wide to discuss in a footnote. I wish simply but strongly to insist, that energy, active in its nature and not due merely to passive reaction, is exerted at the surface of the brain, and that its amount will vary according to the rapidity of the blood's movement, or to the bulk of that fluid in the pia mater, or to the area of surface with which particular vessels are in contact.

[2] Library of Medicine, vol. ii.

[3] "The Causation of Sleep;" Edinburgh, 1872.

PRINTED BY OLIVER AND BOYD, EDINBURGH.