The Milroy Lectures

ON

RESPIRATORY EFFICIENCY IN RELATION TO HEALTH AND DISEASE.

Delivered before the Royal College of Physicians of London

BY MARTIN FLACK, C.B.E., M.B., B.CH. OXON.,
WING COMMANDER, ROYAL AIR FORCE MEDICAL SERVICE.

LECTURE I.*

Dr. Milroy's desire in establishing these lectures was to "promote the advancement of medical science along with the interests of philanthropic benevolence and of social welfare." [1] As showing what was in his mind he states in the codicil to his will that—

"there is a vast amount of protracted malaise and suffering, disablement or lessened capacity for industrial work, and often, too, of slow but eventually fatal sickness in almost every region of the world due to the multiform class of the cachexiæ or those chronic constitutional diseases which consist, according to Cullen's definition, in a depraved state of the whole or of a considerable part of the habit of the body without any primary pyrexia or neurosis combined with that state." [1]

It is my hope to show that this state of physical inefficiency is frequently associated with a state of respiratory insufficiency. Bearing in mind the vast amount of material at my disposal, it will be necessary for me to confine myself to certain lines of thought. In doing this I shall endeavour as far as possible to bear in mind the advice offered by Dr. John Brown.[2]

"The physiology to be taught in schools and to our clients the public should be the physiology of common sense rather than that of dogmatic and minute science ...... and will make them understand enough of the fearful and wonderful machinery of life, to awe and to warn, as well as enlighten."

There can be no doubt as to the necessity of enlightening the public in regard to the correct application of physiology to daily life. The aims of Dr. Milroy for the advancement of social welfare can therefore best be met by the exposition of views in such a form that they can be readily transmitted to the public and be easily understood by them. The views I wish to put forward in these lectures are the result of my experience in the Medical Service of the Royal Air Force, where I have had the opportunity of testing and extending the observations made by two of my former teachers, Arthur Keith and Leonard Hill, to whom I take this opportunity of acknowledging my very great indebtedness. Their work has already been ably set forth by them, but I desire to insist upon the fact that it has been too little applied and that now is the time for its application to everyday life.

The publication of the figures of the war physical census emphasises this point.[3] During the 12 months preceding the armistice 2,425,184 medical examinations were conducted, the men being graded as follows :—

	Actual grading.	Keith's standard.
Grade I.	871,769 (36%)	1,697,595 (70%)
Grade II.	546,276 (22–23%)	485,040 (20%)
Grade III.	756,859 (31–32%)	181,902 (7·5%)
Grade IV.	250,280 (10%)	60,647 (2·5%)

In other words out of every 9 men called up 3 were placed in Grade I., 2 in Grade II., 3 in Grade III., and 1 in Grade IV., a figure sadly below what might be expected from a healthy nation. This is seen when comparison is made with Keith's standard, which is based on the law worked out in regard to other human measurements by Karl Pearson and his pupils. Instead of every 1000 men examined yielding on the average 700 Grade I., 200 Grade II., 75 Grade III., and 25 Grade IV., the actual yield is 359 Grade I., 226 Grade II., 312 Grade III., and 103 Grade IV. The position may be summarised by saying that in round numbers our physical census showed a shortage of 825,000 Grade I. men, an excess of 61,000 Grade II. men, and the alarming excess of no less than 575,000 Grade III. men, and 190,000 Grade IV. men.

When dealing only with the youths of 18 it might be expected that the proportion of fit, and consequently the index of fitness, would be considerably higher. Instead of this it was found among the youths who became 18 years of age during 1918 that there was : (*a*) A deficit of nearly 13,000 Grade I. youths among the 260,000 examined ; (*b*) an excess of over 6000 Grade IV. youths, or, in other words, almost double the number of youths "totally and permanently unfit for any form of military service" which there should have been, judging by Keith's standard.

CAUSES OF DEFICIENCY.

As the official report says, "Such a conclusion can only be regarded as exceedingly disquieting, and in itself throws a lurid light upon the effects of our civilisation upon the adolescent population." The chief causes given for this deficiency were : (1) Poor physique and presence of physical defects ; (2) tuberculosis ; (3) diseases and degeneration of the heart and blood-vessels, in many cases due to various infective conditions.

With regard to the first group, a considerable amount was due to preventable conditions in early life such as dietetic errors. Apart from these, however, a very important cause of defects of physique and of degeneration was the effect of occupation on workers. I quote from a lecture by Sir James Galloway [4] :—

"One of the most striking features of the report of grading in the industrial districts is the rapid fall of the numbers of young men who could be placed in Grade I. at the age of 18 years compared to the numbers who could be placed in the same grade on being examined four or five years later."

This remark applied particularly to the young workers in the textile industries, both in cotton and wool. A medical officer in regard to the south-eastern areas of Lancashire noted that the average man there was for military purposes an old man before he reached the age of 40. Of 200 youths of 18 to 20 years of age examined and rejected in the north-western region of England no fewer than 85 were rejected on account of poor physique.

The second great cause, as I have stated, was tuberculosis. In London 3·1 per cent. of 160,545 examinations made were placed in Grades III. and IV., 2·6 being for tuberculosis of the lungs. As the result of 66,000 examinations made in Liverpool from Nov. 1st, 1917, to Jan. 31st, 1918, which were carried out in close association with the medical officer of health and his officials, about 1·75 per cent. were rejected on account of tuberculosis, the striking fact emerging that of 277 cases proved to be tuberculous 218, or 78 per cent., were previously unknown to the health authorities.

The third great cause noted was disease and degeneration of the heart and blood-vessels. Included in this category are the various forms of heart disease due to rheumatic inflammation of the heart. On these I do not dwell except perhaps to point out that I hope to show efficient respiration to be of great value in aiding to preserve the physical efficiency of such cases. On the other hand, one of the most important forms of circulatory troubles was venous varix in some form. The amount of this was surprising even to experienced medical men, especially in industrial districts and among older men. Varicosity of the veins of the lower extremities to an extent sufficient to disable or be dangerous was found to be very common. It may be pointed out that such diseases are largely associated with deficiency of the respiratory mechanism.

* Lectures II. and III. will be published in subsequent issues of THE LANCET.

RESPIRATORY EFFICIENCY CONDITIONED BY HYGIENE AND SANITATION.

These figures show that the causes of physical inefficiency are to a large extent preventable. I do not wish to enter largely into details of sanitation and hygiene—as, for example, to point out the effects of insufficient or ill-chosen diets, overcrowding, back-to-back houses, and ill-ventilated workshops—but I cannot refrain from pointing out that, apart from the very important question of diet, these evils lead to a condition of respiratory and circulatory inefficiency largely involving the well-being of the individual. From this statement it will be seen that I attach great importance to the respiratory efficiency of the individual in the acquisition and preservation of physical efficiency. In particular is this the case in regard to bodily endurance. I have been led to this view by my work in connexion with the Royal Air Force. It has been my privilege to study the causes which lead to flying fatigue, and also to endeavour to study the bodily qualifications which must be sought for in the successful airman. To do this satisfactorily it was necessary in the first place to examine successful flying officers, as well as those suffering from various degrees of breakdown. As the results of investigations, with which I shall deal later, it became apparent that for efficiency in air work and for the prevention of physical endurance of the stress of flying respiratory efficiency was of particular importance. As the result of the examination of many hundred candidates for the Royal Air Force it has also become obvious that the same condition applies to all physical efficiency and bodily endurance, whether it be for air work or for work on the ground.

PRESENT KNOWLEDGE CONCERNING RESPIRATORY FUNCTION.

Before dealing in detail, however, with the results obtained in connexion with this work it is necessary to review the present state of our knowledge regarding the processes of respiration, since I believe that a considerable amount of the respiratory inefficiency of the present day may be attributed to the fact that the true significance of the mechanism of respiration is not correctly appreciated, and therefore that the fundamental physiological principles of respiration are not correctly taught and applied.

Broadly speaking, movements concerned in respiration are designed to serve three functions: (1) to provide the body with oxygen and to rid it of carbon dioxide; (2) to act as accessory pumps to the circulation, thereby aiding, particularly in the upright posture, the return of blood to the heart; (3) to massage the alimentary tract, thereby helping to preserve the muscle tone of stomach and intestines.

With regard to the movements of respiration, it is not proposed here to enter into the time-worn controversy as to the exact action of the various muscles engaged in the respiratory processes, nor as to exact movements performed by individual ribs. Too much time has already been wasted by hypothecating such actions and movements from minute considerations of the dead structures. There is a great difference between the living and the dead thorax. It is better for ordinary purposes to consider the movements of the thorax as a whole. Although the muscles concerned in respiration are so arranged that they can be coördinated in various ways to bring about the processes of inspiration and expiration, there is, undoubtedly, a most efficient way for each process, and for bodily efficiency and endurance it is important that this way be employed. The essential movements of quiet inspiration are the descent of the diaphragm and the raising of the lower ribs. When inspiration is deeper the movement spreads progressively in undulatory fashion from the lower to the upper ribs, so that the upper part of the chest is seen to rise. This upper chest movement is to be regarded as the accessory part of inspiration. On this account it becomes particularly prominent when breathing is greatly increased in depth by excessive exercise, or becomes laboured in disease, or when correct inspiration is impeded by occupation or clothing.

CLOTHING AND RESPIRATION OF WOMEN.

It may be argued that costal breathing is the normal type of breathing for women. This should not be the case when the clothing is properly adjusted. This does not mean that costal breathing is altogether due to wrong clothing. It is probable that women normally employ the costal element to a larger extent than men—since, as suggested by John Hutchinson, it forms the accessory mechanism for efficient quiet respiration during pregnancy. That such breathing, however, is in large part due to clothing is shown by the fact that in cases of complete hypospadias which have been wrongly regarded as females and clothed as such, the type of breathing has been observed to be what may be termed female in character, although the subjects were in reality males. It would be a mistake to teach that costal breathing alone is normal for the female. Young girls and women should be taught that correct inspiration is always associated with good diaphragmatic action, and that the upper costal element, however large it tends to be, should be regarded as the accessory element. The clothing of women, therefore, should be adapted to give free abdominal movement. I have not had sufficient opportunity to study widely what may be termed normal female breathing, but at a school of physical training I noticed that abdominal breathing was present.† As regards the male, however, it must be emphatically asserted that the time has come to abandon the idea that by striving after a large upper chest expansion the respiratory capacity is greatly increased. In this type of breathing the pit of the stomach is usually observed to move inwards instead of outwards during the inspiratory process, while expiration is accompanied by an outward movement in this region. Many observers have already noticed that this type of respiration is less efficient. In reality the vital capacity in such type of breathing is considerably less.

MEASUREMENT OF UPPER AND LOWER CHEST EXPANSION.

Radiographic evidence has also shown that in such breathing the diaphragm moves little if at all; indeed, in extreme cases the abdominal contents pass farther up into the thorax, so that in reality the apparently increased lung capacity consists of the pushing of the abdominal contents higher into the thorax. Although prevalent at one time in the army, this type of breathing has now been abandoned; possibly it attained a vogue owing to the frequency with which phthisis is found to attack the apex of the lung. As shown later, however, upper costal breathing is adequate only for the expansion of the anterior part of the upper lobes; the efficient expansion of the apex of the lung is largely dependent upon efficient diaphragmatic and lower costal breathing. As a guide to respiratory efficiency the measurement of upper chest expansion should be abolished or at least combined with a measurement of the increased size of the chest at the level of the lower ribs. This latter is the more important measurement. On deep inspiration there should be a movement out of the pit of the stomach, together with considerable expansion of the lower part of the chest. Correct inspiration, therefore, consists of the contraction of the diaphragm, attended generally by an upward movement of the lower ribs, full inspiration being attained by a wave-like movement which passes to the upper ribs. Observation shows that it is the type prevalent in individuals who possess the greatest bodily endurance. By its means the greatest respiratory capacity is attained, and by its means alone is the lung adequately expanded in all its parts.

† Dr. Mina Dobbie, medical officer to the South-Western Polytechnic School of Physical Training, tells me that she attaches considerable importance to the increase of the abdominal measurement during inspiration over that during expiration as a sign of progress in efficiency. Her records certainly bear out this contention.

CORRECT EXPIRATION.

Just as correct inspiration is important so also is correct expiration. If inspiration be correctly coördinated, correct expiration naturally follows; this consists of a contraction of the abdominal muscles, especially those of the upper part of the abdomen, together with a reposition of the ribs by virtue of muscular action. The fact that expiration is a muscular act must be emphasised. Inspiration and expiration are due to the coördinated action of groups of antagonistic muscles. When the leg is flexed, as Prof. Sherrington has shown, both the antagonistic flexors and extensors come into action in order to produce a finely coördinated movement. So in the respiratory movements the muscles of inspiration and expiration are antagonistically concerned. In inspiration, the inspiratory muscles in coördinated fashion overcome the expiratory; in expiration the expiratory overcome the inspiratory. From the beginning to the end of the movement each muscle concerned is balanced, steadied, and controlled by the action of its antagonist.

Reference to text-books of physiology show that in general the act of quiet expiration is regarded as a non-muscular act due to elastic recoil of the expanded lung and the return of the chest by its own weight. This view is undoubtedly based upon the classical work of Dr. Hutchinson[5] published in 1835, and, as Prof. Keith points out, is based upon an error of observation. Michael Foster,[6] in his text-book, writes as follows:—

"In normal easy breathing expiration is in the main a simple effect of elastic reaction. By the inspiratory effort the elastic tissue of the lungs is put on the stretch, so long as the inspiratory muscles continue contracting, the tissue remains stretched, but directly the muscles relax the elasticity of the lungs comes into play and drives out a portion of the air contained in them. Similarly, the elastic sternum and costal cartilage are by the elevation of the ribs put on the stretch, they are driven into a position unnatural to them. When the intercostal and other elevator muscles cease to contract the elasticity of the sternum and costal cartilage causes them to return to their previous position, thus depressing the ribs and diminishing the dimensions of the chest. When the diaphragm descends, in pushing down the abdominal viscera, it puts the abdominal wall on the stretch, and hence when at the end of inspiration the diaphragm relaxes the abdominal walls return to their place, and by pressing on the abdominal viscera push the diaphragm up again into its position of rest. Expiration, then, is in the main simple elastic reaction, but there is probably some, though possibly in most cases a very slight, expenditure of muscular energy to bring the chest more rapidly to its former condition. This is, as we have seen, supposed by many to be afforded by the internal intercostals acting as depressors of the ribs. If these do not act in this way we may suppose that the elastic return of the abdominal walls is accompanied and assisted by a contraction of the abdominal muscles."

It will be seen that active expiration is allowed to be a supposition. Evidence will be adduced later to show that it should be regarded as a necessity, if properly coördinated efficient expiration is to take place.

THORACIC ANATOMY: EXTENSIBILITY OF THE LUNG.

To understand properly the movements concerned in the processes of inspiration and expiration, certain anatomical details in regard to the bony framework and the musculature of the thorax have to be considered. The varying extensibility of different parts of the lung has also to be borne in mind.[7] In the act of inspiration, owing to the varying degree of extensibility of the different structures of the lung, the organ expands in the manner of a Japanese fan—least in the neighbourhood of the great vessels and bronchi (the root of the lung), most in the outermost zone just beneath the pleuræ (subpleural zone). The infundibula are the essential distensible elements of the lungs. They vary in size in these different zones of the lung, being largest in the subpleural zone and smallest at the root of the lung (Fig. 1). The distensibility of any part of the lung depends upon the number and size of the infundibula in that part. The lungs do not expand equally in all directions; the two surfaces which are most expanded are the diaphragmatic and the sterno-costal, or ventro-lateral. In general, the apical surfaces remain almost stationary. It is only when the lungs are well ventilated that the parts most remote from these surfaces of direct expansion are brought properly into action. In people of sedentary habits, therefore, such parts of the lung tend to fall into a condition of disuse, and receive a poor supply of blood, with its

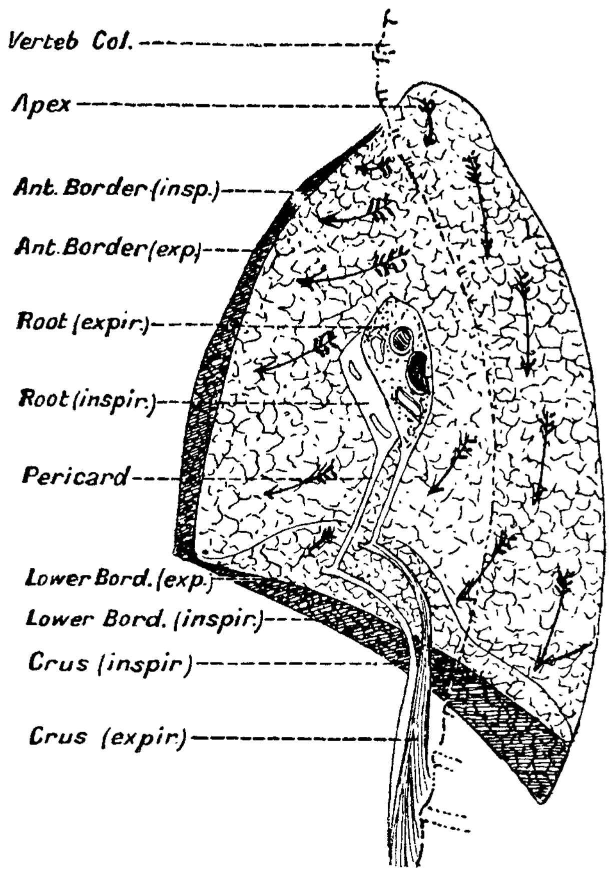

FIG. 1.—Mediastinal aspect of right lung to show respiratory movement of the root (Keith). The crus of the diaphragm is also indicated, and its attachment to the root of the lung through the pericardium. Arrows indicate direction of inspiratory movement of various parts of the lung.

immunising properties. This, as Keith suggests, explains why phthisis so frequently first attacks the apex of the lungs.[8] The great fissure of the lung is of functional significance in providing for the adequate expansion of the lung in all its parts.

In the inspiratory movement the thorax is, or should be, expanded by the movement of the diaphragm and by the movements of the ribs and rib cartilages. There has been considerable speculation as to the exact nature of the movements performed by the diaphragm. The view commonly expressed is that this muscle, by its contraction, in association with muscles which fix the thorax, opens up the angle which it forms with the thoracic wall, thereby enabling the lung to expand in a downward direction. In such a movement the central tendinous portion is supposed not to participate. After contraction, it is assumed that the diaphragm passively returns to the position of rest. Recent study of the diaphragmatic movement by means of the X rays has shown, however, that there is a forward downward movement of the whole diaphragm, accompanied by a definite movement of the abdominal viscera.

The diaphragm may be regarded as consisting of two parts: (1) the spinal or crural, from the spinal column and arcuate ligaments to the back portion of the central tendon; and (2) the costo-sternal, or anterior, attached to the front and sides of the central tendon, and arising by several digitations from the ribs. The arch of the diaphragm rests upon, and is supported equally by, the abdominal viscera, and is at the same time kept constantly applied at the circumference to the inner wall of the thorax by the negative intrathoracic pressure. Thus, when its two parts contract it acts like a true piston, moving in a forward and downward direction. The lungs, including their roots, follow this movement, which therefore tends to bring about expansion throughout the whole lung, including the apex, which would otherwise be ill-expanded. In quiet, normal breathing the amount of movement of the right dome is about half an inch, that of the left dome and of the central tendon somewhat less.

MOVEMENTS OF THE RIBS.

In general, two movements of the ribs have been recognised as taking place in inspiration—namely, (1) round an axis corresponding to the spinal articulation, increasing the back-to-front diameter of the thorax; (2) round an axis corresponding to the spino-sternal articulation, increasing the diameter from side to side. Owing to the variation in size, shape, inclination, and articulation of the ribs, such an explanation, while essentially true in a general sense, is imperfect. It is better, as Keith does, to divide the ribs into two sets: (1) the upper, the second rib to the fifth; (2) the lower, the sixth rib to the tenth. These two sets differ in their musculature, in the nature of their articulation and ligaments, in their shape and arrangement, and in their movements. The first rib is not looked upon as one of the costal series; together with the manubrium sterni it forms an operculum to the chest and performs a special movement of its own. The lowest two ribs, inasmuch as they are unattached in front, are essentially a part of the abdominal wall. It is on the movement of the upper ribs (second to fifth) that most of the observations upon rib movements and the action of the intercostal muscles have been made. The following view has been put forward by Keith as to the mode of action of the intercostal muscles. The purpose of the upper rib movement is the expansion of the upper lobe of the lung, particularly in its anterior part. When concerned in inspiration both sets of intercostal muscles act together, and draw up the upper ribs towards the operculum, which acts as a fulcrum. During the succeeding expiration the lower set of ribs are fixed and act as a fulcrum, the upper set being drawn down towards them by the intercostal muscles. There is some experimental evidence to show that the external intercostal muscles act during inspiration. The fibres slant from above downwards and forwards, and shortening, raise the ribs. The fibres of the internal intercostals, on the other hand, slant from above downwards and backwards, and shortening, lower the ribs. The two, acting together, make rigid the thoracic wall. The intercartilaginous fibres act with the external intercostals. The purpose of the movement of the lower ribs is primarily to expand the lower lobe of the lung. In this action the diaphragm is intimately concerned, aided by the ilio-costalis, and the action of the external intercostal and the interchondral muscles. The antagonistic muscles are the external oblique, the internal oblique, and the transversalis. During inspiration, owing to the mode of articulation of the ribs, the lateral and anterior part of each moves outwards more than the one above. At the same time, the lower ribs are raised, together with the sternum, so that the net result of the lower rib movement is to increase the transverse and back-to-front diameter of the lower thorax, and with the diaphragm moving downwards, the vertical diameter of the whole cavity.

The first pair of ribs and the manubrium sterni are intimately bound together and form a lid or operculum to the thorax. This lid is articulated behind with the spinal column, in front with the body of the sternum, the manubrio-sternal joint (Fig. 2). During inspiration there is a slight upward movement of the lid, allowed by the manubrio-sternal joint, which causes an expansion of the anterior part of the apex to the lungs. This movement is particularly marked in the thoracic type of breathing. In persons with ill-developed chests there is but little movement here. The posterior part of the apex of the lung is but little affected by the movement of the operculum, its expansion being secured by diaphragmatic breathing. Inspiration is, therefore, a very complex act,

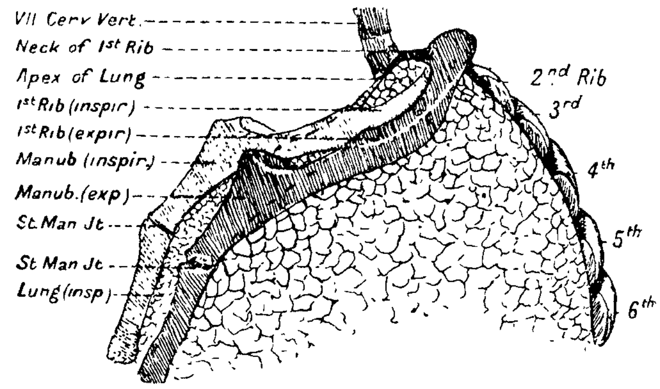

FIG. 2.—Diagram to show respiratory movements of the first pair of ribs and manubrium sterni, and the effect of these movements on the expansion of the apex of the lung (Keith).

and it is owing to the complicated nature of the movements concerned that the lungs are divided into lobes. The upper ribs are chiefly concerned in the expansion of the upper lobes, the lower ribs in the expansion of the lower lobes, the diaphragm promoting the expansion of the whole lung. As already stated, expiration is controlled by muscular action; generally speaking, the extensibility and elasticity of the thorax are to be regarded as factors in producing expansion or compression of the lung only when the ribs pass into extreme inspiratory or expiratory positions.

MECHANISM OF CIRCULATION.

The mechanism of the circulation has been so contrived that it remains constant and efficient, not only in the horizontal position, but also when the living animal is ceaselessly shifting the position of his body. The hydrostatic influence of gravity had a most important bearing on the evolution of the mechanisms which control the circulation. In the upright posture the blood under the influence of gravity continually presses downwards, and would sink if the veins and capillaries of the lower parts were sufficiently extensile to contain it and there were no mechanisms to counteract the effect of gravity.[9 10] Such is actually the case in the snake or eel; in them, as Leonard Hill has shown, the heart empties so soon as they are immobilised in the vertical posture. This does not occur if the snake or eel be immersed in water, since the hydrostatic pressure of the column of water outside them balances that of the blood within. During the evolution of man there have been developed special mechanisms by which the sagging of the blood to the lower parts is prevented and the assumption of the erect posture rendered possible. In fishes, amphibia, and reptiles there are venous valves for preventing regurgitation of the blood from the sinus venosus into the great veins. In the warm-blooded vertebrates, with the appearance of the diaphragm and the fusion of the sinus venosus with the right auricle, a venous cistern formed by the superior and inferior venæ cavæ and by the innominate, iliac, hepatic, and renal veins, takes the place of the sinus venosus. Six pairs of valves prevent regurgitation from this cistern—namely, those placed in the common femoral, the subclavian, and jugular veins (Fig. 3). The cistern, when filled, may hold some 400 c.cm. of blood. In the liver there may be some 500 c.cm. of blood. This can be expressed into the cistern by abdominal pressure. The portal venous system, when distended, may hold another 500 c.cm., which can be expressed through the portal veins and the liver into the cistern. There is thus a large volume of blood for the heart to draw upon during diastole, and this may be of particular value during the performance of a great muscular effort. Although the aspirating action of the thorax tends to suck this blood into the heart in the upright posture, it is the descent of the diaphragm during inspiration and the efficient contraction of the abdominal muscles during expiration which play the greatest part in forcing blood onwards from the liver and cistern into the heart. The intra-abdominal pressure may be raised considerably on bending or straining. Under such conditions the pericardium protects the right side of the heart from being over-distended with venous blood. If a tame hutch rabbit with a large patulous abdomen be suspended and immobilised in the erect posture, death may

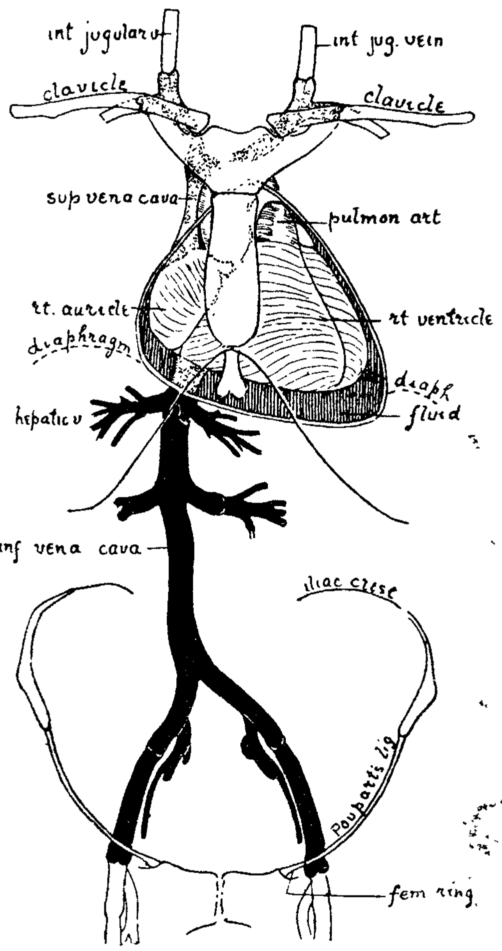

FIG. 3.—Diagram of the venous cistern from which the heart is filled (Keith). The abdominal or infra-diaphragmatic part of the cistern is indicated in black; the thoracic or supra-diaphragmatic is stippled. The heart is compressed upwards and backwards against its attachments.

result in from 15 to 30 minutes, for the circulation through the brain ceases and the heart soon becomes emptied of blood. If, however, the capacious veins of the abdomen be confined by an abdominal bandage no such result occurs.

In a man six feet high the hydrostatic pressure of a column of blood reaching from the vertex of the head to the sole of the foot is equal to 140 mm. Hg. But during the evolution of the upright posture man provides himself with an efficient abdominal belt wherewith to counteract this pressure. The splanchnic arterioles also are maintained in tonic contraction by the vaso-motor centre, and the flow of blood to the abdominal viscera thereby confined within due limits. The veins of the limbs are broken into short segments by valves, and these support the weight of the blood in the erect posture. Every contraction of the skeletal muscles compresses the veins of the body and limbs, for these are confined beneath the taut and elastic skin. Guided by the valves of the veins, the blood is by such means continually driven upwards into the venæ cavæ. In the hanging motionless arm the veins, as seen at the back of the hand, soon become congested. Forcible clenching of the fist or elevation of the limb demonstrates the great influence which muscular exercise and continual change of posture have on the return of blood to the heart. It becomes wearisome and soon impossible for a man to stand motionless. When a man is crucified, immobilised in the erect posture, the blood slowly sinks to the most dependent parts, œdema and thirst result, and finally death from cerebral anæmia ensues. In man standing erect, the heart is situated above its chief reservoir—the abdominal veins. The blood is raised by the action of the respiratory movements, which act both as a suction and as a force pump; for the blood is not only aspirated into the right ventricle by the expansion of the thoracic cavity, but is expressed from the abdomen by the descent of the diaphragm, and the contraction of the abdominal muscles. When a man faints from fear, his muscular system is relaxed and respiration inhibited. The blood, in consequence, sinks into the abdomen, the face blanches, and the heart fails to fill. He is resuscitated either by compression or by being placed in a head-down posture. Men and women with lax abdominal wall and toneless muscles take refuge in the wearing of abdominal belts. To maintain a vigorous circulation and digestion it is necessary to exercise the muscles daily, particularly those of the abdomen.

Leonard Hill studied the question experimentally by passing cannulæ down the external jugular vein and carotid artery into respectively the superior venæ cavæ and aorta of a dog, anæsthetised and placed upon a specially constructed animal table, made to turn round an axis passing through the body at the level of the cannulæ, so that upon turning the table any alteration in the level of fluid in the manometer tubing is avoided. On placing the animal in the feet-down posture, the arterial and venous pressures immediately fall (Figs. 4, 5, and 6). The venous pressure remains down until the horizontal posture is once more assumed, when the arterial pressure rapidly rises again to normal, and it may often be found to

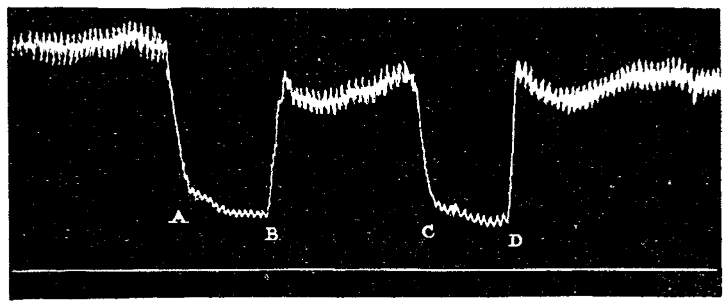

FIG. 4.—Aortic pressure (Hill). A = Vertical feet-down position B C = Effect of abdominal compression D = Horizonta position.

rise above normal. The respiratory undulations are frequently intensified while the animal is in the feet-down posture. If left long in the feet-down position the compensatory mechanism gradually fails and the arterial pressure falls. By division of the spinal cord

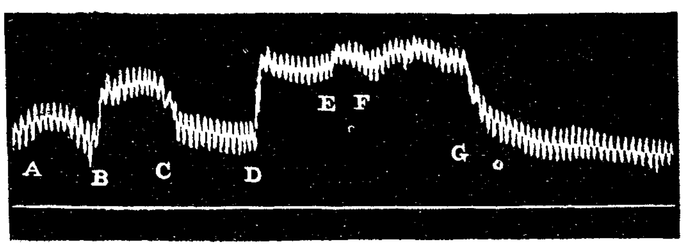

FIG. 5.—Aortic pressure (Hill). A = Horizontal position; B C = Abdomen compressed; D = Vertical feet-up position; E F = Abdomen compressed; G = Horizontal position.

at the level of the first dorsal vertebra, the influence of the bulbar centres on the parts below the section is removed. Abdominal and intercostal respiration is paralysed, and the breathing becomes purely diaphragmatic. The tone of the arterioles of the great splanchnic area and of the musculature of the abdominal wall is lost, and the capacity of the abdominal vessels is thus greatly increased. On the animal, when lying in the horizontal posture, the total effect is a considerable fall of arterial pressure, and a marked diminution of the respiratory undulations of pressure; in the vertical feet-down posture, the arterial pressure falls rapidly, and may reach zero; the circulation is then at an end. Under the influence of gravity the whole of the blood collects in the great abdominal veins; it can pass rapidly through the dilated arterioles, there is no mechanism left for filling the heart, and the latter, empty of blood, continues to beat to no purpose. If the abdominal wall be compressed with the hand (B, C, Fig. 4), the capacity of the veins and splanchnic area is reduced, the right heart is once more filled with blood, the arterial pressure rises, and the circulation is renewed. On taking off the hand, the heart once more empties, the arterial pressure falls, and the circulation again ceases. When the animal is returned to the horizontal position, the influence of gravity is abolished, and the circulation becomes re-established. The effect of compression of the abdomen in the horizontal position is also evident (B, C, Fig. 5) but slight. In the feet-up position the aortic pressure rises under the influence of gravity, returning to normal as compensation takes place or when the horizontal position is resumed (Fig. 5). Such experiments prove that in the anæsthetised animal there are two chief compensatory mechanisms by which the hydrostatic effect of gravity is overcome—namely, the vaso-motor mechanism of the arterioles and the respiratory pump.

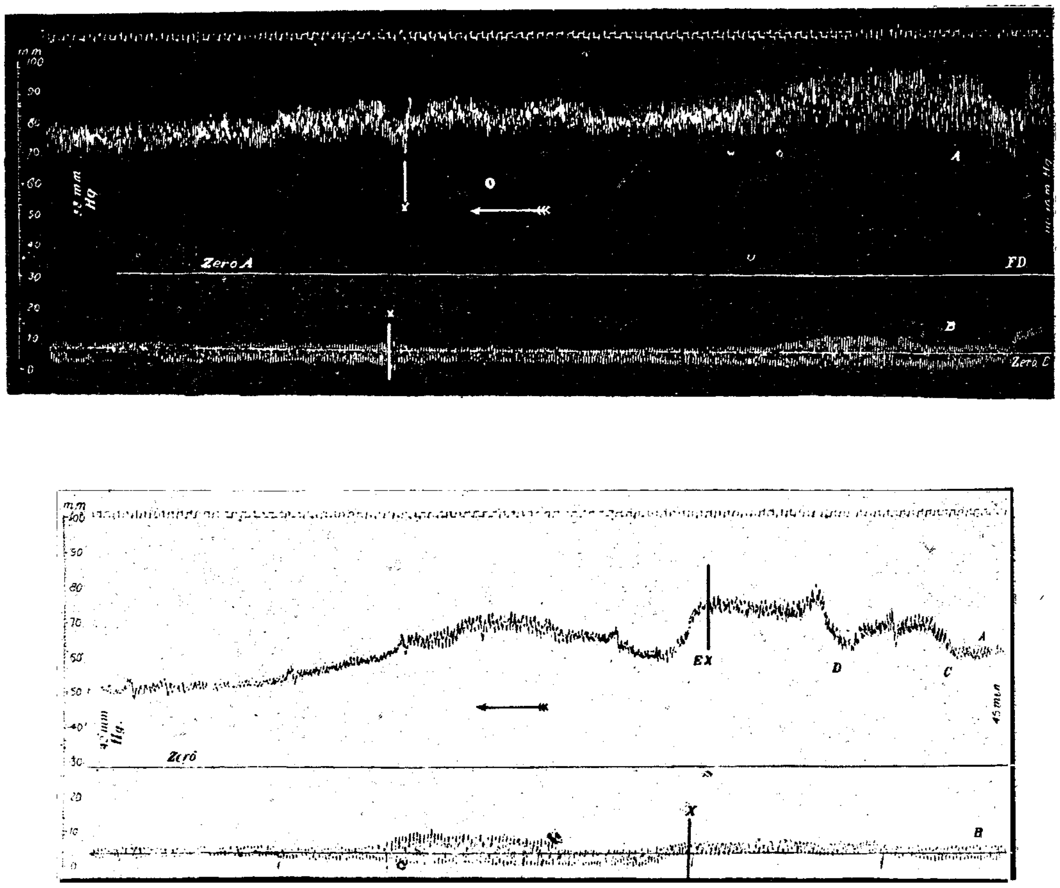

FIG. 6.—To show effect of gravity upon the circulation: carotid and superior vena cava pressures of dog (Hill). F D = Animal turned into feet-down position with cannulæ in axis of rotation. The arterial pressure fell in 50 minutes from 110 mm. Hg to 42 mm. Hg. From C to E X animal was immersed in a bath which was deepened to chin at D. Note increased effect of respiration on venous pressure after F D and again after bath. Note also fall of pressures at F D, and compensatory rise of arterial pressure, which gradually weakens.

COMPENSATORY MECHANISMS.

The vaso-motor tone of the arterioles splanchnic area can be abolished, without interference with the respiratory mechanism, by section of the splanchnic nerves through a lumbar incision. The result of this procedure in the vertical feet-down posture is that the arterial pressure falls very considerably; but, nevertheless, the circulation may remain efficient, on account of the action of the respiratory pump. By greatly increased respiratory movements, combined with powerful abdominal compressions, the diastolic filling of the heart is maintained and the velocity of flow through the splanchnic capillaries checked. Withdrawal of the support of the abdominal muscles by a crucial incision of the abdominal wall leads to dilatation of the splanchnic vessels, and the pressure falls to a further extent. Finally, opening the thorax causes the pressure to fall to zero and the circulation ceases. By compression of the abdomen, or by a return to the horizontal posture, the circulation can be once more renewed. Such an experiment shows that the respiratory pump can compensate for the influence of gravity when the vaso-motor mechanism is paralysed. The respiratory pump can be paralysed by itself, and without damage to the vaso-motor mechanism, by the injection of curari. The power of the heart may then be sufficient by itself to maintain the circulation in the feet-down position, so long as the capacity of the abdominal vessels is kept under control by the vaso-motor nerves.

In man measurements of arterial pressure likewise reveal the effect of gravity upon the circulation.[11] In a normal man standing upright the pressure in the post-tibial artery in the leg is higher than the pressure in the brachial artery by the height of the column of blood which reaches from one artery to the other, about 70 mm. Hg. (See Table I.)

In changes of posture, then, the pressure in the brachial artery—that is, in the root of the aorta—is maintained at practically a constant height by the tone of the splanchnic arterioles and action of the respiratory pump. If the splanchnic arterioles are in an efficient state of tone, and if the abdominal veins are supported by the tone of the abdominal walls, then the splanchnic vessels will not dilate under the hydrostatic stress of gravity. The nervous mechanism involved is probably of the simplest nature, for if the arterial pressure suddenly rise or fall at the moment of change in posture, the bulbar centres are thereby either directly or reflexly excited to increased or decreased activity. A sudden fall of arterial pressure provokes acceleration of the heart, amplified respiration, and increased vaso-constriction. A sudden rise of pressure, on the other hand, provokes a slow heart, shallow respiration, and vaso-dilatation.

When the compensatory mechanism is abolished by destruction, exhaustion, or inhibition of the bulbar centres the circulation fails and becomes inadequate to maintain life in the vertical posture. The blood passes into the capacious reservoirs of the toneless abdominal veins, the heart empties, and the cerebral circulation ceases. There can be no doubt that the control of this compensatory mechanism is one of the most important and necessary functions of the group of bulbar centres—a function which must have been evolved to its highest point, as man in his evolution assumed the erect posture. During the

TABLE I.

Posture.	Pressure in mm. Hg. Brachial artery.	Pressure in mm. Hg. Posterior tibial artery.	Difference in mm. Hg.	Difference calculated from height of column in mm. Hg.	Height of column separating armlets in cm.
Horizontal ..	106	106	0	0	0
Standing	110	165	55	58	75·4
L. posture legs up	115	85	30	33	44
Vertical head down	115	50	65	63	82

course of each day the compensatory mechanism becomes fatigued; especially is this so after severe muscular exertion. By sleep and rest in the horizontal posture the compensatory power is restored. In conditions of neurasthenia, of weakness and exhaustion after bodily strain and disease, of shock after severe injury or hæmorrhage, this power may be greatly lessened.

A useful clinical guide to the condition of the compensatory mechanism in man is afforded not only by the pressures in the brachial artery, particularly the diastolic pressure, but by the rate of the pulse on change of posture. If the heart greatly accelerates on rising from the horizontal to the vertical position, the mechanism is deficient. From the above the importance of the respiratory movements as regards circulatory efficiency is clearly seen. The downward plunge of the diaphragmatic piston during inspiration, and the inward thrust of the abdominal wall during expiration, are necessary for man's efficiency in the upright posture.

Finally, I would draw attention to the importance of the correct muscular movements of breathing in massaging the abdominal contents. The descent of the diaphragm in inspiration, the contraction of the abdominal wall in expiration provide massage mechanism which plays an important part in the preservation of the tone of the smooth muscle of the abdominal contents.

One of the present-day evils is constipation, which does not occur when a good tone of the abdominal wall is preserved. Equally as important is the fact that the state of semi-constipation is abolished, the state in which the bowels, although acting daily, act only in insufficient fashion without the use of occasional purgatives. By what means good tone of the external abdominal muscles induces good tone of the smooth muscle is not sufficiently known, nor can it yet be adequately explained how conditions affecting directly the tone of the smooth muscle, as, for example, enteritis, bring about a relaxation of tone of the external muscles. The fact remains, however, that good tone of the muscles constituting the natural abdominal belt play an important part in preserving a healthy condition of the abdominal contents.

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SPINA BIFIDA.[1]

BY FREDERICK C. PYBUS, M.S. DURH., F.R.C.S. ENG.,
ASSISTANT SURGEON, ROYAL VICTORIA INFIRMARY; LATE SURGEON, HOSPITAL FOR SICK CHILDREN, NEWCASTLE-ON-TYNE.

BY spina bifida we mean a congenital defect of the vertebræ, usually the posterior arch, associated, in most cases, with some protrusion of the spinal contents. The defect may involve a large or small area of the spine, but when a tumour is present this is due to a protrusion of contents due to increase in the intraspinal pressure. This increased pressure may be temporary, as such cases can be cured or may undergo spontaneous cure, while others are progressive in character and are often associated or followed by hydrocephalus. Probably various combinations of these factors account for the production and different varieties of this condition. This defect occurs in about one in 1000 births and is often incompatible with life; at the best many cases succumb during their first year, and others exist for a time with various accompanying deformities.

Development of Spine and Spinal Cord.

Fully to understand the anatomy of the condition it is essential to know the method of development of the spine and spinal cord. Briefly it is as follows: in the dorsal middle line a groove appears, the neural groove, which sinks into the underlying mesoblast and subsequently, its edges fusing, it becomes the neural canal. This becomes separated from the surface, the surrounding mesoblast forming the spinal membranes. Round the spinal cord and membranes thus formed the vertebræ are developed. Cartilage being formed round the notochord and being in its turn replaced by bone, centres of ossification appear for the bodies and posterior arches. The process of ossification for the bodies commences in the mid-dorsal region and progresses up and down the spine, while the centres for the neural arches commence in the cervical region, the process extending backwards, so that the lumbar and sacral elements are the last to have a bony roof. Development may be arrested at any one of these stages and accounts for the different types of spina bifida met with clinically.

Spina Bifida as a Family Defect.

Spina bifida is met with almost equally in the two sexes, and we can only suggest that it is due to some somatic defect. Occasionally it is a family defect. One member of such a family is depicted in Fig. 1.

FIG. 1.

Meningo-myelocele in a child aged 4 months, showing large thin-walled translucent sac in the sacral region.

Here all four children had some degree of spinal defect. The eldest died at the age of 18 months with spina bifida, the type of which is unknown, and with hydrocephalus. The second child, now aged 10 years, has a spina bifida occulta, indicated by a scar and depression in the upper dorsal region and by slight scoliosis. A radiograph of this portion of

[1] A post-graduate lecture delivered at the Royal Victoria Infirmary, Newcastle-on-Tyne.