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ART. I.—*Considerations on the Circulation of the Blood, with Special Reference to Counter-Iritation, and to the Effect of Increased Atmospheric Pressure.* By ANDREW H. SMITH, M. D.

WHEN we consider the extreme intricacy of the vascular system, its infinite subdivision, and the immense variety of organs with their differing functions which are dependent upon the supply which it brings to them, and then reflect that the blood is propelled through this system by the action of one central organ, any change in which must affect all parts alike, we must be struck with the fact that each organ or tissue receives precisely its due share of blood—a supply varying exactly with the varying function of the part, and adapted with absolute precision to its physiological demands. And we cannot fail to perceive that the mechanism by which the quantity of blood thrown into the aorta with each cardiac systole is thus duly apportioned to all the parts of the organism must be one of extreme delicacy. Considering the blood-vessels from an anatomical stand-point, we find that this regulating power is confined to the arteries and the veins, the capillaries being destitute of contractile tissue. The arteries, and with some exceptions the veins, are supplied with muscular fibres, and are capable of contracting under stimulus conveyed to them through a set of nerves distributed to them, and named from their function the vaso-motor nerves. The contraction of an artery diminishes the supply of blood to the part to which the artery is distributed; while the contraction of a vein augments the resistance to the circulation and causes distention of the capillaries, and a prolonged sojourn of the blood in contact with the tissues. These varying actions are made to subserve the purposes of nutrition and function, and are presided over by the nervous system with a delicacy and accuracy so subtle and unerring as to seem like a localized intelligence, defying all attempts at analysis or explanation.

This regulating power is of extreme importance, since the amount of blood required in any given part is constantly changing, and depends upon the activity of the part for the time being. Whenever an organ, before at rest, is brought into action, a demand is occasioned for an increased supply of blood, and the vessels leading to the part dilate to the extent required.

I regard all function, with the exception of that of the organs of special sense, as the result of the chemico-vital reaction between the tissue of the acting organ and the blood which courses through its capillaries; and the nervous system as having no other office in this regard than that of regulating the supply of the nutritive fluid. Hence, blood being an essential factor, and the quantity in the system being pretty nearly constant, it follows that a number of activities cannot be carried on simultaneously for want of a sufficient supply of this necessary fluid. This conclusion, arrived at theoretically, is sustained by observation. We find that a proper performance of the digestive function is incompatible with great muscular activity; that the brain and the muscles cannot put forth at the same time the maximum of effort; and, when a full meal has created a demand for a largely-increased circulation through the capillaries of the stomach and intestines, the brain is rendered anæmic, and drowsiness results. No two of the great emunctories of the system can be stimulated to excessive action at the same time. A diuretic and a diaphoretic will not act well together, nor will either act during the operation of a cathartic. These well-known facts are usually explained by assuming that the nerve-force is the primary element in all these activities, and that it is a constant quantity, and cannot be expended in one direction without being proportionally deficient in others. This explanation, however, appears to me to involve difficulties which do not pertain to the one already given.

But fortunately there is seldom necessity for several activities at the same moment, and thus the organs which are at rest can spare the blood demanded by those in action. There is scarcely a moment during our waking hours that the equilibrium of the circulation is perfect. It is doubtless one of the objects of sleep that the circulation may be relieved for a time from the perturbating influence of the contending demands of the different functions, and the blood thus allowed to distribute itself simply according to mechanical laws, and to provide for a harmonious nutrition of all parts of the body.

Under certain conditions of disease it may become desirable to attempt to modify, artificially, the nutrition or the function of some given organ or part.

Among the means resorted to for this purpose *counter-irritation* holds a prominent place. This consists in creating an irritation in a healthy part in order to relieve a morbid condition in another locality more or less distant. This morbid condition is for the most part either inflammation or pain without inflammatory symptoms, and it is a matter of daily observation that these conditions may be relieved in a great many cases by the practice in question.

The *modus operandi* has been the subject of endless and acrimonious discussion, which still leaves us so much in the dark that Headland sums up our knowledge upon the subject in these words: "It appears that, as a consequence of the action of counter-irritants, the attention of the nervous system may be drawn off from the morbid process going on at some other part of the body;" and again, "The term '*counter-irritation*' is employed to express this action, the nature of it being but ill understood. A powerful impression on any surface of the body, external or internal, seems to be capable of arresting and diverting, as it were, the attention of the system, and thus, for a time, of checking a morbid process."—(On the "Action of Medicines," pp. 67, 97.) These statements are scarcely more intelligible and scientific than the famous aphorism that "Nature abhors a vacuum." They express, however, as clearly as it is possible to express any thing so intangible, the ideas intended to be conveyed by the term "*substitution*," the substitution of one morbid process for another by a sort of hoodwinking of the system. But "substitution" has to share the honors with "*revulsion*" or "*derivation*," terms employed to express the accumulation of an excess of blood in the place irritated, which excess is supposed to be drawn, wholly or in part, from the diseased locality. This idea has at least the merit of being intelligible, and expresses, I think, a partial truth. But it is met by the objection that the extra quantity of blood under a sinapism, for example, is so insignificant that its abstraction could have no appreciable effect upon a distant organ, with which there may be no direct vascular connection. This objection is valid from the stand-point from which it is taken.

Rejecting the idea that either the nerves or the blood-vessels play any considerable part in the action of counter-irritants, Mr. Ross[1] has put forward the theory that the effect is produced by a modification of nutrition, communicated from cell to cell of the intervening parenchyma, without regard to whether the tissues be continuous, or, as in the case of internal organs, merely contiguous. The absurdity of his theory is shown by one of his illustrations, that of flatulent colic, relieved by a sinapism to the abdomen. He affirms that the irritation causes a change of nutrition which is propagated from cell to cell through the integument, fasciæ, and muscles, until it reaches the inner surface of the parietal peritonæum, whence it is transferred to the visceral serous surface, and penetrates to the muscular coat. Here it produces an *improved nutrition*, which gives the muscular fibre sufficient power to expel the flatus. (!)

Except in cases resembling the above, in which the pain results from a mechanical cause capable of being removed by muscular action excited by reflex irritation, I hold that all the benefits resulting from counter-irritation are obtained di-

[1] "On Counter-Irritation: A Theory constructed by the Deductive Method of Investigation." By James Ross, M. D. London, 1869.

rectly or indirectly through the circulation. In the first place, I consider all pain (excluding that from extraneous irritation) as proceeding from imperfect nutrition, even though there be no evidence of inflammation. This is only in accordance with the proposition that there can be no derangement of function without change of structure. Now, if the morbid condition be one dependent upon the *quantity* (not quality) of the blood supplied to the part which is the seat of pain, then, in my view, counter-irritation may be of service, but not otherwise.

In the case of inflammatory action, the agency of the vessels will be admitted with less argument. But the difficulty in either case has been that already stated—that the *apparent* change in the circulation is too trivial to be credited with the results observed. I reserve the word "apparent," and on this reservation my entire argument will rest. With the exception mentioned in the foot-note,[1] in all the discussions upon this subject, up to the present time, so far as my knowledge extends, attention has been confined to the excess of blood contained in the irritated part. If, for example, the entire mass of tissue to which the irritation extends could be cut out at one stroke, and the blood expressed from it, the excess of this blood over what would naturally be contained in the same quantity of tissue, would represent what has been considered as the sum total of the change supposed to have been effected in the circulation at that point. Or, if the irritation was supposed to be reflected upon some other point, the result there was regarded in the same light.

It is here that I think a mistake has been made. *The question is not, how much blood the vessels of the irritated part will hold, but how much they will transmit in a given time.* This becomes evident when we consider that a given amount of blood passes through the capillaries of the body in each unit of time, and is transferred from the arterial to the

[1] The germ, from which the views here given are developed, is derived from a lecture by Prof. Virchow, which I heard in 1860, but which I have never seen in print. His reference to the subject was limited to the suggestion that increasing the capillary circulation in the part supplied by an arterial twig implied a diminution of the circulation in the capillaries derived from collateral branches.

venous side of the circulation, and that the quantity passing through any one part must affect that passing through the remainder of the body, since the latter must be the exact complement of the former. Thus, if in a given time four pounds of blood pass through the capillaries of the entire body, and one pound passes through the capillaries of the arms, it follows that three pounds must pass through the remainder of the capillary system. Now, if we plunge the arms into hot water, and dilate the vessels so that an additional half pound passes through them, the remaining vessels will transmit but two and a half pounds, and the tissues which they supply will be deprived for the time of one-sixth of their nourishment. It will be perceived that this is a matter entirely apart from the quantity of blood which might be contained in the arms if severed from the body.

The consideration of the increase of the carrying power of tubes, in comparison with the increase in their diameter, involves some of the most interesting points in the mechanics of fluids. The resistance to the passage of the fluid being derived chiefly from the friction against the sides of the tube, will increase in proportion to the ratio of the circumference to the area of the section. Now, the circumference of a circle increases directly as the diameter, while the area increases as the square of the diameter. The friction is obtained by dividing the circumference by the area, and therefore decreases directly as the diameter increases, as is shown by the following formula:

Diam.	Circum.	Area.	Friction.
a.	b.	c.	$\frac{b.}{c.}$
2 a.	2 b.	4 c.	$\frac{2\ b.}{4\ c.} = \frac{b.}{2\ c.}$

From which it appears that doubling the diameter of a tube quadruples its area, and at the same time divides the friction by two.

But, great as is this disparity, it is immensely increased in practice, especially when the tube is of very small calibre and tortuous or branching. The following experiments serve to show how slight an increase in the diameter of a tube will suffice to augment its carrying power enormously:

EXPERIMENT I.—A caoutchouc tube of 5 mm. bore, and 3 feet long, perfectly straight and of uniform diameter, was found to transmit a given quantity of water in 115 seconds. Another tube, of 6 mm. diameter, but perfectly similar in other respects, transmitted the same quantity in 65 seconds.

In this case an increase in the diameter of 20 per cent., and in the area of less than 40 per cent., gives an increase in the carrying power of nearly 100 per cent.

EXPERIMENT II.—A glass tube 10 inches in length, and having an inside diameter of .052 inch, gave passage to 6 drachms of water in 122 seconds. Another tube, of the same length, and under the same conditions, but having a diameter of .08 inch transmitted the same quantity of water in 20 seconds.

In this case the addition of one-half to the diameter of the tube allowed the passage of six times the quantity of fluid.

EXPERIMENT III.—The same tubes were used as in the last experiment, and all the conditions were the same, except that defibrinated bullock's blood was employed instead of water. The blood was previously strained through very fine linen. The smaller tube required 1,440 seconds to transmit 6 drachms; while the larger tube gave passage to the same quantity in 142 seconds.

The ratio here is one-half to ten, instead of one-half to six, as when water was employed.

In applying the results obtained from these experiments to the question of counter-irritation, we find that certain stimuli applied to the skin act in such a way upon the vaso-motor nerves as to cause a relaxation of the terminal arteries, and a dilatation of the capillaries. If the irritation be considerable, the surface assumes a bright-scarlet hue, in the place of its previous flesh-color. Such a change in the color implies a very considerable increase in the diameter of the capillaries.

EXPERIMENT IV.—A tall narrow vessel was partly filled with water, at the temperature of 120° Fahr., and the naked forearm thrust into it to near the elbow, the arm resting upon a support. Enough water was then added to exactly fill the vessel. Within half a minute the vessel began slowly to over flow and continued to do so for several minutes. At the conclusion of the experiment, it was found that half an inch of water had been displaced. This, of course, represents a corresponding increase of volume in the arm, and, as this could take place only by an increase of the quantity of blood in it, it follows that half of a cubic inch of blood was added to the amount present before the observation. This represents the increase in the *area* of the capillaries, and measures what has heretofore been considered the extent of the effect produced upon the circulation.

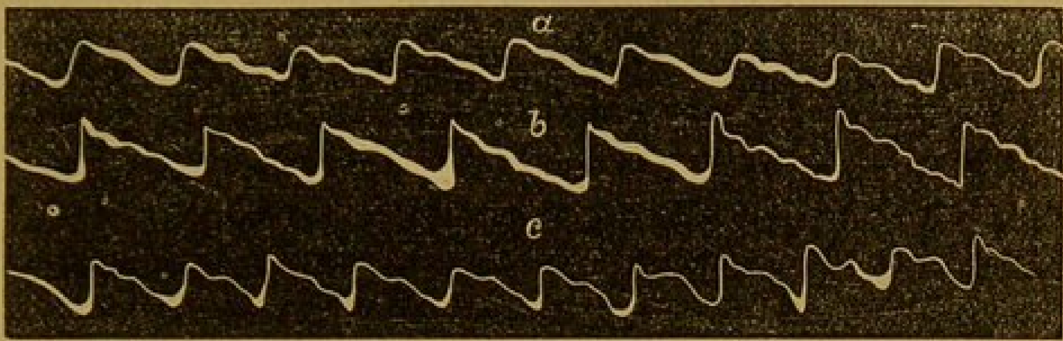
But, in view of the results observed in Experiment III., it will be seen that this can by no means be taken as a criterion of the effect obtained, the increase in the carrying power of the vessels being so greatly in excess of the increase in their area.

This increased carrying capacity is illustrated in an extreme degree by an observation of Bernard. He found that, by galvanizing the branch of the lingual nerve which is distributed to the sublingual gland, the circulation through the capillaries of the gland was increased to such an extent that the pulsation of the arteries was transmitted to the veins, and the blood escaped from the latter in jets.

Of course this excess in the circulation in one part implies a corresponding deficiency in some other part. Were the blood-vessels passive tubes, the deficiency would at once be distributed over the whole body; but the larger arterial trunks, at a distance from the point of irritation, but between it and the heart, contract in proportion as the pressure upon them is lessened, and thus the effect is confined within a limited area, and the excess is at the expense of neighboring vessels.

When, however, a large portion of the surface of the body is exposed to an action affecting the area of the capillaries, the entire circulation is changed as the result. This is shown by the following experiment:

Experiment V.—By means of the sphygmograph, a tracing was obtained of the pulse of a young man in full health and under ordinary conditions, the temperature of the air being about 82° Fahr. The pulse was found to be of fair volume as represented at *a* in the annexed cut. Without disturbing the instrument, the lower half of the body was then immersed in water at 70° Fahr. After the feeling of chilliness had passed off, a second tracing was taken. The pulse was much larger and stronger, as is shown at *b*. Hot water was then added to the bath, until a temperature of 120° Fahr. was obtained. A third tracing then showed the pulse to have less volume than before, and less tension than in the normal state.



The effect of the cold bath in this case was to contract the vessels in that portion of the body to which it was applied. The result was, that the blood, meeting with increased resistance in that half of the body, was distributed in greater proportion to the part where the resistance was normal, and hence a larger pulse at the wrist. When the temperature of the bath was raised to 120°, the vessels of the lower half of the body relaxed, and again presented an easy passage for the blood, restoring the equilibrium, and hence the radial pulse became smaller.

But, aside from this direct action in the immediate vicinity of the part irritated, there may be in some cases another action in parts more remote. A reflex impression may affect the vaso-motor nerves in parts having the requisite nervous or "sympathetic" relation to the one irritated, and this transferred action would then be the same in kind as that already described, and a similar change in the circulation would result. Bernard found that applying acetic acid to the tongue produced a very marked change in the circulation of the sublingual glands, the amount of blood coursing through their capillaries being immensely increased, and the blood in the veins of the glands retaining its arterial hue.[1] Numerous other examples might be cited, showing that the circulation in one

[1] Leçons sur la Physiologie et la Pathologie du Système nerveux.

part may be modified by irritation in another, but they are so familiar that they will immediately suggest themselves to the reader.

There are, then, as I conceive, four conditions in which counter-irritation may act to relieve pain, or abate inflammation:

1. When there is a direct vascular connection between the irritated surface and the diseased part. In this case, counter-irritation acts by opening a larger passage for the blood through the sound tissue, and thus diverting the circulation in part from that which is diseased. An example of this is afforded by the application of blisters to the neighborhood of inflamed joints.

2. When a large surface is exposed to the irritating agent, in which case the entire circulation of the body, including that of the diseased part, may be modified. An example of this may be found in the use of hot foot-baths, to relieve congestions of the thoracic or abdominal organs, or of hot applications to the chest and abdomen to relieve wakefulness.

3. When the irritation is transferred to a distance by reflex action, and there simulates the first condition. As an example of this, may be cited the employment of blisters to the breast, to act upon the lungs, there being no direct communication between the vessels of the skin and those of the diseased organs.

4. When pain is the result of a mechanical cause, which cause may be removed by exciting muscular action through the reflex function; as when, in flatulent colic, the muscular coat of the intestines is brought into action by irritation applied to the abdomen, and expulsion of the flatus results. Of course, two or more of these conditions may coexist, and probably in most cases such is actually the fact, and the result is thus rendered more or less complex.

There is a secondary consequence of the dilatation of the vessels which I have described, which may be mentioned, though its practical importance is probably not great, except in rare instances. I refer to the fact that, when the capillaries of a part are widely dilated, the blood, being in excess of the physiological demand, does not acquire the full venous character, but preserves to a greater or less extent the properties of arterial blood, even after it reaches the veins, as in Bernard's experiment already referred to. It is conceivable that some of the relief afforded in cases of dyspnœa by enveloping the chest in a sinapism may be owing to this cause, the blood reaching the lungs in a condition to require less than the usual amount of oxygen.

If the views which I have advanced respecting the effect of counter-irritation upon the circulation be correct, it follows that the aim should be so to manage the irritation as to cause the greatest possible flow of blood through the part. We should, therefore, stop short of inducing inflammation, as this tends rather to impede or arrest the capillary circulation than to promote it. More effect will be produced by irritating a large surface to a moderate degree, than by exciting an intense action within narrow limits. This is illustrated in the advantage which is derived from "flying blisters" in subacute inflammation of the joints or in sciatica. These blisters are applied for a short time only, so as not to produce complete vesication, and are repeated at short intervals. They are found to be much more efficacious than when the full action of a blister is produced.

It is not intended by this suggestion to ignore the effect which may result from the evacuation of serum by means of vesicants, or of the drain which may be established by maintaining suppuration from a blistered surface. This comes under the head of depletion rather than of counter-irritation, the latter being merely incidental to the former.

In examining the capillary system, we shall find that the skin on the one hand, and the mucous membranes and the solid internal organs on the other, are very richly supplied with these vessels, while the muscular and cellular tissues have much fewer in proportion. Excluding the latter, we may, for the sake of convenience, speak of the cutaneous system and the visceral system of capillaries. These two systems, comprising so great a proportion of all the capillaries in the body, stand in a certain antagonism to each other. The health of the body requires that neither of these should receive for any considerable time an undue proportion of blood.

Such a condition involves a double departure from the normal state, as the excess in one system necessitates a corresponding deficiency in the other. Let us suppose, then, that the cutaneous capillaries are by any means increased in diameter to a considerable degree, as they may be, for instance, by the hot bath: we shall find as a result that, the resistance to the flow of the blood through them being diminished, a much larger proportion will seek that channel to reach the venous system than will pass through the capillaries in other portions of the body. As a consequence, the remainder of the body will be left with an insufficient supply. We may sometimes observe the results of this in phenomena appreciable to the individual. Thus, the lassitude felt after the warm bath may be attributed to imperfect nutrition of the muscles from the insufficient supply of blood to them resulting from this action. The tendency to syncope produced by the protracted use of the warm bath is probably owing to the diminished supply of blood to the brain, caused by the increased facility for its passage through the capillaries of the skin. On the same principle, the wakefulness of insanity may sometimes be overcome by hot applications to the chest and abdomen.

The converse of this is observed in the vigor which results from the use of the cold bath, or from exposure to a cold and bracing atmosphere. Here we have the vessels of the skin reduced in calibre, and as a consequence a greater proportion of the blood sent out by each contraction of the heart is compelled to find its way to the veins through the capillaries of the muscular and nervous systems.

But, under certain conditions not well understood, an impression of cold upon the surface leads to such a diminution in the cutaneous circulation, and consequently to such a distention of the visceral capillaries, as to induce a lesion of some one or more of the viscera. The pneumonia, bronchitis, nephritis, or diarrhœa, as the case may be, is then said to be the result of "taking cold." If in the very earliest stage the warm bath or some internal sudorific be resorted to, and a free channel thus opened in the skin for the passage of blood, the internal organ may be relieved, and the threatened disease averted.

But an impression of cold upon the surface may, under some circumstances, prove salutary. Thus, in syncope, we dash cold water into the face and upon the chest, in order, as we say, to rouse the system by the sudden shock. The shock may perhaps have something to do with the result, but we do not find other means of rousing the nervous system to be equally efficacious. Shaking, flagellation, etc., so useful in opium-poisoning, do not approve themselves to us in this case. But cold water, combining with the shock a sudden contraction of the cutaneous vessels, and thus forcing more blood into the internal organs, including the nerve-centres, is an agent which has been used from time immemorial with success.

Medicines which are supposed to have a certain degree of control over the diameter of the capillaries are described in works on materia medica, and not unfrequently prescribed in cases in which the design is to affect the circulation in some diseased locality through the general action of the drug. The reasoning is as follows: "This medicine acts upon the capillaries—the capillaries in the diseased organ require such action —*ergo*, the medicine is indicated." Now, if the diseased part is supposed to be acted upon only as a portion of the general organism, and not from any special relation to the medicine, the employment of the latter must result in disappointment, for the simple reason that, if all the capillaries of the body are acted upon alike, no change in the distribution of the blood will ensue. The most that can happen is, that the labor of the heart will be increased or diminished. The same result would be attained by employing a cardiac sedative or a cardiac stimulant.

These remarks will apply to the use of opium and of ergot as antiphlogistics. I do not intend to raise a question as to their efficacy for this purpose, but merely to attack the theory of their supposed mode of action, which I believe to be untenable; unless, indeed, it can be shown that the capillaries of inflamed parts are peculiarly sensitive to their influence.

Closely allied to this subject is one which has recently assumed especial importance in connection with a new method of laying the foundations of piers for bridges. I refer to the physiological and pathological effects of high atmospheric pressure.

In constructing the piers for the bridge across the Mississippi at St. Louis, in 1869, a novel plan was adopted for reaching the rock below the bed of the river. An immense diving-bell was constructed, having the horizontal dimensions of the proposed pier. This was sunk down to the bed of the stream, and upon its top was built the masonry of the pier. The interior of the bell—or *caisson*, as it was termed—was kept clear of water in the usual manner, by forcing in air through pipes leading from pumps located on the shore. Excavation was carried on within the caisson, the earth being removed through a shaft in such a way as not to permit the escape of air. As the work progressed, the caisson was constantly sinking into the earth, while the masonry above was being built up in the same proportion, so as always to keep the top of the pier above the surface of the water. In this way, the earth being removed from beneath and the stone being added above, the vast structure, having in the case of one of the piers an area of thirty-six hundred square feet, was carried down to a depth of one hundred and ten feet, when it rested upon solid rock. The interior of the caisson was then filled up with concrete, and a perfectly solid foundation for the pier was secured.

Of course, in proportion as the caisson descended, the pressure of the air required to keep out the water constantly increased, until at last it attained the enormous figure of fifty-five pounds to the square inch in excess of the normal rate, a pressure nearly equal to the maximum capacity for resistance of an ordinary steam-boiler, and twice as great as the working pressure usually employed.

It was to be expected that such a pressure would exercise a very decided influence upon those exposed to it, but experience proved that the effect was much less than was anticipated. Beyond an unpleasant sensation in the ears while passing through the air-lock on entering or leaving the caisson, there was no uncomfortable feeling whatever. It was observed, however, that the pulse was accelerated to the extent of about 20 beats per minute, during the first hour of the sojourn in the caisson, after which it fell to about 20 beats below the normal standard.

The phenomena resulting from the increased pressure were minutely studied by Dr. A. Jaminet, of St. Louis, who has published a very interesting monograph upon the subject,[1] to which I am indebted for the facts referred to in this connection, so far as they relate to observations at St. Louis.

It was not until the pressure had reached twenty-four pounds to the square inch, that the workmen began to suffer. The symptoms, which were almost constant, were violent epigastric pain, shooting pains in the back and extremities, and coldness and pallor, or, in some cases, lividity of the skin. In a large proportion of cases there was associated with these symptoms a degree of paralysis, most frequently assuming the form of paraplegia, but sometimes involving at the same time one or both of the upper extremities. In a few instances the paralysis remained permanent, but in most cases it passed off in the course of a few days. Some of the patients in whom there was no paralysis were able to resume work on the following day.

Ninety-seven cases occurred, with eight deaths. The *post-mortem* appearances indicated an intense degree of congestion of the brain and spinal cord, and, in some cases, softening. The abdominal viscera were also more or less congested.

But what was very remarkable, and contrary to all expectation, was, that at no time during the progress of the work, even when the greatest pressure was attained, was any inconvenience experienced *while in the caisson.* It was invariably while the pressure was being lessened in the air-lock, or after emerging into the open air. Hence it would appear that it was not the pressure, but the removal of the pressure, which produced the pathological result. Dr. Jaminet rejects this obvious inference, and considers that the symptoms observed were due entirely to exhaustion caused by excessive tissue-change resulting from increased consumption of oxygen.

As this method for submarine operations has been adopted by the Brooklyn Bridge Company, and is likely hereafter to be frequently resorted to, it becomes important to determine, if possible, what is the true explanation of the pathological phenomena in question.

It appears to me that all the facts of the case point plainly

[1] "Physical Effects of Compressed Air." By A. Jaminet, M. D.

to a derangement of the circulation as the chief cause of the symptoms observed.

In considering the effect of increased atmospheric pressure upon the circulation, it is plain that it will vary according as the vessels interested are located in a part which is soft and compressible, or in a cavity the walls of which are firm and unyielding. In fact, the result in these two cases will be directly opposite. In the first the tendency will be to press the sides of the vessels together and expel the blood they contain, provided it can find any place to escape into where the pressure is less. In the second case the vessels will be protected from pressure from without, and would be entirely unaffected were they not in communication with other vessels exposed to such pressure. Such being the case, however, they will necessarily receive blood from these latter vessels until an equilibrium of pressure is produced.

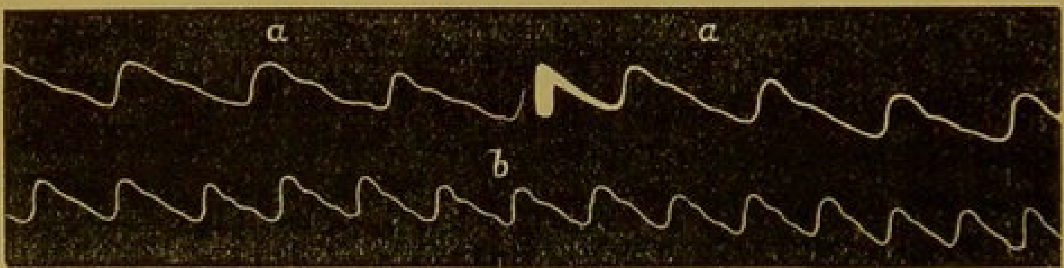
Now, the vessels of the body generally, exclusive of the bones, fall into the first category, while those within the cranio-spinal cavity belong to the second. It follows, therefore, that in a condensed atmosphere a man will have more blood in his brain and spinal cord than in the normal state. This accords precisely with the results of the autopsies in the fatal cases recorded by Dr. Jaminet. In every instance the brain and spinal cord were found to be intensely congested.

But the pathological results cannot be attributed to this congestion, else they would be developed while in the caisson instead of after leaving it. In fact, the congestion seems to exert no unfavorable influence upon the function of the cerebro-spinal axis, probably because the pressure is so equably distributed. But how does the matter stand when, after an equilibrium has been established between the vessels of the general system and those of the cranio-spinal cavity, the pressure is suddenly removed from the former? Obviously there must be an action the reverse of that we have just considered, and there must result a reflux tendency from the brain and spinal cord toward the general circulation, in order to reestablish the equilibrium. This would oppose the current of blood going from the heart to those parts, and a more or less perfect arrest of the circulation in the smaller vessels would result. This would be aided by the ready yielding of the vessels of the general system, whose tone would be lost in proportion as it had been superseded by the external pressure. In this way a channel would be opened for the blood, which it could take much more readily than to overcome the current from the brain and cord. Hence, we should have these latter organs congested with effete stagnant blood, which not only would afford them insufficient nourishment, but would expose them to the ulterior danger of embolism. The fact that, in every case narrated by Dr. Jaminet, in which death was delayed for a sufficient time, softening of portions of the brain and spinal cord was found, points strongly to the probability of the occlusion of some of the vessels by thrombi, although in only one instance the finding of an embolus is mentioned.

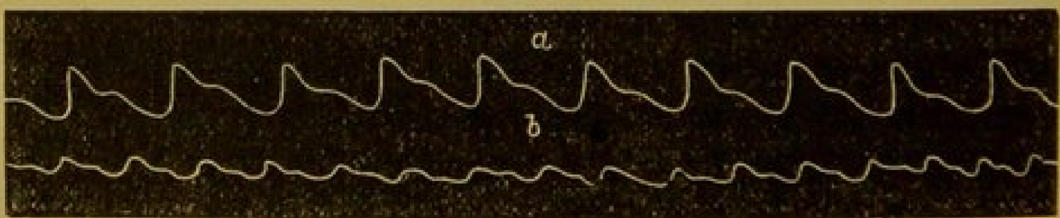
This reasoning derives additional support from the fact already stated, that, while the pulse was accelerated during the first hour or two passed in the caisson, it afterward fell about 40 beats, being 20 less than the normal rate. This shows a process of gradual adaptation to the new conditions, effected probably chiefly through an excessive evacuation of fluid from the system. The quantity of the urine was greatly increased, and the perspiration was also augmented to a very great degree. It is not possible that a result, thus gradually reached, could give place at once to the normal state, on removal into an atmosphere of normal density. A somewhat gradual process of readaptation would be necessary, pending which grave accidents might well occur. The experience of Dr. Jaminet shows that the longer the time passed in the caisson, and consequently the more perfect the adaptation to the increased pressure, the greater will be the danger on coming out.

That bad effects do not follow in every case, is only in accordance with what is observed in regard to exposure to cold, or to malaria, contagion, etc.

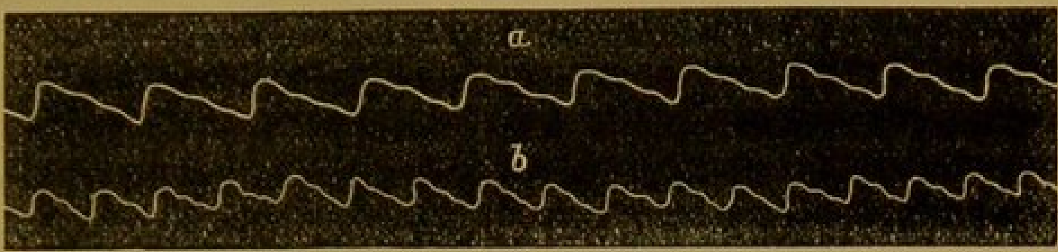
The method already described has been adopted in sinking the piers of the Brooklyn Bridge. During the past year I have had several opportunities of studying the circulation in the workmen in the caisson on the Brooklyn side, for which I am indebted to the courtesy of Mr. Collingwood, one of the engineers. I invariably found the pulse accelerated, ranging in different persons between 102 and 132. At the same time the volume was sensibly diminished. On one occasion I took sphygmographic tracings of the pulse of several of the men before they entered, and again while in the caisson, after being exposed to a pressure of thirty-two pounds to the inch for about an hour. In order to insure the reapplication of the instrument in precisely the same manner, the following precautions were observed: To the end of the tape which secured the instrument in position, I attached a light weight which was allowed to hang down, and exert an even and constant traction upon the tape, while this was being passed backward and forward across the back of the wrist, and over the hooks attached to the instrument. This weight being the only traction applied to the tape, there was insured a uniform degree of pressure. After the first tracing was taken, and before the instrument was removed, the outline of the pad was traced on the wrist with ink. At the second adjustment the pad was so placed as to exactly coincide with this outline. These precautions rendered it easy to adjust the instrument the second time precisely as it was when the first tracing was made.



The annexed figures show the effect produced by the increased atmospheric pressure. It will be observed that the pulse is accelerated in every case, while its volume is lessened, and the dicrotism generally somewhat increased. This is due to



the difficulty which the heart experienced in driving the blood through the vessels, narrowed by the extraordinary atmospheric pressure. These tracings, which I believe to be the only ones ever made under like conditions, afford abundant evidence of the profound disturbance of the circulation which



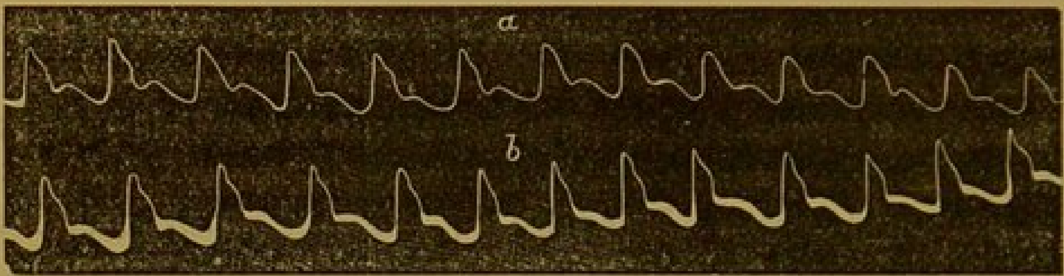
takes place, and are strongly suggestive of the consequences which might result from a sudden reversal of the conditions in persons whose circulatory apparatus was not in perfect vigor.

A few cases of paralysis occurred while sinking the Brooklyn pier, but all speedily recovered.

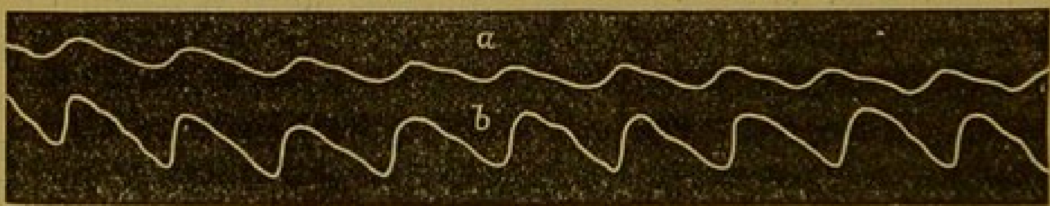
The treatment employed by Dr. Jaminet consisted almost entirely in the administration of alcoholic stimulants and beef-tea. This was in accordance with his theory of exhaustion, and was fairly successful. But, if the views which I have advanced as to the etiology of the affection be correct, the treatment should aim to diminish in some way the area of the vascular system. The most efficient plan would be to have a chamber constructed in which air might be condensed to nearly the extent of the pressure in the caisson. The patient being placed in this, the pressure should be raised by degrees to a point approximating that under which he had been working, and then be very gradually reduced until it reached the normal standard. Or, a like effect in a less degree might be produced by bandaging firmly the extremities, and, as far as practicable, the trunk. At the same time, those medicines should be administered which tend to give tone to the vessels and diminish their calibre. This effect is attributed to opium, and the cold and clammy state of the surface would seem to call for its use in stimulating doses. But, theoretically, ergot, which stimulates unstriped muscular fibre everywhere to contraction, should be specially efficacious. It is contended that, when gangrene is produced by this substance, it is by its inducing spasm of the arteries, and thus shutting off the supply of blood from the extremities where the circulation is at all times relatively feeble. This action in a proper degree is precisely what is required in this case to stimulate the lax and yielding vessels to contract upon their contents, and thus to give increased force and velocity to the circulation.

This action of ergot may be demonstrated by the sphygmograph, as in the following experiment:

EXPERIMENT VI.—A tracing was taken of my own pulse under normal conditions, and again twenty minutes after taking a drachm of the fluid-extract of ergot. The result is shown in the annexed cut, in which the upper line represents



the normal pulse, and the lower one the pulse after taking the ergot. The increase in the volume expresses the increased capillary resistance. Though, according to the theory of Marey, the excursion should diminish in proportion as the capillary resistance increases the arterial tension, yet experiment shows that obstructing the venous circulation, which likewise causes increased tension in the artery, has the effect of augmenting the excursion. This is shown in the tracing below, in which the increased volume is the result of placing



a ligature above the elbow, as if for a venesection. A like effect is produced by holding the breath, the unaërated blood passing with difficulty through the capillaries.

Alcoholic stimulants, by imparting increased energy to the heart, will be useful, but their effect will be much greater when the vessels have regained their tone, on the principle that a pump of a given power will deliver much more fluid through a rigid than through an elastic tube.

Dr. Jaminet was led to prohibit the use of the warm bath as a remedial measure, from observing that it aggravated the tendency to paralysis. In fact, in several instances paralysis came on while the patient was in the bath. The train of reasoning which I have adopted would lead us *a priori* to expect this result, as the warm bath would relax still more, if possible, the already passive, toneless vessels.

Dr. Jaminet recommends that the time passed in the air-lock when going into the caisson should be twice as long as when coming out, he considering that the system requires more time to adapt itself to an increased than to a diminished pressure. But the facts point to a directly opposite conclusion, and I cannot see that their force is lessened by the view which Dr. Jaminet defends. Inasmuch as the ill effects occur in every case while the pressure is being restored to the normal standard, or within half an hour afterward, I should make this restoration as gradual as possible.

As a prophylactic measure, the use of a moderate quantity of an alcoholic stimulant immediately before leaving the caisson would no doubt be advantageous. This would give the heart greater power to cope with the difficulties about to be encountered in the changed conditions of the circulation.

But, above all else, the duration of the sojourn in the caisson should be regulated to correspond with the degree of pressure. The greater the pressure, the more rapidly will the circulation go through the process of adaptation, and the sooner it will reach a given degree of departure from the normal state. In proportion to this departure is the danger when the pressure is removed. Hence, the hours of labor should be diminished as the caisson descends. Dr. Jaminet found that, with a pressure of fifty pounds, the men could not work longer than two hours at a time without serious danger.

My object in writing this paper has been to present certain mechanical points in reference to the circulation, which I believe to be of practical importance. The tendency of the present day is to confine our investigations too exclusively to the domain of the microscope and the test-tube, to the neglect of other studies equally important. The mechanics of medicine deserves to be elevated into a distinct branch of medical science, and offers a field for the display of the highest qualifications for scientific investigation.

ART. II.—*The Origin of Cæsarean Section; an Historical Sketch.* By C. F. RODENSTEIN, M. D., Westchester, N. Y.

SURGERY is an art which gives no scope to the exercise of the imaginative faculty. Within its domain romance and poetry find no material for idealization. The operation for cataract and the Cæsarean section form, perhaps, the only exceptions to this remark. The exact investigations of modern ophthalmology have robbed the first of the awe and mystery which attended its performance, when learned Arabians and less learned mountebanks travelled through Europe and restored sight to the rayless orbs of the blind; but to the second cling still some of the vague terrors inspired by surgical procedures not perfectly understood, some of the mythological mists of the ages in which it is said to have originated.

In fact, there is something in the very circumstances under which this operation is performed, which excites an undefined dread. The very process of parturition is shrouded, to the unprofessional mind, I know not in what halo of sacredness and mystery. When labor is difficult or obstructed, the interest is heightened; and that mingled sentiment of dread and anxiety, of alternate doubt and hope, culminates when, in the most desperate crisis of dystocia, Cæsarean section is performed, as the last resource of obstetric art.

Sometimes this heroic intervention is adopted to save two lives from impending destruction; sometimes to save a mother after her child has already been sacrificed to her safety; sometimes the dead body of a woman is opened to deliver a living child, thus literally rescuing life from the embrace of death.

An operation so grand in its simplicity, so brilliant in its success, so mysterious in its disasters, is well calculated to im-