made the subsequent procedure of matching the colors difficult and often decidedly unreliable. Thus, an otherwise delicate and accurate method of analysis became under certain circumstances, wholly unreliable.

In some recent work in this laboratory,[2,3] the use of the reagent was often accompanied by pronounced turbidities, and in instances involving relatively large amounts of copper, some actual precipitation resulted. An attempt was made, therefore, to remedy this situation. Considering that the turbidity and precipitation were the result of the coagulation of a colloid, it was at once suggested that some suitable protective agent might solve the problem. With this in view, gum tragacanth and gelatin were used and found to solve the difficulty. Both these colloids were equally effective and satisfactory. Having found a way out of the situation, no other colloids were studied. Undoubtedly there are others quite as suitable for the purpose.

The following outline is offered as furnishing conditions under which satisfactory results may be obtained as indicated by the experience of the writers with the modified method. When the final volume of the carbamate mixture is somewhat less than five cc there is sufficient volume for matching colors in a microcolorimeter, or block comparator. In the latter, small calibrated fermentation tubes or Wassermann tubes are useful. The various proportions used were as follows: 1 to 2 cc of the unknown copper solution; 1 cc of the gelatin or gum tragacanth solution, freshly filtered; 1 to 2 cc of copper free water, depending upon the volume of the unknown used; and 0.6 cc of the carbamate reagent (conc. 0.1 per cent.). The total volume is thus kept at 4.6 cc.

When graduated pipettes are used in the measurements, the errors obtained in matching a series of ten standards (0.01–0.10 mg) against a duplicate set of standards were found to lie between 0.0001 and 0.0020 mg of copper. If a microburette is used with a similar set of standards, the errors between the observed and calculated values lie between 0.0001 and 0.0010 mg of copper. The accuracy may be improved by selecting the range of standards lying between 0.01–0.04 mg, where the errors were found to be less, namely, 0.0000 to 0.0006 mg of copper.

A preliminary determination on the unknown will show the dilution necessary to make it fall within the more accurate range, *i.e.*, 0.005 to 0.04 mg of copper in one cc of the solution.

The reduction in the amount of the unknown, as described above, makes it possible to begin with an amount of original material containing from 0.05 to 0.40 mg of copper and subsequently dilute the volume of the unknown to 10 cc. This volume is ample for making from four to nine determinations, depending upon the copper concentration.

HAL W. MOSELEY
ARTHUR G. ROHWER
MARGARET C. MOORE

DEPARTMENT OF CHEMISTRY
TULANE UNIVERSITY

[2] Moseley and Rohwer, "The Determination of Minute Amounts of Copper," unpublished thesis, 1933, Tulane University.

[3] Moore and Moseley, "Examination of Oyster Liquors for Copper," unpublished report, 1933, Tulane University.

SPECIAL ARTICLES

THE THIRD MAJOR MECHANICAL FACTOR IN THE CIRCULATION OF THE BLOOD[1]

NEARLY 25 years ago during studies on the heart and the circulation of the blood Henderson[2] was led to the opinion that besides the heart and the vasomotor nervous control of the blood vessels there must be a third factor in the circulation. It is the factor that sends the blood back to the heart through the veins. Without it the blood would stagnate in the tissues instead of returning to the heart. To the factor that insures the venous return to the heart he gave the name of the "Venopressor Mechanism."

In spite of a vast deal of work no one has succeeded in defining just what the venopressor mechanism is. It is important to know: for it is the failure of this third mechanical factor in the circulation, rather than that of either the heart or vasomotor system, that causes the weakened circulation of the blood following illness and the extreme depression of the circulation in surgical shock.

There have been many attempts to explain the variations of the venous return and their regulation by contraction or relaxation of the veins. The vasomotor nervous system influences veins as well as arteries. But no explanation of the venous return under vasomotor regulation that is mechanically satisfying has been developed. Experimentally it was found by Henderson and Harvey[3] that, if the entire vasomotor mechanism is stimulated by an injection of adrenalin, both arterial and venous pressures rise. But if the injection of this vasomotor stimulant is continued, only the arterial pressure is maintained; venous pressure falls again to its former level. Clinically also adrenalin fails to restore a de-

[1] Read before the National Academy of Sciences on April 24.

[2] Y. Henderson, *Am. Jour. Physiol.*, 27: 152, 1910.

[3] Y. Henderson and S. C. Harvey, *Am. Jour. Physiol.*, 46: 533, 1918.

pressed circulation; it does not restore and maintain a normal volume and pressure of the venous return.

William Harvey 300 years ago recognized that every contraction of a muscle drives blood into the veins and on toward the right side of the heart. Every text-book describes this action. But this fact does not explain how, when a healthy man is lying motionless and relaxed, the blood is sent back to the heart. It does not explain why the force causing the venous return is so much diminished in states of physical depression.

It is well known that in health, even during complete bodily rest, every muscle in the body has tonus: that is, it exerts a slight pull. It is also well known that in physical depression, such as occurs even after an attack of influenza, the tonus of the muscles of the body is lessened. Simultaneously the circulation is weakened. But the lowering of general body tonus has always been imputed to the poor circulation. In reality, as our results indicate, the poor circulation is largely due to the lowered body tonus.

We propose now to reverse the present conception of cause and effect. We have reached the conclusion that the tonus of the muscles of the body is the principal force involved in the venous return. We have determined experimentally that a muscle in a state of tonus has an internal pressure. This pressure amounts to 50 to 70 mm of water column, even during complete rest. When muscle tonus is increased, this pressure is higher: up to 90 mm or more. When tonus is abolished the internal pressure is also abolished.

Our method of measurement is to thrust a hypodermic needle into the middle of a muscle, usually the biceps, and to determine the pressure required to cause a minute amount of saline to run in. We find that the intramuscular pressure varies with the tonus of the muscle. It is too small to have any considerable direct effect upon arterial blood pressure and flow into a muscle; but quite sufficient to exert a strong influence upon the venous outflow from a muscle.

Of course the so-called *vis à tergo,* the push from behind, imparted to the blood by the left heart, is the force that drives the blood into the vessels in the muscles. If the muscles have tonus a part of this force is taken up by their elasticity and presses the blood on into the veins leading to the right heart. But in the absence of muscle tonus the entire force of arterial pressure is lost in the flaccid tissues and the blood stagnates there instead of flowing on back to the right heart.

These mechanical relations are best understood by comparing them to the circulation of water in the atmosphere. The sun by its heat lifts water from the sea into the clouds. It supplies the energy, as the heart does in pumping blood from the low pressure in the veins up to the high pressure in the arteries. Meteorological conditions determine where rain shall fall, much as the vasomotor system controls the distribution of the arterial blood to the various organs. If the rain falls on mountains or a high plateau, the water runs back to the sea with a force that can be used to turn mill wheels or produce hydroelectric power. Such streams from high levels are analogous to the venous blood streams from muscles in good tonus.

If, on the contrary, the rain falls on a swamp at sea level or other low ground, the stream back to the sea is sluggish. Similarly, when the tonus of all the muscles in the body is low, the venous stream to the heart is sluggish. And because of the diminished venous supply to the heart the volume pumped by the heart into the arteries is diminished and the entire circulation is depressed.

It is not merely by positive pressure that muscle tonus promotes the flow of blood to the right heart. The negative pressure in the chest, which draws the venous stream toward the heart, likewise varies with the tonus of the thoracic muscles. After surgical operations and anesthesia involving even a slight degree of depression of vitality, or shock, the tonus of the diaphragm is decreased, and because of the relaxation of this muscle the so-called vital capacity of the lungs is diminished. In cases of considerable depression a partial atelectasis, or even a massive collapse of the lung, may develop. This relaxation of the diaphragm, established by x-ray observations, first suggested to us the relation of muscle tonus to the circulation.[4]

It has now become the general practise of anesthetists to terminate anesthesia with an inhalation of carbon dioxide. Surgeons find that this inhalation prevents atelectasis. It produces this result largely by increasing the tonus of the diaphragm. The lungs are thus expanded, and both the negative pressure in the thorax and the positive pressure in the abdomen are increased. As the anesthetic is eliminated, the increase of muscle tonus all over the body induces a rapid restoration of the pressure and flow of the venous stream to the heart and a corresponding increase in the volume of blood pumped into the arteries by the heart.[5]

This conception of the influence of bodily tonus upon the venous return affords a clear picture also of the relation of heat production and metabolism to respiration and the circulation. Basal metabolism is largely determined by the tonicity of the muscular

[4] For literature see Y. Henderson, *Jour. American Medical Association,* 95: 572, 1930.

[5] Y. Henderson, H. W. Haggard and R. C. Coburn, *Jour. American Medical Association,* 74: 783, 1920.

tissues of the body. The amounts of oxygen consumed and carbon dioxide produced determine the volume of the circulation needed to transport these gases between the tissues and the lungs, as well as the volume of respiration needed to exchange them with the atmosphere.

We can now see that muscle tonus, itself controlled from the central nervous system and considerably influenced by the respiratory center, is the basic factor determining both the amount of metabolism and the correlated volumes of the circulation and respiration.

In particular, we conclude that muscle tonus is a factor of prime importance in the venopressor mechanism.

YANDELL HENDERSON
A. W. OUGHTERSON
L. A. GREENBERG
C. P. SEARLE

YALE UNIVERSITY

A SPECIES AND GENUS OF FRESH-WATER BRYOZOON NEW TO NORTH AMERICA

FOUR years ago while collecting fresh-water bryozoa for class purposes in the Delaware and Raritan Canal at Princeton, New Jersey, the writer found on the leaves of water plants small colonies, of from four to thirty polyps each, which were at first taken for very young colonies of *Pectinatella* or possibly colonies of this form which remain flat without forming the prominent globular mass of jelly that usually characterizes this species. It was noticed, however, that the colonies were not round but roughly triangular in shape, with the polyps mostly on one side and the opposite angle well drawn out. It was then seen that the colonies were freely motile, moving up to as much as three or four inches per day. They were then surmised to be the genus *Lophopus* until an examination of the statoblast showed the swim-ring (Fig. 1) to be an elongate oval over a millimeter in length with a group of rod-like projections at each end, each rod bearing from two to eight strongly curved hooks. This was so remarkably different from any of the other hook-bearing statoblasts of the Phylactolaemata that it was realized that the species was new to America at least.

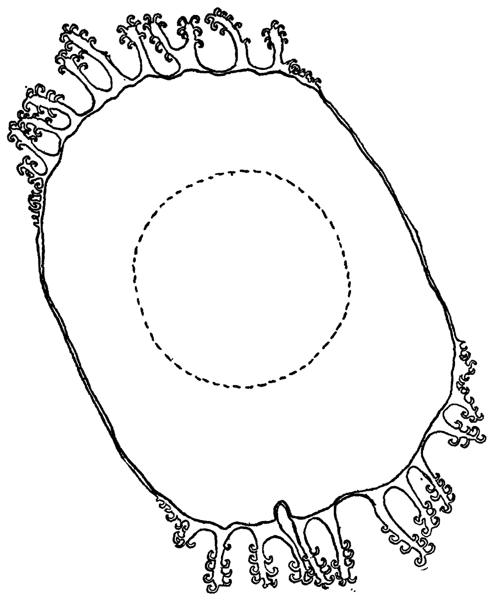

FIG. 1

The phylactolaematous bryozoa of eastern North America had been so faithfully collected and studied by Leidy, Hyatt, Potts, Davenport and a host of others that it seemed impossible that this very abundant form could have been overlooked.

It was found that the genus had been recorded by H. J. Carter in Bombay, India, from a single statoblast in 1859. He called it a species of *Lophopus.* In 1881 Hyatt recognized that it was not a *Lophopus* and made it a new genus *Lophodella carterii,* naming it after its first discoverer. Annandale has found it abundantly and widespread in India in 1911. Kraepelin in 1906 and Vorstman in 1927 describe it from the East Indies and Siam, etc. Oka in 1906 describes it from Japan and Ulman in 1907 from equatorial Africa. Wherever it grows, it is very abundant, literally covering the leaves of plants as well as sticks and stones in favorable seasons. How then did it escape Leidy and his followers only forty miles from Philadelphia?

The writer concludes that it is a recent introduction, from India probably. He has collected extensively in the fresh waters around Princeton since 1890 and had never seen it until four years ago when it was abundant in the canal, but not in the lake or other Princeton streams or ponds. Last season, 1933, it appeared in the lake and Millstone River in abundance. It will be interesting to trace its further spread. The statoblasts are very resistant and could have been easily transported from India and introduced into the canal on many kinds of cargo. It resists the winter, although it comes from a warm source. It is a beautiful form, splendid for class work, easily kept in aquaria and easily expanded for study. The body is clean, not dirty, like *Plumatella.*

ULRIC DAHLGREN

PRINCETON UNIVERSITY

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