purely natural sciences like astronomy and entomology. For not only is the earth spherical and therefore limited in extent but man's period of occupancy is relatively short. In other words, while prehistoric archeology of necessity was one of the last special branches of research to get really under way, it is likely to be the first to finish its task. Indeed, if archeological investigations, historic and prehistoric, continue to progress at the same accelerating rate as in the past, it would seem that the next hundred years or so might easily see us in possession of all the essential facts. Those more or less indestructible facts or documents once in hand and the spade set aside, archeologists may have to change their titles to those of curators or something even less high-sounding. At all events, those professionally concerned may then devote their entire time to the permanent arrangement and final interpretation of all the available material culture traits, with a view to offering a visible demonstration of how, step by step from small beginnings, things as they are in the human world actually came to be so. That accomplished, when every one has become familiar with our recreated past, we shall be more nearly free and in the best possible position to give our whole-hearted attention to the really major creative problems of the present and the future.

HOW BREATHING BEGINS AT BIRTH[1]

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ONE of the oldest problems of science is: Why does the baby begin to breathe at birth? The purpose is clear; but the cause and means are obscure.

Half an answer has long been available. It is well established that for many weeks or even months before birth the fetus makes distinct rhythmic respiratory movements. Ahlfeld[2] in 1915 published excellent graphic records of these movements. They were taken from the surface of the mother's abdomen. And a number of recent investigators have obtained moving pictures of respiratory movements in animal fetuses delivered by Cesarean section in a bath of warm saline.[3] But these movements are ineffective in expanding the lungs and keeping them expanded. The question then becomes: How are the feeble and ineffective respiratory movements of the fetus transformed into the effective breathing of the newborn?

The answer, I believe, is to be found in the fact that a certain function is deficient in the fetus; and that this function is quickly developed at birth and is then continually maintained throughout life. It is a function of critical importance alike for respiration, circulation and metabolism: the function of muscle tonus.

Many years ago I found that, when a man or animal dies, the muscles lose their tonus within five or ten minutes.[4] I was investigating various forms of manual artificial respiration. What I found was that only so long as tonus continues do the thoracic muscles and diaphragm retain a sufficient degree of elasticity to keep the lungs well expanded. And only so long as the lungs are thus held to a fair degree of expansion is manual artificial respiration effective. Pressure upon the chest, abdomen or back squeezes air out of the lungs. The inspirations that occur between compressions are produced wholly by the tonic elasticity of the victim's own muscles that pull the chest back to mid-expansion. After the body is entirely flaccid no form of manipulation can induce the slightest inspiration. When tonus is lost, the cubic capacity of the chest decreases and the lungs are correspondingly deflated. Even if the lungs are then inflated with a bellows, they deflate again as soon as the inflation is ended.[5] In normal breathing a large volume of air is held in the lungs even during expiration: the so-called stationary air.

The maintenance of a considerable volume of stationary air is extremely important. Unless the lungs are continually held in a sufficient degree of inflation, adequate aeration of the blood, either by artificial or by natural respiration, is impossible. Hess[6] has shown that even the movements of normal breathing may be regarded as essentially due to rhythmic variations in the degree of tonus in the respiratory muscles and particularly in the diaphragm. Extending this idea we may consider that the extent of the inflation

[1] Read before Connecticut Academy of Arts and Sciences, New Haven, Conn., December 10, 1936.

[2] F. Ahlfeld, *Monatsschr. f. Geburtsh. u. Gynäk.*, 21: 143, 1915.

[3] J. Barcroft, "The Brain in Its Environment," Yale University Press (in press).

[4] Y. Henderson, *Jour. Amer. Med. Assoc.*, Vol. 67: 1, 1916.

[5] The fact that no form of manual artificial respiration can directly induce an appreciable degree of inspiration affords no valid reason for the use of apparatus for artificial respiration. So long as tonus is present, manual methods are effective. When tonus disappears, the victim is dead beyond recall. Such apparatus as the pulmotor and others that apply suction to the lungs, promote, not recovery, but a further deflation of the lungs. For resuscitation in cases of atonic asphyxia of the newborn (*asphyxia pallida*) intratracheal insufflation is much more effective than any form of artificial respiration.

[6] W. R. Hess, "Die Regulierung der Atmung," Leipzig, 1931.

at which the lungs are normally held is a function of the tonus normally maintained in the respiratory muscles. The posture of the head and body in sitting or standing is well known to be dependent upon the maintenance of tonus in the muscles of the neck, back and legs. Similarly, the degree of inflation of the lungs that is maintained throughout life may be regarded as a posture dependent upon the tonus of the respiratory muscles. From birth to death the lungs are never deflated, because the diaphragm is never completely relaxed. For the development of effective pulmonary respiration at birth, tonus is essential.

The beginning of effective breathing may be aptly compared to the starting of an automobile. When the car is standing still, but with its engine running gently, we speak of its motor as "idling." And so it is with respiration before birth. The analogy may be carried even further. The baby that is born in asphyxia resembles a motor that is stalled. And as with the motor, so with the baby, a restoration of activity may be induced in two ways. The motor may be cranked and spun until, in spite of poor carburetion and ignition, a "cough" is induced. The baby likewise may be manhandled, as it formerly commonly was, until a reflex gasp is elicited. Or, on the contrary, in the car the carburetor and ignition may be adjusted until the motor starts at a touch. And in the baby the oxygen and carbon dioxide that its nervous system needs may be supplied by inhalation, as has now become the accepted practice; and resuscitation is thus effected without "cranking."

In such resuscitation it is not merely respiration that is involved.

Recently Oughterson, Greenberg, Searle and I[7] have produced evidence that muscle tonus normally plays a no less important and necessary part in the circulation of the blood. The slight pull that tonus maintains in all muscles even during relaxation induces a pressure between the muscle fibers like that produced between the strands of a rope under tension. This pressure prevents the blood from stagnating in the capillaries and promotes its flow into the veins and onward back to the heart. In the venous return muscle tonus plays an essential part. In the maintenance of the circulation the venopressor mechanism is second in importance only to the heart itself; for without the venous return the heart can not operate. The control of the venous return is exercised largely through muscle tonus by the motor centers in the spinal cord. It is distinct from the control of arterial pressure and the distribution of the arterial blood by the vasomotor, or sympathetic, nervous system. Cannon[8] has shown that, even after complete removal of the entire chain of sympathetic ganglia, animals (cats) may live in a fair degree of vigor. But, as I found 30 years ago,[9] when the venous return fails, the circulation stops; and as we have recently shown muscle tonus is an essential support for the venous return.

At birth the circulation undergoes a fundamental change. As the placental vessels contract, the blood is sent in full volume through the lungs. Previously the flow of blood back and forth between the fetus and the placenta has needed no support by muscle tonus. But at birth the circulation takes on a new vigor. The left side of the heart comes into action and arterial pressure rises to a higher level. For this adjustment a full venous return, induced and maintained by muscle tonus and intratissue pressure, is essential. This is shown by the fact that whenever, because of asphyxia during birth, tonus fails to develop, the flaccid baby exhibits the infantile form of shock, *asphyxia pallida*.

Before birth the fetus, floating in a fluid at body temperature, need produce little heat of its own. After birth the baby must assume the maintenance of its own heat supply to compensate for a continual loss of heat to a generally colder world. Normally the requirements of body temperature are soon met by the establishment of a basal metabolism sufficient to meet this requirement. And in the control of metabolism tonus plays a major part. The tonic pull of the muscles involves a consumption of oxygen, production of carbon dioxide and liberation of heat. And all these related functions are thus influenced by the nervous impulses from the motor centers in the spinal cord that chiefly induce tonus.

In respect then to the three vitally important functions of respiration, circulation and metabolism, the fetus has little need for tonus. But, if the baby is to establish and maintain its independent life, tonus is essential. In fact, the difference between the vigorous child and one that barely lives even in an incubator—the case of "Lebenschwäche" as the Germans term it—probably consists chiefly in the degree of their tonus. Even in the normal baby the lungs are dilated only gradually during the first day or two after birth. In the premature with a subnormal tonus the lungs may remain partially unexpanded for weeks. Along with the continuance of atelectasis the circulation is weak, metabolism and oxygen consumption low and heat production inadequate. Correspondingly the production of carbon dioxide is inadequate to produce full breathing; cyanosis develops; respiration is further depressed, and asphyxia ensues. Experience is showing that the most effective way to break this "vicious

[7] Y. Henderson, A. W. Oughterson, L. A. Greenberg and C. P. Searle, *Amer. Jour. Physiol.*, 114: 261, 1936.

[8] W. B. Cannon, *Amer. Jour. Physiol.*, 89: 84, 1929. Also "The Wisdom of the Body," New York, 1932.

[9] Y. Henderson, *Brit. Med. Jour.*, 2: 1872, 1906; and Y. Henderson and S. C. Harvey, *Amer. Jour. Physiol.*, 46: 533, 1918.

circle" is to stimulate an increase of tonus and deeper respiration by inhalation of carbon dioxide. Deeper respiration is the most effective means of inducing a better oxygenation of the blood; it is far more effective than inhalation of pure oxygen without deeper breathing. In the mixtures of oxygen and carbon dioxide now commonly used the carbon dioxide is the effective agent and the oxygen only a slightly better diluent than mere air.[10] A decisive demonstration of the life-saving value of the inhalational treatment of premature infants was afforded by Dr. A. R. Dafoe's success with the Dionne quintuplets.

But is it true that muscle tonus is practically absent in the fetus and develops at birth? The answer is afforded by observations made by D. H. Barron in Professor Barcroft's laboratory and reported by the latter[11] without, however, the full interpretation which I have here assigned to tonus.

The observations of Barcroft and his collaborators have been made chiefly upon sheep at various stages of gestation. The fetal lambs are delivered by Cesarean section and the placental circulation is maintained while the mother's body is immersed in a bath of warm saline. Under these conditions, as Barcroft reports, Barron has recorded the tonus of fetal lambs by means of the method described by Adrian for recording the electrical state of the muscles. "So long as the fetus is in its normal environment, or in a bath of warm saline, with the placental circulation unrestricted, the fetal muscles are entirely devoid of tonus. Take the fetus out of the saline and expose its skin to the air; tone at once appears in its muscles, only again to be abolished by replacing the embryo in the bath."

What tonus means for the beginning of life can be verified by noting the crucial part that this little noticed but fundamental function often plays in the end of life. The condition of physical depression that may follow serious physical injuries and major surgical operations—the state that in its extreme form is termed shock—has long been explained as due to fatigue, paralysis or some other form of failure of the control by the sympathetic nervous system over the vasomotor mechanism. A few investigators, including the writer, have refused to accept this conception; but until recently we failed to offer a wholly satisfactory alternative conception.

Now it is becoming clear that the depression lies, not in the sympathetic nervous system, but in the motor centers of the spinal cord; and that it results in such a depression of muscle tonus that respiratory metabolism and heat production are diminished, the blood stagnates in the tissues, the venous return to the heart fails, and the respiratory muscles relax until parts of the lungs are deflated.[12] Decisive experimental evidence for this conception of postoperative depression and shock is afforded by the fact that a condition in all respects like shock can be induced temporarily by spinal anesthesia. This occurs whenever the anesthetic reaches, not merely the sensory neurones for which it is intended, but the motor neurones that induce muscle tonus.[13]

To summarize: At birth the motor centers of the spinal cord come into action. By inducing tonus in the musculature of the body they increase metabolism and heat production, and render respiration effective. Without muscle tonus the blood would stagnate in the tissues and the circulation would fail. During life a high tonus is a feature of vigorous health. It is such tonus that enables the young soldier to stand long at attention. The elderly man of lessened tonus can not stand long without fatigue. The invalid may have sufficient tonus to permit him to sit, but not to stand. The patient with a low tonus and weak after operation or illness can scarcely hold his head up from the pillow. And, as death approaches, it is the failure of tonus that permits the major functions of respiration, circulation and metabolism to fail.

[10] Y. Henderson, SCIENCE, 83: 399, 1936.

[11] J. Barcroft, *Setchanov. Jour. Physiol.*, 4: 35, 1935; *Physiol. Rev.*, 16: 103, 1936; J. Barcroft and D. H. Barron, *Jour. Physiol*, 88: 56, 1936.

[12] Y. Henderson, *Bull. N. Y. Acad. Med.*, 11: 639, 1935; *Lancet*, July 27, 1935, p. 178.

[13] O. O. Schuberth, *Acta Chir. Scand.*, 78: Suppl. 43, 1936.

OBITUARY

MARSHALL AVERY HOWE

DR. MARSHALL AVERY HOWE, director of the New York Botanical Garden, died at his home in Pleasantville, New York, on December 24, 1936, in his seventieth year. Scion of an old Vermont family, he was born at Newfane, in the southern part of that state on June 6, 1867. In 1891, the year following his graduation from the University of Vermont, he went to the University of California as instructor of cryptogamic botany; there he remained for five years, devoting himself particularly to studies on hepatics and marine algae, the plant-groups which continued to hold his interest for the remainder of his life, although the algae received more of his attention than the hepatics in later years.

In 1896 he enrolled for graduate study at Columbia University, where he was a fellow in 1897–98, received the Ph.D. degree in the latter year, and remained as curator of the herbarium until 1901. At Columbia he was closely associated with those who