RESPIRATORY EXERCISES

IN THE

TREATMENT OF DISEASE.

NOTABLY OF THE HEART, LUNGS, NERVOUS AND DIGESTIVE SYSTEMS.

BY

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PREFACE

By modifying the respiratory movements in certain ways we can produce profound effects upon the organism. Not only can we regulate the absorption of oxygen and the elimination of the respiratory excreta, but we can also influence the circulation of blood and lymph, both generally and locally.

Now, it occurred to me that some of these effects might be useful in the treatment of disease, and after prolonged and careful investigation I have come to the conclusion that properly-devised respiratory exercises have a great therapeutical value.

This mode of treatment being founded on physiological principles, it has been necessary to define those principles, and this has involved a somewhat severely technical exposition. Those who have not the leisure nor the inclination to study this portion of the book may proceed at once to the more practical portion of it, beginning at Chapter XX.

The present work is the outgrowth of a larger one on the mechanical treatment of heart disease, a subject which has occupied my thoughts from the very outset of my medical career. It was not until the book was well advanced that I became aware that I had been in a measure forestalled by the physicians of Nauheim. Their therapeutical methods were arrived at empirically; mine by an application of physiological principles. Each line of investigation has a value of its own; and just as I have been able to supplement my methods by the empirical methods of Nauheim, so conversely, as I shall hope to show in this and my larger work, the Nauheim methods may be extended and corrected by applying the truths of physiology.

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CHAPTER I.

THE ELASTICITY OF THE LUNGS—PULMONARY SUCTION.

The lungs occupy that part of the thorax not occupied by the mediastina, but they are not large enough to fill this space without a considerable stretching of the elastic fibres with which they are richly furnished, and hence they are ever tending to contract, this tendency increasing during inspiration and during contraction of the bronchial muscles. The pressure of the atmosphere within them, however, counteracts the tendency, and keeps them closely applied to the chest-walls, heart, aorta, and other contiguous structures. When the chest is opened after death, and the atmosphere allowed to press upon the outside of the lungs as well as from within, they necessarily undergo considerable contraction. Hence, we must think of these organs as ever striving to break away from their surroundings, and as thus exercising a negative pressure or suction upon them. We may speak of this as *pulmonary suction*,*

* Some authors write of the lungs as exercising *traction* upon the contiguous structures; but this is not strictly accurate, inasmuch as

and it is owing to it that the pressure in the pleuræ and pericardium is negative.*

From the foregoing remarks it will be clear that the lungs in no sense *support* the chest-walls, but, on the contrary, tend to suck them in. It is only towards the end of a deep expiration, or when an expiratory effort is made with closed glottis, that they exert anywhere a positive pressure. In the latter case they may be made to compress the heart and great bloodvessels with such force as actually to stop the circulation.

The diaphragm, as the most yielding portion of the chest-wall, is the part most influenced by pulmonary suction. The pressure on its abdominal surface is almost always positive. Hence, in its passive state, the diaphragm is sucked upwards into the dome-shaped form, and every contraction and consequent flattening of it has to overcome pulmonary elasticity.

When the deepest possible inspiration is taken, the diaphragm tends to be more than usually elevated, owing to the increase in pulmonary suction (see p. 59).

The elastic force exerted by the lungs at the end of an ordinary expiration is equal to a column of from 5 to 7 mm.

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there is no physical union with them. They do indeed drag upon the visceral pleuræ, but not upon other parts—the chest-walls, for instance. These latter are not *drawn* inwards: they are *driven* inwards, or tend to be so, by the atmospheric pressure, which is greater than the pressure which the lungs exert upon the chest-walls.

* The negative pressure in the pleuræ and pericardium can be estimated by introducing into one of these cavities a cannula connected by means of a rigid tube with a manometer, care being taken to exclude the air. It may also be shown that the intra-thoracic portion of the œsophagus is similarly affected by pulmonary suction, and that this increases with every inspiration.

Leyden and Quincke have tested the negative pressure in the pleuræ after drawing off a pleuritic effusion. The former has shown it to be as low as −42 mm. Hg during a deep inspiration, and the latter as low as −40 mm. Hg.

of mercury, for if after death, when the chest is in a position of ordinary expiration, a manometer is fixed in the trachea the mercury rises to about this height on the chest-walls being punctured and the lungs thus permitted to collapse. When the chest is forcibly inflated to the position of ordinary inspiration, the mercury rises to about 10 mm., and the rise increases to 30 mm. if the chest is distended to the position of extraordinary inspiration. At the end of an extraordinary expiration elastic force is absent, the lungs then being actually smaller than after removal from the body.

Hence, the elastic force or suction exerted by the lungs under varying degrees of expansion is as follows:

At the end of an	extraordinary	expiration,	0.	
,, ,,	ordinary	,,	5	mm. Hg.
,, ,,	,,	inspiration,	10	,,
,, ,,	extraordinary	,,	30	,,

The elastic force exerted by the bronchial muscles, when contracted, is estimated at from 1 to 2 mm. Hg.

Other aspects of pulmonary suction have now to be considered.

All the tissues of the body tend to become less elastic with advancing years. It is, for instance, owing to loss of elasticity that the skin becomes wrinkled with age; it gets permanently stretched, and, no longer tightly adapting itself to the underlying structure, is thrown into folds. As with the skin, so also with the lungs. Their elasticity, and consequently the suction they exert, diminishes with advancing years. In the senile lung it is comparatively small. Pulmonary elasticity diminishes much more rapidly in some cases than in others, so that while in one we may find prematurely senile lungs at fifty, in another elasticity may be well preserved at seventy. It may also be diminished by disease. All organic diseases of the lungs—pneumonia, bronchitis, phthisis—diminish it. In emphysema the diminution is a characteristic feature, and plays a prominent part in its pathology. Elasticity is also probably always diminished in protracted fever; Cohnheim finds it absent in typhoid; Perls has found it diminished in typhoid, typhus, and diphtheria; and both have noticed its loss in phosphorus-poisoning.

Undue stretching of the pulmonary alveoli is another very potent cause of its diminution or entire loss. It is in this way that effort, such as coughing and lifting weights, diminishes elasticity. Chronic dyspnœa diminishes it in the same way—namely, by causing overexpansion of the lungs—and hence also the injurious tendency of all exercises causing breathlessness, such as running rapidly upstairs, swimming for a long time under the water, etc. (see pp. 93, 94).

It is seldom, however, that pulmonary elasticity is so completely lost as to do away with all suction—in fact, probably in the most advanced cases of emphysema only. When a portion of the lung is solidified, as in pneumonia, it necessarily loses all elasticity, and therefore all suction. Post-mortem examination gives no evidence, however, that the parts thus solidified press upon the chest-walls, as from their distension we might perhaps expect them to do. This is because the thorax over the affected region expands, and I have no doubt that Sir James Douglas-Powell is right in attributing this expansion to loss in pulmonary elasticity. He holds that 'as the inflamed lung increases in bulk, the thoracic wall retreats,' owing to the removal of pulmonary elasticity, which normally causes the ribs to be sucked in beyond the neutral point.* I would suggest that a more important factor even than this is the overaction of the inspiratory muscles. This overaction necessarily results

* 'Diseases of the Lungs and Pleuræ,' 4th edit., p. 19.

from the diminution of suction, and is, moreover, predisposed to by dyspnœa (see Chapter on Dyspnœa).

Effusion of gas or liquid into the pleura diminishes pulmonary suction, the stretched elastic fibres of the lung becoming more and more lax as the effusion increases and the lung shrinks, and it continues to diminish until the shrinkage of the lung has proceeded to the point at which the pulmonary fibres are no longer stretched, when it completely disappears. The continuance of effusion beyond this point causes the pressure in the pleura to become increasingly positive. In one case of hydrothorax Leyden found the pressure of the pleural fluid to be 28 mm. Hg, and in a case of pneumothorax he found the pressure of air in the pleura to vary between 5 and 10 mm. Hg. In pleuritic effusion the heart is displaced to the opposite side before the diaphragm is thrust downwards; for directly the pulmonary suction of the affected side diminishes—and this occurs at the very beginning of the effusion—the heart will be drawn over by the greater suction of the opposite side, but the pressure on the abdominal aspect of the diaphragm being positive, it will not be until the pleural pressure becomes still more positive that the diaphragm will be thrust downwards. Hence, as Douglas-Powell observes, 'displacement downwards of the abdominal viscera is a late phenomenon in pleuritic effusion,'* and 'the stomach note may be obtained at the sixth rib in the nipple line in the presence of a large effusion on that side.'

In gaseous effusion into the pleura the heart is immediately sucked over to the unaffected side, but the pressure cannot be sufficiently positive to displace the diaphragm until the occurrence of considerable liquid effusion.

Just as pulmonary suction diminishes as the elastic fibres of the lungs become more and more lax, so on the other

* *Op. cit.*, p. 106.

hand, does it increase the more these fibres are stretched, for the greater this stretching, the more do the lungs strive to retract from the chest-wall and other adjacent structures. Hence, suction is greater during inspiration than expiration. The lung presses against its contiguous structures with a force equal to the pressure of the air in the air-vesicles less the amount of elastic force these latter exert upon their contained air. The alveolar air-pressure at the end of an ordinary inspiration is about 1 mm. Hg less than the atmospheric pressure—*i.e.*, 59 mm. Hg—and the alveolar elastic force is then about 10 mm. Hg. Hence, at the end of an ordinary inspiration the lungs press upon the surrounding structures with a force equal to 749 mm. Hg, this being 11 mm. Hg less than the atmospheric pressure. At the end of an ordinary expiration the alveolar air-pressure is about 2 mm. Hg more than the atmospheric pressure—*i.e.*, 762 mm. Hg—and the alveolar elastic force about 5 mm. Hg. Consequently, the lungs then press upon surrounding structures with a force equal to $762 - 5 = 757$ mm. Hg, this being 3 mm. Hg less than the atmospheric pressure.

It is therefore clear that during ordinary breathing the structures contiguous to the lungs are subject to suction which increases with every inspiration.

At the end of an extraordinary *in*spiration the negative pressure on the extra-pulmonary structures is considerable, while at the termination of an extraordinary *ex*piration the pressure may become very decidedly positive. The effect of vigorous inspiration and expiration is still more pronounced when the entrance to the respiratory tract is closed. Thus, a vigorous inspiration with completely closed mouth and nostrils may reduce the pressure to -70 mm. Hg, or further.* This is known as 'Müller's

* According to Oertel, it may fall as low as -100 mm. Hg. (Von Ziemssen's 'Handbook of General Therapeutics,' vol. iii., p. 577).

experiment.' The diminution of pressure is essentially due to rarefaction of the intra-pulmonary air, and not simply, as in inspiration with open glottis, to stretching of the elastic lung. On the other hand, a forcible expiration with closed mouth and nostrils, after the method used by aurists to inflate the mid-ear, may raise the intra-pulmonary pressure 120 mm. Hg above that of the atmosphere, the heart and great bloodvessels and intra-pulmonary vessels being in this way so firmly compressed as seriously to interfere with the circulation. This is known as 'Valsalva's experiment.' A similar effect is produced by all forms of effort when a powerful expiration is made with partially or completely closed glottis.

The intra-pulmonary air-pressure may in a similar way be modified by causing the air which is inhaled, or that into which the expired air passes, to be condensed or rarefied.

Means for maintaining Pulmonary Elasticity.—Since loss of pulmonary elasticity induces many evils, foremost among which is, as we have seen, emphysema, it is of the greatest importance to preserve the elasticity as much as possible. To this end we should endeavour to check the advent of premature senility by urging the individual to lead a healthy, temperate life; the lungs should be carefully protected from bronchitis, pneumonia, and other diseases; coughing, the blowing of wind instruments, straining at stool, and all other muscle-efforts with fixed thorax, should be avoided; and special means should be adopted to prevent overdistension of the thorax from dyspnœa. The methods given in Chapter XXI. for increasing and preserving the mobility of the thoracic cage are also useful in maintaining the elasticity of the lungs.

It is by no means impossible to avoid the fixation of the chest which accompanies effort. The fixation is effected by closure of the glottis, and one should therefore get into the habit of always keeping the glottis open during muscular exertion, for under these circumstances it is impossible to raise the intra-pulmonary pressure unduly, and thus distend the alveoli to a dangerous degree. To take a particular instance: much injury may be done to the lungs by habitual straining at stool, but this may be entirely avoided by never allowing the glottis to be closed during defæcation.

CHAPTER II.

INTRA-ABDOMINAL TENSION—FUNCTIONS OF THE ABDOMINAL MUSCLES.

The pressure in the abdominal cavity is under normal conditions positive, *i.e.*, greater than the atmospheric pressure, wherefore the abdominal contents press against their containing walls, tending to bulge them. When, as sometimes happens, the internal pressure is negative, these walls are sucked in.

Positive intra-abdominal pressure plays a not unimportant part in expiration. The diaphragm when in a state of rest lies high, the pressure on its under surface being positive, and that on its upper surface negative. When its muscle-fibres contract, it flattens out, and in so doing it has to work against the intra-abdominal pressure, which it increases. The abdominal viscera constitute, so to speak, an elastic buffer, which is compressed with every descent of the diaphragm, and by its recoil drives the diaphragm up at the end of inspiration.

This positive intra-abdominal pressure depends upon the pressure of the atmosphere upon the yielding abdominal walls, and also upon the contraction of the abdominal muscles. Thus, it is greatest in muscular men, while it is least in multiparous women with flaccid abdominal walls.

The fact that the abdominal walls are yielding and not rigid, renders it difficult to get a negative intra-abdominal pressure, owing to the pressure of the surrounding atmosphere. Under certain circumstances, however, it is negative. Thus, when a deep costal inspiration is taken, the diaphragm is sucked upwards by pulmonary suction, and the abdominal walls are sucked inwards, this suction being increased if the breath is taken with closed glottis. The effect of this upward movement of the diaphragm upon the pressure within the abdomen is comparable to the pulling out of the piston of an air-pump. It is said that the intra-abdominal tension in some women is habitually negative, a phenomenon very difficult to account for, except on the assumption that it is produced by pulmonary suction.

Intra-abdominal tension is increased by forcible contraction of the abdominal muscles, especially if the glottis is partly or completely closed, as in cough or muscle-effort—straining at stool, for instance. In the latter case the diaphragm is fixed, and the contracting abdominal muscles compress the underlying structures with great force.

Inasmuch as intra-abdominal tension is greater in muscular men than in women with flabby abdominal walls, abdominal operations are more difficult in the former than in the latter. In the very muscular the intestines are forcibly driven out directly the cavity is opened, and the hand when introduced may be so firmly grasped as to render exploration of the viscera impossible, without pushing anæsthesia to its limit.*

The degree to which the abdominal muscles compress the underlying viscera is largely determined by occupation. Thus, as Bruce Clarke points out, the abdomen of a fisherman is hard and flat, and may remain so, even up to advanced age, a circumstance he attributes mainly to the effect of

* See 'On Some Effects of a Lack of Muscular Development,' W. Bruce Clarke, *Brit. Med. Jour.*, 1896, vol. ii., p. 1493.

rope-hauling in developing these muscles; he also calls attention to the marked influence of this occupation in diminishing abdominal obesity. It may be observed, in passing, that all muscle exercises do not cause fat to disappear at the same rate all over the body. The fat tends to be absorbed chiefly in the neighbourhood of the muscles most actively employed. Thus, if a stout man takes to fencing, the loss of fat takes place chiefly about the chest, and similarly, rope-hauling, which calls the abdominal muscles into active play, is especially calculated to remove fat from the belly.

The chief causes of abdominal flaccidity, with its consequent low intra-abdominal tension, are: a sedentary life, the wearing of stays (which prevent the free play of the abdominal muscles), and the distension of the abdominal walls produced by repeated pregnancies and by ascitic and adipose accumulations. Thus, the abdomen of a person who, from being very stout, has become rapidly thin, is very apt to be flaccid. Intra-abdominal tension is, of course, also diminished by paralysis of the abdominal muscles, as in myelitis and in idiopathic muscle-atrophy, of which I have a good example at present under observation.

But the tension within the abdomen, though mainly dependent on the contraction of the abdominal walls, may be increased by other conditions. Thus, the pressure within the stomach and intestines varies from hour to hour even in health. Often it is negative, but it is frequently also positive; *e.g.*, after a heavy meal it may be very decidedly positive, and may cause a considerable bulging of the upper part of the belly. (It is this positive gastric pressure which is the essential factor in causing dilated stomach.) Again, the stomach and intestines may be distended by flatus, and intra-abdominal tension is then much augmented, the abdominal walls often being stretched as tight as a drum.

Ascitic and other dropsical accumulations and abdominal tumours also greatly increase it. Quincke found the average intra-peritoneal pressure in ascites to be 25 mm. Hg. A full bladder increases abdominal tension. A large deposit of fat within the belly favours high tension.

Secondary Effects of Low Intra-abdominal Tension.—A fairly high intra-abdominal tension is essential to health. When the abdominal muscles fail to maintain adequate pressure on the underlying parts several evils result:

(*a*) Dislocation of the abdominal viscera is apt to occur. Bruce Clarke lays great stress upon the part taken by the abdominal muscles in maintaining the underlying viscera in their proper position. When the abdominal walls are habitually flaccid, all the viscera, including the liver, spleen, and pancreas, tend to travel downwards. This is a potent cause of floating kidney, which is never met with in those with well-developed abdominal walls. Visceral descent also causes lengthening of the mesentery and the 'bulging' abdomen, and it leads to certain symptoms very common in women. 'There is pain in the back and a continued sense of weariness. Gastric symptoms are prominent; the most conspicuous are a sense of burning in the epigastric region, vomiting, pain, loss of appetite, distress after food, and more or less dyspepsia. . . . The symptoms are more or less relieved by pressing upon the lower parts of the abdomen with the two hands, or by the wearing of a supporting belt. Many patients are unable to move about until they have adjusted their supports or bands.'*

(*b*) Constipation is induced. Increase of intra-abdominal tension is an important factor in defæcation, and when the abdominal muscles are weak they are incapable of effecting the necessary degree of tension, and defæcation becomes difficult.

* Treves, *Brit. Med. Jour.*, 1896, vol. i., p. 1.

(*c*) There is, as Leonard Hill has so well shown, a tendency for the blood to accumulate in the splanchnic area, with consequent syncope. The great splanchnic veins, like the veins in general, are very susceptible to pressure, and the amount of blood they contain is largely dependent upon the pressure the abdominal walls exert upon them. Thus, a large quantity of blood may be squeezed out of them by simply pressing the belly firmly with the hand. Now, owing to the influence of gravity, the blood is very apt to accumulate in the splanchnic veins in the upright position; and it is not, therefore, surprising that women, who so frequently suffer from abdominal flaccidity from the combined influences of child-bearing, tight-lacing, and bodily inactivity, should be prone to faintness or actually to faint, especially when the stays are removed. I have myself known of more than one instance of a woman fainting upon the removal of her stays. The same thing may happen, and for a similar reason, when a large quantity of ascitic fluid is suddenly removed, or even after emptying the bladder in the upright position—especially, as Lauder Brunton observes, if a patient with aortic regurgitation suddenly gets out of bed to do this. Stays correct the evil in question while they are on, but the most efficient stays are natural ones, in the shape of well-developed abdominal muscles. In the normal subject the transversales in the upright position keep the anterior and posterior abdominal walls in firm contact, and prevent the undue accumulation, through gravity, of blood in the splanchnic area. Such an accumulation, with its consequent faintness, often occurs when a patient first gets up after having lain in bed for a long time. Leonard Hill attributes this to failure, through disuse, of the regulating vaso-motor action of the splanchnic vessels, which normally compensates for the effects of gravity in the upright position;

but I think it may also in part be due to weakness of the abdominal muscles consequent upon disuse and, it may be, disease. In prolonged fever, for instance, the nutrition of the muscles always suffers.

Since the above was written, Hill has published, in conjunction with Harold Barnard, a second paper on the influence of gravity on the circulation,* in which the part played by the abdominal muscles in preventing the gravitation of blood into the splanchnic veins is worked out. They show that when the splanchnic vaso-motor mechanism is intact it suffices of itself to prevent this, but that when, as by section of the splanchnic nerves, this mechanism is destroyed, a second mechanism comes into play in the shape of 'expiratory compressions of the abdomen occurring simultaneously with inspiratory thoracic suctions,' the former squeezing, and the latter sucking, the blood out of the splanchnic pool. This enables the circulation to be carried on, though not so efficiently as before. We may speak of this as the respiratory mechanism. That the latter mechanism is not so efficient in compensation as the former is shown by the fact that the effects of gravity may be entirely compensated for after the injection of curare, which paralyzes the muscles and thus destroys the respiratory mechanism. This quite harmonizes with one's clinical experience. We sometimes meet with patients in whom this mechanism cannot operate, but who, nevertheless, are able to assume the vertical posture without fainting. Such are women with lax, atrophied abdominal walls and fixed emphysematous chests (in which, therefore, thoracic suction is practically absent). The ability of such to stand without fainting implies, of course, a vigorous state of the splanchnic vaso-motor system.

Both mechanisms may be destroyed by dividing the cord

* *Jour. Phys.*, vol. xxi., p. 323.

at the first dorsal vertebra. If the animal operated on be then held vertically with the head up, the whole of the blood collects in the splanchnic veins, and 'the empty heart continues vainly to beat.' On compressing the belly, however, the blood is squeezed into the heart, and the circulation is re-established.

(*d*) The accelerating influence of the diaphragmatic movements on the circulation is interfered with. These movements, as will be shown in Chapter XIII., play an important part in assisting the abdominal circulation by rhythmically increasing intra-abdominal tension ; but when the abdominal walls are very flaccid, the descent of the diaphragm will have little or no effect upon the tension, and consequently on the flow of blood in the intra-abdominal veins.

(In the above experiment of dividing the cord, the diaphragm continues to act, inasmuch as the phrenics arise above the section. By its action it is able to increase thoracic suction slightly, and to squeeze a small quantity of blood out of the abdominal veins. The latter action is, however, infinitesimal, owing to the paralyzed state of the abdominal muscles, which prevents the abdominal pressure from being raised, except very slightly, by descent of the diaphragm.)

The Action of the Abdominal Muscles.—The action of the transversalis abdominalis has been to a large extent overlooked by anatomists. The superior fibres, stretching as they do across the costal arch, tend to narrow it, and thus to favour expiration. The middle fibres, taking their origin posteriorly from the lumbar fascia and stretching forwards towards the mid-abdomen, by their strong contraction bring the anterior and posterior abdominal walls in this region into firm contact, thus shutting off the upper part of the abdominal cavity from the lower. This contraction leads to considerable compression of the kidneys, and it does not seem improbable that the normal healthy tone of the transversalis has a good deal to do with keeping the kidneys in their normal position; contraction of the middle fibres also presses the stomach, liver, and intestines firmly up against the diaphragm, and, by interfering with the descent of this structure, enables it to expend its energy in elevating the ribs rather than in flattening itself. The upper and middle portions of the transversalis may be said to constitute 'Nature's stays.'

The lowermost fibres springing from the iliac crests and Poupart's ligaments cause by their contraction a flattening of the lower abdomen.

The most transversely disposed fibres of the internal oblique have a similar action to the middle fibres of the transversalis, and retract the mid-abdomen.

All those fibres of the external and internal oblique which are attached to the ribs are powerful expirators, and are capable of depressing the thorax with great force. In this way the diaphragm is carried downwards, and the abdominal cavity being thus diminished in height, the anterior walls tend to bulge forwards.

The recti are very powerful muscles. They depress the sternum and ribs. Each rectus is capable of acting more or less independently of its fellow, and each fasciculus also has apparently independent action, and may contract independently in order to protect any painful tissue underlying it. These muscles play an important part in rendering the belly flat and in supporting the underlying viscera.

Method of testing the Tone of the Abdominal Muscles.—Whenever the tone of the abdominal muscles is defective, we can improve the condition of our patient by restoring them to a healthy state. The result of treatment directed to this end is sometimes quite remarkable. In all cases, therefore, where we have reason to suspect undue flaccidity of the abdominal walls, we should make a careful inspection of the abdomen. Sometimes the skin is so loose, the walls so flaccid, that it is quite easy to inspect and to palpate the various underlying organs. In such cases a wide interval can generally be felt between the recti. When, however, as often happens, the actual condition of the muscles is concealed by a copious deposit of fat, and the abdominal wall appears normal, even though its muscles be flabby and wasted, we should ask the patient gradually to raise the body while lying supine, or to bear down forcibly, and we shall then, by the feel of the muscles under the skin, be able to estimate their condition fairly accurately.

When forming an opinion upon the state of the abdominal walls, we must bear in mind that normally they are considerably influenced by age and sex. In infants and young children the belly bulges very much, therein displaying a characteristic of man's quadrumanous ancestry, protrusion of the belly being a well-marked feature in the anthropoidal apes. A further characteristic of the young child's anterior abdominal wall is the separation of the recti. If, for instance, we observe the belly of an infant while it is lying on its back and endeavouring to sit up, we shall perceive a spindle-shaped swelling along the region of the linea alba. This is due to the protrusion of the fibrous membrane uniting the two recti, owing to heightened intra-abdominal tension. It is especially pronounced in infants who suffer from chronic flatulent distension—a common complaint with them. In such, the abdomen is more than usually prominent and the interval between the recti abnormally wide.

As the child gets older the belly flattens, and the recti approach one another, and it is not until the belly has attained the maximum flatness that the recti become fixed in close approximation, the fibrous membrane between them becoming so narrow that it can no longer be protruded. This takes place, according to my observations, at about the third or fourth year.*

Accompanying this abdominal flattening is a similar flattening of the thorax, which, like the belly, is round in the infant and the anthropoids, and no doubt the process has in each case a similar object, *i.e.*, the maintenance of the vertical position by keeping the centre of gravity vertically above the narrow basis of support afforded by the feet.

The abdomen continues flat in the male, if he remains in good condition, until the end of life; but in the female a considerable deposit of subcutaneous fat occurs in the anterior abdominal wall at puberty, so that in the normal adult female the belly is rounded.

Exercises for strengthening the abdominal muscles are given in Chapter XX.

* I have, however, often noticed the protrusion referred to above some time after the belly has attained its maximum degree of flatness.

CHAPTER III.

THE ELASTICITY OF THE THORACIC CAGE.

I USE the term 'thoracic cage' to denote the chondro-osseous walls of the 'thorax,' this latter term signifying not only the parietes of the chest, but its contents also.

The thoracic cage is elastic, *i.e.*, its several parts, including the ribs, cartilages, sternum, spine, and also the clavicles (for they in a measure belong to it), are capable of being bent, and of springing back to their original positions when the bending force has ceased to act.

John Hutchinson measured the elasticity of the thoracic cage by driving air into the lungs with sufficient power to rupture them, and then noticing the height to which the returning air was able to lift a column of mercury. In one case he found that by forcing in the amount of air which corresponded to the 'vital capacity' of the individual—namely, 200 cubic inches—the returning air was able to raise 4·5 cubic inches of mercury; therefore the complete expansion of the chest in that case 'must have demanded a muscular power equal to resisting an elastic force commensurate to 4½ inches of mercury, upon every square inch of his chest which was moved or expanded by muscle.'* Hutchinson further calculated that this man, in taking a deep inspiration, must have exerted a muscular power capable of raising 450 lbs.; and in another case he found that the thoracic elasticity must have equalled 1,000 lbs.

* *Med. Chir. Trans.*, 1846, p. 207.

The elasticity of the ribs, cartilages, and sternum is greatest in early life. Hence, in young children the thorax is very easily compressed. With advancing years, especially in old age, these structures tend to become increasingly rigid from the deposit of lime salts in them, and we therefore frequently find the costal cartilages calcified. Humphrey regards this change as a morbid rather than a normal senile change. He points out that the costal cartilages of old people can often be as readily cut with the knife as those of the young, and he found that in one man a hundred years old they contained no excess of mineral matter.

Calcification of the costal cartilages is more common in men than in women.

The elasticity of the thoracic cage serves several useful ends :

1. It enables the component parts of the cage to be so bent during the respiratory movements as to increase or diminish thoracic capacity. One is apt to think that the sternum, ribs, and cartilages always preserve the same form, and that they have exactly the same curvatures at the end of a deep inspiration or expiration as in the mean position of the thorax; but such is far from being the case. During a deep inspiration the anterior vertical convexity of the sternum increases, the upper costo-cartilages tend to bulge forwards beyond the sternum, while the ribs themselves undergo considerable bending. For the most part they straighten out, the posterior bends, or 'angles,' however, becoming more pronounced, as may be felt by placing the hand upon them during a deep inspiration. These various structures are also bent during a deep expiration, but in a contrary manner. The former we may term the 'inspiratory,' and the latter the 'expiratory,' bend.

The mean or *neutral* position of the thoracic cage—*i.e.*, that position in which its constituent parts are wholly unbent—does not, as one is so apt to suppose, correspond to that attained at the end of an ordinary expiration, for then the thoracic cage is bent somewhat inwards by pulmonary suction. It more nearly corresponds to the position which the chest assumes at the end of an ordinary inspiration. The fact is that ordinary expiration starts at about the neutral position, the lungs during the entire period of expiration sucking in the thoracic cage beyond that position. This is shown by the fact that when the chest is opened after death, and pulmonary suction thus arrested, the thoracic cage expands.

The inspiratory and expiratory bends induce recoils which become factors in producing the respiratory movements. Thus, at the end of an extraordinary inspiration the cage recoils by virtue of the inspiratory bend towards the neutral point, being helped in this movement by pulmonary suction; and, similarly, at the end of an extraordinary expiration an outward recoil occurs by virtue of the expiratory bend, this movement being, of course, assisted by the action of the costal elevators.

The part played by thoracic recoil in ordinary, tranquil breathing requires special reference. We have seen that at the commencement of an ordinary expiration the chest is in the neutral position, or nearly so, and that it becomes bent inwards during the expiration; consequently, at the end of it an outward recoil is available as an inspiratory force, and carries the cage back towards the neutral position, which, according to Douglas-Powell, is barely reached in ordinary inspiration. Inasmuch, therefore, as the movement of the ribs during ordinary inspiration is purely a matter of recoil, 'the sole resistance to be overcome by the inspiratory muscles is that of the lungs.'*

* Douglas-Powell arrives at the above conclusion in the following way. After death, when the chest is in a position of ordinary expira-

What happens, then, is this: During expiration the ribs, cartilages, and sternum are bent into a position from which they tend to recoil outwards, and during inspiration the inspiratory muscles exert just sufficient force to overcome pulmonary suction, the thoracic cage by its passive recoil assuming the position attained at the end of ordinary inspiration, and not offering any dead weight to be raised by the inspiratory muscles. It, however, appears to me an error to suppose, as Douglas-Powell apparently does, that inspiration is facilitated by this arrangement.*

2. The elasticity of the thoracic cage enables its component parts to move more or less independently of one another. Consider what would happen if the ribs, cartilages, and sternum were absolutely rigid. It would then be impossible, unless we assume a preternatural laxity of the joints, to move one rib without moving all the others to the same degree. As a matter of fact, however, during a deep inspiration, the upper ribs approximate to one another, while the intervals between the lower ribs increase. Andral long ago pointed out that the ribs can move independently of one another,† and Sibson refers to the independent action of each intercostal muscle.‡ It is, moreover, pos-

tion, the thoracic cage is bent inwards beyond the neutral point; for upon opening the pleuræ, and thus removing pulmonary suction, the girth of the chest is increased from 1·63 mm. to 3·9 mm.; but the thoracic girth in ordinary inspiration is only increased by 2 to 3 mm., and hence he concludes that in the ordinary quiet inspiration of health 'the limit of thoracic recoil is barely reached.' *Op. cit.*, pp. 6-19.

* Suppose pulmonary suction were not sufficiently powerful to draw in the bony thorax during ordinary expiration, there would be so much the less opposition to the inspiratory muscles. The inspiratory muscles have to overcome pulmonary suction minus the force of the outward recoil of the thoracic cage. If we suppose pulmonary suction to diminish by this amount of force, so that the ribs are not drawn in, as may happen in emphysema, the force to be overcome by the inspiratory muscles will obviously remain the same.

† *Clin. Méd.*, tom. i., p. 68.

‡ *Med. Chir. Trans.*, vol. xxxi., p. 353.

sible—especially in women, whose upper ribs acquire unnatural mobility from the use of stays—to expand the upper chest more than the lower, and it is still more easy to do the converse of this.* It is also possible, after a little practice, voluntarily to expand one side of the chest independently of the other, or nearly so. In a patient who had long suspected tubercle of the right apex, I found the movement on this side greater than on the other: by constant attention to it, he had got into the habit of expanding it more than the other. Again, inequality in the movement of the two sides of the chest is frequently observed in disease; the whole of one side may be practically immobile, or the defective movement may be limited to two or three ribs.

3. Thoracic elasticity enables the cage to adapt itself to alterations in the volume of the thoracic contents. Thus, in phthisis the parietes tend to fall in, while in pleural effusion and cardiac enlargement the overlying walls tend to bulge. This adaptation is the more complete the greater the elasticity of the cage, and it is therefore more complete in the young than the old. It serves, be it noted, a useful purpose. Thus, if the chest-wall did not fall in in phthisis, not only would there be a considerable upward dislocation of the diaphragm, and consequently of the heart and abdominal viscera, but also great stretching of the bronchi and alveoli. Again, a greatly enlarged heart may cause dyspnœa, especially in children, by encroaching on the space which should be occupied by the lungs, and it is precisely in children that precordial bulging is most easily effected. Such bulging, indeed, always accompanies any considerable cardiac enlargement in their case, and may be so well defined and so decided as to render it almost possible to map out the shape

* See p. 57.

of the heart on mere inspection. It should also be observed that the enlarged heart often makes room for itself by thrusting the diaphragm downwards; one can sometimes, indeed, almost grasp the heart in the epigastrium.

The degree of thoracic elasticity is important in relation to external compression of the thorax. A rigid chest resists compression; an elastic one readily yields to it. It would not require much compression of a child's chest to destroy life completely, while it would take a good deal of force to produce the same effect in a very muscular middle-aged man.

The effect of external compression of the chest on the circulation will be considered later. Suffice it here to say that it impedes the output of blood from the right heart, damming it back upon the great veins. Hence, as Hill and Barnard observe, 'it is the weaker women and children with compressible chests that are first affected in panic-stricken crowds. . . . The stronger man with a rigid chest escapes.'*

The elasticity and consequent compressibility and resiliency of the thorax are of practical interest in relation to artificial respiration. The more elastic the chest, the better can artificial respiration be carried on, and it is partly to this fact that Leonard Guthrie attributes the better recovery from chloroform collapse of children than adults.† In the former case he recommends the application of rhythmic pressure to the lower part of the thorax, while in adults he prefers Silvester's method.

* *Jour. Phys.*, vol. xxi., p. 334.

† *Clin. Jour.*, March 24, 1897, p. 336.

CHAPTER IV.

THE FACTORS DETERMINING THE MEAN SIZE OF THE CHEST.

What are the factors determining the mean size of the chest—*i.e.*, its size when midway between ordinary inspiration and expiration? We do not answer the question by saying that the size of the chest depends upon that of the lungs, since this statement gives no clue as to the way in which the correlation is effected. We know, for instance, that pulmonary phthisis diminishes the size of the lungs, and that the chest-walls tend to collapse in consequence; on the other hand, we know that exercises which develop the lungs expand the chest, and we are apt to assume that the collapse in the one case is due to diminished pulmonary support, and the expansion in the other to an actual thrusting outwards of the chest-walls from pulmonary hypertrophy. Seeing, however, that pulmonary suction tends to draw in the chest-walls, this latter assumption is manifestly wrong.

How, then, are we to explain the correlation between pulmonary development and chest capacity? Given ribs, sternum, heart, etc., of certain size, thoracic capacity will depend upon two main factors: (*a*) The degree of pulmonary suction tending to contract the chest, and (*b*) the excess of tonic contraction of the muscles expanding the thoracic cage over that of the corresponding contractors.

(*a*) Pulmonary suction is increased in phthisis during ordinary breathing, for destruction of pulmonary tissue leads to excessive stretching of the unaffected parts—*i.e.*, to an undue drag upon the visceral pleura, this being still further increased by the contraction of scar tissue within the lungs. Hence, the collapse of the chest-walls in phthisis does not result from diminished support from within, but rather from increased pulmonary suction.* I say that pulmonary suction is increased in phthisis in ordinary breathing. In health it is greater during extraordinary inspiration than it is in phthisis.

Pulmonary suction is, on the other hand, diminished by exercises tending to develop the lungs, for the more perfectly the air-passages and alveoli are developed—and it must be remembered that in ill-developed lungs a number of alveoli are partly or completely collapsed—the less will the elastic elements of the lungs be stretched, and the less will be the traction upon the visceral pleura. Hence, increased development of the lungs expands the thorax, not by thrusting it outwards, as Lagrange assumes,† but by diminishing the suction on its inner walls.

(*b*) Next as regards the muscle factor. First be it noted that the thoracic elevators are much more constant in their action than the corresponding depressors, for ordinary expiration may be regarded as purely passive, while even in the extraordinary breathing attending muscle exercise the inspiratory muscles are much more actively engaged than the expiratory. This is because breathlessness *tends to excite the inspiratory muscles more than the expiratory*

* The lungs are frequently adherent to the chest-walls in phthisis, and in such cases we may speak of the adherent portions as actually *dragging* in the thorax, rather than as sucking it in.

† Lagrange rightly observes that muscle exercise develops the lungs and enlarges the thorax essentially by inducing breathlessness, but he does not explain how breathlessness produces this result.

(see p. 93). The influence of the thoracic elevators thus preponderating over that of the depressors, the tendency of muscle activity is to increase thoracic capacity.

There can be no doubt that the breathlessness attending muscle exercise leads to an increase in the mean size of the chest. Such an increase occurs during running, rowing, and the like. Thus, during a hundred yards' sprint the chest is always very prominent, the respiratory movements taking place about a larger mean than ordinary, so that, while inspiration exceeds the average, expiration does not reach its usual limit. This increased mean thoracic capacity during muscle activity has a double advantage, for not only is the mean respiratory area thereby increased, but the resistance in the pulmonary circuit is diminished* —a great advantage, seeing that the right heart is so apt to be distended in violent muscle exercise. Such exercises as mounting a ladder, running upstairs, hill - climbing, and diving, tend, by the dyspnœa which they induce, to cause great expansion of the chest. So greatly, indeed, may the chest be expanded in this way that the lungs may become unduly stretched, and their elasticity thus permanently injured. Now, loss of pulmonary elasticity is a potent cause of emphysema, and hence it is that exercises of this kind may actually induce it.†

Those who inhabit mountainous regions and who thus habitually breathe rarefied air, have expanded chests. This is because the inspiratory muscles are excited to extreme activity by the breathlessness which the rarefied air is apt to induce.

We see now how it is that those with strong muscle systems and leading active lives have more capacious chests than those with weak muscle systems and leading sedentary lives. It is among the latter that the phthinoid chest is

* See Chapter XIII. † See Chapter XXII.

most frequently found—the *chest of superextraordinary expiration*, as we may term it, in which the clavicles, scapulæ, and sternum are low, the ribs very oblique, the sagittal diameter small, the costal arch very acute, and the diaphragm high, the heart being correspondingly high up and superficial. The opposite type of chest is met with in subjects of strong muscle development: the clavicles, scapulæ, and sternum in them are high, the ribs less oblique, while the chest is deep, the costal angle well opened out, and the diaphragm low, the heart being correspondingly low and also deep. The typical large-lunged emphysematous chest is an exaggeration of this, and may be termed *the chest of superextraordinary inspiration.*

How large a share the muscles take in determining the mean size of the thorax is well shown by the effects of paralysis. I have now under my care a boy suffering from idiopathic paralysis. Several of the cervical muscles are paralyzed, he has no power of flexing the neck or head, the scaleni are practically absent, while the sterno-mastoids are reduced to riband-like bands. In consequence of this the sternum has descended a good inch, the ribs being correspondingly oblique, and the chest very flat. The clavicles, instead of being horizontal, or nearly so, as they should be, slope markedly downwards and inwards, their outer ends being maintained in position by the trapezius, which is not paralyzed. This marked downward and inward slope of the clavicles is, I believe, frequently met with among those with feeble muscle development and phthinoid chests, and is a feature to be sought for.

Seeing that a feeble muscle system is common among those actually afflicted with phthisis, we have an additional reason why the thorax should collapse in this disease.

All diseases which enfeeble the muscle system tend to diminish the chest capacity. Thus, I have little doubt that in the course of a long debilitating disease, such as typhoid fever, the thorax undergoes a decided diminution, provided, of course, it be not already fixed from age. The same may even happen if a sedentary existence succeed to an active, outdoor life. Conversely, a single long walk may temporarily increase the chest capacity in one leading a sedentary life.

Not only the breathlessness of muscle exercise, but also that induced by disease, tends to cause expansion of the chest, and in the same way—namely, by exciting the inspiratory more than the expiratory muscles. Indeed, in most cases of dyspnœa from disease the chest is found to be in a state of inspiratory expansion, this expansion not only increasing the respiratory area, but facilitating the pulmonary circulation which is then so apt to be impeded. It should be observed that thoracic expansion does not occur in the dyspnœa resulting from considerable obstruction in the air-passages, which, on the contrary, induces collapse—a condition likewise favoured by weakness in the inspiratory muscles and chest wall, and hence its frequency in the bronchitis of marasmic and rickety children. Wilson Fox observes that the chest is generally expanded in cardiac dyspnœa, and I can bear out this statement. We can on similar lines explain—partly at least—the expansion of the chest during the asthmatic paroxysm.*

The important part taken by the inspiratory muscles in determining the mean size of the chest is well shown by the expansion of the thoracic cage which takes place at birth. I believe this to be due to tonic contraction of certain thoracic elevators. Before birth the lungs are collapsed. Immediately after birth they expand, and the

* See Wilson Fox, 'Treatise on Diseases of the Lungs,' pp. 65-67.

thorax is correspondingly enlarged; this enlargement could not be maintained except by muscle-action. It is true that pulmonary suction is absent in the new-born animal (the lungs suffering no collapse if the pleuræ are opened immediately after birth), and consequently the thoracic cage is subjected to the same pressure on its inner as on its outer side; but even with this supporting pressure from within, the cage would yet surely tend to shrink to its ante-partum dimensions did not the expansile forces of respiration preponderate over the contractile.* Moreover, it is not long before pulmonary suction *is* established, and this, I suggest, is due to the gradual increase in the mean size of the thoracic cage, owing to the preponderating action of the costal elevators, the elastic fibres of the lungs being thereby put on the stretch, rather than (as has been suggested) to the thoracic cage growing more rapidly than the lungs, though such inequality in rate of growth may contribute to the result.

We have not yet explained why the mean size of the chest should be *permanently* increased as the result of long-continued overaction of the inspiratory muscles, and why it does not shrink to its pristine dimensions directly excessive inspiratory action ceases. Suppose that, by means of suitable exercises, we increase the mean thoracic girth from 32 to 36 inches; this signifies that the clavicles, ribs, and sternum are held in a new mean position, that there has been established a new mean position about which the respiratory movements take place. It may, indeed, be no longer

* Among the expansile forces of respiration we must, of course, include the action of the diaphragm. This is the chief respiratory muscle in the infant, and it might be argued that the increase in mean thoracic capacity brought about at birth is not due to an increase in the capacity of the *cage*, but to a lowering in the mean level of the diaphragm from tonic contraction of its muscle fibres. I imagine, however, that there can be little doubt that the capacity of the thoracic cage is actually increased at birth.

possible for an individual whose chest has been thus increased to make it, by the most forcible expiration, as small as before the exercises were undertaken.*

How is the chest fixed in this new position, and why does it not return to its original size when excessive inspiratory action ceases? This question has never, so far as I know, been discussed. There are at least two factors tending to fix in a new position a chest which has been chronically expanded:

(*a*) Permanent shortening, or contracture, of the thoracic elevators. Long-continued overaction of these muscles increases their tone, namely, their permanent contraction. They remain chronically contracted, no longer relaxing to the same extent as before the period of their overaction. This, in course of time, leads to their organic shortening, or contracture, for there can be no doubt that long-continued overaction of a group of muscles does lead to such shortening. Thus, it is owing to the preponderating action of the great flexors of the trunk that gymnasts so often contract the stooping posture, and the habitual flexion of the forearm observed among horse-riders may be explained on the same principle. A still more remarkable illustration is afforded by the extreme shortening that takes place in muscles whose antagonizers have become paralyzed. It is to a similar shortening of the thoracic elevators that the permanent expansion of the chest above referred to is largely attributable.

(*b*) Alteration in the joints, their articular surfaces and ligaments undergoing changes adapting them to their new position. In later life a veritable ankylosis of them may occur.

* I am referring to ordinary cases. In instances it might be possible for the individual whose chest had been considerably expanded by exercises to reach his original expiratory limit. This, however, would necessitate great thoracic mobility, and would probably only be possible if special exercises for increasing expiratory mobility were resorted to.

CHAPTER V.

THE MOBILITY OF THE THORACIC CAGE.

THE mobility of the thoracic cage is determined by many circumstances, such as the expansibility of the lungs and the condition of the abdominal viscera. There is, however what may be termed an intrinsic mobility of the thoracic cage, due to its elasticity and the mobility of its various joints, independent of conditions within and without the chest, and capable of being accurately tested in the freshly-prepared 'ligamentous thorax.'

Among the factors determining thoracic mobility, special reference must be made to the action of certain thoracic muscles. Thus, depression of the ribs may be limited by permanent shortening of the costal elevators.

Individuals differ very considerably in respect of thoracic mobility. The most mobile chests are met with in the young, for in them the bones and cartilages are very flexible and the thoracic joints freely movable. With advancing years the thoracic cage gets less and less mobile, until in old age it may become almost completely fixed. This is due to increasing rigidity of the bones and cartilages, to stiffness and even ankylosis of the thoracic joints, and generally also, I believe, to contracture of the thoracic elevators.

We must not neglect to reckon among the thoracic joints the articulations between the costal cartilages and the sternum. These joints are provided with synovial membranes and admit of considerable movement. In old age, however, they tend to disappear, the cartilages undergoing calcification and becoming welded with the sternum, with which they then form one rigid piece. In like manner the costo-vertebral joints tend to stiffen with age, owing, apparently, to shortening and thickening of the ligaments, and to the deposition of new bone in the neighbourhood of the joints.

Thoracic mobility, as John Hutchinson's classical observations show, tends to increase with stature, and it is owing to this circumstance rather than to increase in mean thoracic capacity that 'vital capacity' tends to increase with it also.

Arnold* confirms Hutchinson's observation as to the relation between stature and thoracic mobility. He finds the average thoracic mobility for various heights to be as follows:

Height.	Chest mobility.
157 to 165 cm.	6·5 cm.
165 ,, 170 ,, ...	7 ,,
171 ,, 175 ,, ...	7·5 ,,
177 ,, 180 ,, ...	8 ,,
181 ,, 191 ,, ...	8·5 ,,

Arnold also finds that the mobility of the chest tends to increase, though not to the same extent, with its girth† as well as with the height of the individual. This is not surprising, seeing that the height and girth of the thorax tend to increase together.

While the most rigid chests are most frequently met with in the aged, rigid chests, as Frederick Roberts observes, are not uncommon in young subjects, in whom they are often

* Waldenburg, 'Die Pneumatische Behandlung der Respirations- und Circulations-krankheiten.' Berlin, 1880, s. 161.

† *Ibid.*, s. 115.

traceable to 'hard, physical work, and excessive indulgence in athletics and allied exercises.'* I believe that the breathlessness induced by excessive muscle exercise is largely responsible for the fixity of the chest in these cases, leading as it does to overaction and contracture of the thoracic elevators, and not infrequently to actual emphysema also.†

Another cause of thoracic rigidity in muscular subjects has been suggested to me by Dr. McCann. It is that powerful thoracic muscles imply correspondingly strong ribs and sternum. We know that the skeleton is more massive and that the roughened osseous surfaces for the attachment of muscles are more pronounced in those of powerful muscle development than in those with feeble muscle systems, and we can scarcely doubt that this implies a corresponding rigidity of the bones.

Hence laborious muscle exercise must be included among the causes of thoracic immobility. All diseases which induce breathlessness tend in like manner to limit the mobility of the chest, and in consequence we never find a freely mobile chest in those suffering from emphysema,‡ chronic bronchitis, and serious heart disease.

Another cause is the inactivity of the muscle system with its consequent restriction of respiratory movement. It is indeed astonishing how immobile the chest generally is in those leading sedentary lives. This is especially noticeable among women, many of whom seldom, if ever, resort to deep breaths. The breathing being thus habitually shallow, the respiratory range gradually narrows.

Defective mobility does not always involve the entire cage equally. Thus, in the civilized woman the lower part may, owing to the use of stays, be comparatively fixed, while the

* Dr. Roberts does not explain how the rigidity is brought about.

† See Chapter XXII.

‡ The way in which emphysema induces fixity of the chest is considered in detail in Chapter XXII.

upper part may be abnormally mobile. In the man, on the contrary, the defective movement may be most noticeable in the upper part.

Means of testing Thoracic Mobility.—Thoracic mobility may be estimated in various ways. The most accurate method is to ascertain the relation between 'vital capacity' and the mean size of the thorax. The greater the former in relation to the latter, the greater the mobility. There is no convenient way of exactly determining mean thoracic capacity, but for all practical purposes it may be arrived at by adding the girth and height (measured in the nipple line) of the thorax. In this way we obtain a figure which bears a fairly constant ratio to capacity.*

Another plan is to take the difference between thoracic girth at the end of a complete inspiration and expiration. The measurement should be made both at the level of the nipples and of the xyphoid cartilage, seeing that mobility is sometimes greater at the one end and sometimes at the other. The average difference between maximum and minimum in the male adult is, in my experience, about 2 inches. Fetzer found it to range among 392 recruits between 4 and 12 cm., the range being most generally between 6 and 10 cm. I have known a man to claim a difference of 6 inches, but this must be very exceptional. At Barnum's Show in London a few years back was a man possessed of extraordinary chest mobility. By forcibly expanding his thorax he was able to snap a strong belt fastened round the chest when in the position of full expiration. It should be mentioned that those endowed with large and powerful thoracic muscles can effect a considerable increase in thoracic girth simply by contracting these

* In the case of the very stout it may be necessary to take off some inches from thoracic girth in order to arrive at the right measurement.

muscles, and thus causing them to swell up. Sandow, for instance, claims to be able to increase his chest circumference from 48 to 62 inches—*i.e.*, to the extent of 14 inches. I have little doubt that this increase is brought about almost entirely by the swelling up of the great muscles enveloping the chest. It is probable that the increase in his bony chest is not more than from 2 to 3 inches, seeing that his vital capacity is only 275 cubic inches.

Thoracic mobility can further be tested by noticing the degree to which the costal arch opens up and closes during an extreme inspiration and expiration; also by observing the extent to which the episternal notch can be raised and depressed. In a very mobile chest it can be made almost to touch the chin when the head is held erect. This latter test is, however, somewhat unreliable, seeing that in some cases the chest may be lifted in mass without undergoing appreciable expansion.

By means of respiratory exercises the mobility of the chest may be very considerably augmented, these exercises leading to development of the lungs and respiratory muscles and to increased flexibility of the ribs and sternum, as well as to a loosening of the thoracic joints when these have become stiff. The younger the subject, the greater is the gain in mobility likely to be. If he be under twenty-five years of age, he may be able to increase a maximum-minimum difference of $1\frac{1}{2}$ inches to 3, 4, or even more inches, and even after middle life we may effect a considerable augmentation. Not only are we thus able to increase thoracic mobility, but also to delay the advent of senile rigidity. It is not surprising that the latter should set in prematurely in those who seldom or never resort to extraordinary breathing.

For means of increasing thoracic mobility the reader is referred to Chapter XXI.

CHAPTER VI.

THE PLEURÆ AND THEIR FUNCTIONS—THE MOVEMENTS OF THE LUNGS.

The Functions of the Pleuræ.—The pleuræ consist of two large lymphatic sacs into which the lymph is pumped from the peritoneum by the respiratory movements and thence through the lungs and thoracic parietes. Their chief function is to enable the lungs to expand equally and in all directions. Seeing that the visceral and parietal surfaces are in apposition, and that the lungs in consequence remain in contact with the chest-wall, every expansion and contraction of the chest leading to a corresponding expansion and contraction of the lungs, the question not unnaturally occurs, What need is there for the pleuræ? Why should not the lungs be adherent to the chest-wall? The answer is a simple one: It is because such an arrangement would not permit of their equal expansion in all directions during inspiration. Simple diaphragmatic breathing, *e.g.*, would cause the lowermost vesicles only to expand, and these very unequally, seeing that all parts of the diaphragm do not move to the same extent, while the upper portions of the lungs would probably suffer no expansion whatever. By means of the pleuræ, however, the lungs are enabled to move in various directions within the chest, and thus to expand in all their parts, so that even in pure abdominal inspiration, in which the thorax enlarges in the vertical diameter only, the upper parts of the lungs are enabled to expand freely.

It has been urged—among others by Oertel—that when the diaphragm descends, it is the basic portions of the lungs that are chiefly expanded, and that when, on the other hand, the upper part of the thorax is expanded more than the lower, pulmonary expansion takes place in the apical regions chiefly—in short, that the lung expands most when the movement of the overlying chest-wall is most marked. Sibson held the same view, and enunciated it in precise terms.*

There can be little doubt that it is correct, though I think Oertel and Sibson push it too far. Thus, during an abdominal breath air appears, from the test of auscultation, to enter the apices freely. It is therefore questionable whether there is any foundation for the view that tubercle is prone to attack the apices, because in ordinary breathing, which is mainly abdominal, they expand much less than the bases. When, however, the pleuræ are adherent, the case is different, for whatever interferes with the upward and downward gliding movement of the lungs within the chest will necessarily interfere with the proper expansion of the apices in ordinary breathing. Hence, those with pleuritic adhesions should frequently resort to costal breathing.

The Lower Limits of the Pleuræ.—It is necessary to ascertain the lower limits of the pleuræ, for these determine those of the lungs when expanded to their fullest

* According to this authority, ascent of the first five, or *thoracic* ribs expands the superior and middle lobes; elevation of the sixth to eighth, or *intermediate* ribs, expands 'the upper portion of the lower lobe, and on descent of it, the lower portion of the upper lobe'; while elevation of the ninth to twelfth, or *diaphragmatic* ribs, expands the lower and back part of the lungs.—*Med. Chir. Trans.*, vol. xxxi., pp. 357-359.

possible extent. Each pleura extends downwards as far as the attachment of the diaphragm to the thorax. It is stated by some writers that the diaphragm is attached to the rim of the costal arch, and this gives the erroneous impression that the lungs may extend as far as this. Such is, however, not the case. Posteriorly, the diaphragm is attached to the bodies of the lumbar vertebræ, to the tip of the transverse processes of the first lumbar vertebræ, and to the twelfth ribs; outside this it is attached to the lower margin of the costal arch and to the *inner* aspects of the last six ribs, this internal attachment extending in the mid-axillary line about 1 vertical inch, and in the nipple line about 2 inches, beyond the arch, while inside this line it gets progressively smaller. Thus, the upper limit of the diaphragmatic attachment, and consequently the lower limit of the pleura, does not correspond with the costal arch, the margin of which the lungs can therefore never be made to reach.

The Movements of the Lungs within the Chest.—During ordinary breathing the lungs move forwards and downwards, movement being most marked below and in front—*i.e.*, where the thorax is most movable. Hence, pleuritic adhesions cause a greater interference with the movement of the lungs in this situation than elsewhere. In the posterior and apical regions they interfere very little with pulmonary movement.

The way in which the lungs move within the thorax depends very largely upon the way in which the latter is expanded. In the woman, in whom the chest is more movable above than below, there may be—especially when the stays are worn—a gliding upwards of the lungs during tranquil inspiration; in purely abdominal breathing the movement is almost entirely downwards, while in a costal breath with fixed clavicles it is almost wholly forwards. In a costal breath with elevation of the clavicles it is upwards as well as forwards.

It may here be observed that it is possible to move the lungs within the chest without actually breathing. Thus, the diaphragm may be made passively to ascend and descend—the lungs, of course, following—by alternately raising and depressing the lower ribs with closed glottis; and, similarly, the lower costal chest may be made passively to contract and expand by contracting with closed glottis, first the diaphragm, and then the transversales abdominalis.

It is useful to ascertain the limits within which the pulmonary margins are capable of moving, for in this way we can gain information as to the presence of pleuritic adhesions, and also as to the effects of treatment.

Inasmuch as the lower pulmonary margins travel up and down with the respiratory movements, it is clear that they have no fixed boundary, and that they cannot correspond to the lower limits of the pleuræ. As a matter of fact, the lungs only extend thus far when the fullest possible inspiration is made, and then only if well developed. The mean position of the lower pulmonary margin differs somewhat on the two sides, owing to the asymmetrical position of the heart. It is roughly represented by a line drawn from the sterno-xyphoid articulation sloping slightly downwards to the spine, and cutting the upper border of the sixth rib in the nipple line, the eighth rib in the axillary line, and the tenth rib posteriorly.

The extent to which the lower margin of the lung travels down in ordinary inspiration may be ascertained by (*a*) inspection and (*b*) percussion.

(*a*) During the movements of the diaphragm the liver moves up and down, but it does not move bodily, the coronary ligament fixing the organ posteriorly, and allowing it to swing up and down, as upon a hinge, so that the movement is greatest in front and least behind. Now, it is probable that the movement of the anterior margins of the liver and of the lower pulmonary margin in front practically correspond, and we are sometimes able, by careful inspection of the abdomen, to see the anterior margin of the liver moving. I have several times observed this, both when the liver has been normal and when enlarged. The extent of the movement is about half an inch in ordinary, and nearly 2 inches in extraordinary, breathing; and we may accept these figures as representing the extent to which the lower margin of the lung moves in each case.

I have been able to ascertain by inspection that the downward movement of the lung is as great posteriorly as anteriorly. A child, five years of age, had considerable collapse of the right lung in consequence of empyema, the left lung being compensatorily hypertrophied, and its movements correspondingly exaggerated. There was extreme emaciation, and this enabled me to observe, through the thin chest wall, the ascent and descent of the lower edge of the hypertrophied lung.

(*b*) Percussion in suitable subjects confirms the results obtained by inspection. The breath is held at the end of an ordinary inspiration, and the lower margin of resonance then carefully percussed by means of Sanson's pleximeter. When the disturbance in breathing due to this cessation is recovered from, the breath is again held at the end of an ordinary inspiration, and the line of resonance similarly percussed. In like manner we can ascertain to what degree the line of resonance alters in extraordinary breathing.

In a well-developed man, with free chest movement, the difference between the uppermost and lowermost limits of the lower margin of the lung in the nipple line is about 4 inches, the lung in a complete inspiration travelling nearly as far as the costal arch, and after a complete expiration receding to 4 inches or more above this. The lower margin of the lung, as judged by percussion, is the same in a full costal as in a diaphragmatic inspiration, and practically corresponds to the costal arch—*i.e.*, resonance can be got in each case right down to the edge of the arch—a fact the more remarkable when it is reflected that the lung cannot actually extend thus far. There can be no doubt that the margin of the lung travels as far down in a complete costal as in a complete diaphragmatic inspiration, because the diaphragm flattens in the former case, owing to the elevation of the costal arch.

The line of resonance in a complete diaphragmatic expiration is rather lower than in a complete costal expiration, as one would expect.

The movements of the anterior margins of the lung can also be ascertained by percussion. In well-developed lungs the superficial area of cardiac dulness can be obliterated by a deep inspiration.

CHAPTER VII.

INSPIRATORY AND EXPIRATORY FORCE.*

The force with which the air is inspired and expired we term respectively inspiratory and expiratory force. It is measured by means of a graduated U-shaped glass tube, partly filled with mercury, to one end of which is attached a flexible tube, which is applied to the mouth or nose. An inspiration or expiration is then made, and the alteration in the height of the mercury read off.

When the operation is done *per oram*, a mouthpiece is fitted on to the free end of the tube, and introduced well back on to the base of the tongue. Care must be taken that the buccal cavity is not shut off from the naso-pharyngeal during the operation, for if this should happen the mercury may, on the one hand, be sucked up, instead of breathed up by the inspiratory forces; while, on the other hand, it may be driven down by the contraction of the buccinators, as in blowing a wind instrument, instead of being forced down by the expiratory forces.

This difficulty is obviated when the operation is performed

* Our earliest knowledge of this subject we owe to two English workers—Hales and Hutchinson. Within recent years it has been taken up on the Continent by Donders and a number of German observers. Foremost among these is Waldenburg, to whose work, 'Die Pneumatische Behandlung der Respirations- und Circulations-krankheiten,' Berlin, 1880, I am mainly indebted for the substance of this chapter.

by way of the nares. In this case a nose-piece is attached to the tubing, and inserted into one nostril, inspiration and expiration being made with closed mouth, and with the nose so held that the entire current of air is directed along the tube. The objections to this method are its unpleasantness and the extreme frequency of nasal obstruction.

All the above objections are avoided by the employment of a mask, fitted, in air-tight fashion, to the face, over the nose and mouth, the latter being kept wide open during the operation, and care being taken not to press the mask too tightly against the face, as by modifying the air-pressure within it may influence the height of the mercury.

Breath-power may be tested either by a sudden forced breath or by a slow gradual one. In the former case the influence of inertia causes the modifications in the height of the mercury to be greater than in the latter; but it is, for practical purposes, the better method.

In testing a subject, several observations should be taken, and the maximum result recorded. Some instruments are provided with a special mechanism for registering this.

In tranquil breathing the mercury moves from 1 to 2 mm.; in forced breathing the movement is very much greater. Thus, in average adult men inspiratory force varies from 80 to 100 mm. Hg; expiratory force, from 100 to 130 mm. Hg. In women the former is represented by from 60 to 80 mm. Hg, the latter by from 70 to 110 mm. Hg.

It will thus be seen, as John Hutchinson long ago pointed out, that expiratory force is about one-third greater than inspiratory. This difference is not due to a corresponding difference in the strength of the expiratory and inspiratory muscles, but to the fact that the former have to overcome pulmonary suction, the elasticity of the thoracic walls, and the weight of the thorax—all of which aid the respiratory muscles in the act of expiration. We thus see how it comes about that the full expiratory force can only be obtained after a full inspiration, while the full inspiratory force can be obtained as well after an ordinary as after an extraordinary expiration.

Breath-force chiefly depends upon the strength of the respiratory muscles, the mobility of the thorax, and the elasticity of the lungs. The important share the last two factors take in the result is shown by the fact that in young and slender subjects, with very elastic lungs and very mobile chests, it has generally a high relative value.

It should here be observed that there is no relation between breath-force and vital capacity; the former may be great while the latter is small, and *vice versâ*.

The Breath-Force in Disease.—In emphysema expiratory force is always diminished in relation to inspiratory. In moderate degrees of this disease the latter is normal, while the former is slightly defective. When dyspnœa begins, the falling away of expiratory force is more marked, and it may actually become less than the inspiratory, continuing to diminish as the disease advances till it may even sink to the level of one-third of the inspiratory force. This latter, for the most part, continues at the normal, though it may rise above this, owing to hypertrophy of the inspiratory muscles. In the last stages of the disease inspiratory power may sink below the normal, but it always remains greater than the expiratory.

The modification in breath-force observed in emphysema is doubtless partly due to loss of pulmonary suction (which works against the inspiratory and with the expiratory movements), and partly to the contracture of the inspiratory muscles, and the consequent interference with the expiratory movement.

In phthisis, pleurisy, and pneumonia, inspiratory power is diminished. Expiratory power is also diminished, but remains greater than the inspiratory, though in some cases of pleural effusion it may sink below it.

In bronchitis there is deficient expiratory force, as in the first stage of emphysema. This deficiency is observed both in the acute and chronic forms, in the latter case even when uncomplicated by emphysema.

In spasmodic asthma there is similar expiratory deficiency, and this though pulmonary elasticity may not have suffered.

Obstruction in the larynx and trachea diminishes inspiratory force chiefly or solely.

In scoliosis and kyphosis inspiratory and expiratory force are both defective, but especially the former.

Fever leads to a deficiency in both, but chiefly in the expiratory force, these changes being due to the defective muscle-power and pulmonary elasticity induced by the febrile state.

Relative Strength of the Inspiratory and Expiratory Muscles.—We have seen that inspiratory and expiratory force do not respectively represent the strength of the inspiratory and expiratory muscles. It has even been contended that the inspiratory muscles are the stronger, though I am not aware that this is capable of proof. They are the more constantly in action, and, from the respiratory point of view, the more important, seeing that expiration can take place without muscle action, while inspiration is wholly dependent upon it; even in the extraordinary breathing induced by breathlessness, the action of the inspiratory muscles vastly preponderates over that of the expiratory. In spite of this, the expiratory muscles, which chiefly consist of the great abdominal muscles, are very powerful. Their great strength, however, is not primarily for the purpose of extraordinary expiration, but has quite other ends, such as fixing the chest, rendering the skeleton rigid during effort, and increasing intra-abdominal tension during defæcation, etc., in all of which actions the glottis is closed and expiration prevented. It should further be observed, in this connection, that when extraordinary breathing is resorted to for physiological purposes, the abdominal muscles are never called into full play. Seldom, if ever, does the individual need to expire beyond the limit of ordinary expiration; in great breathlessness he does not even expire thus far, the increased range of respiratory movement which then occurs being due to increased depth of inspiration.

It is very seldom, in fact, that the 'complemental' air is got rid of, and that the great abdominal muscles are called upon to contract the chest to the utmost. There can therefore be no doubt that the amount of muscle-force spent in effecting the inspiratory movements, not only of tranquil but also of extraordinary breathing,* is vastly in excess of that employed in effecting the expiratory movements, and that if the expiratory muscles are more powerful than the inspiratory, it is because these muscles need great strength for other purposes than expiration.

Special mention may here be made of the strength of the diaphragm. This is a very powerful muscle. I am acquainted with a man who can actually move a grand piano by means of it, and I have often been struck with the extraordinary strength it displays in disease. Even in the last moments of life, when the belly has been tightly distended with fat and ascitic fluid, I have observed—and that in an old woman—considerable abdominal movement, testifying to the strength of this muscle.

Exercises for strengthening the respiratory muscles are given in Chapter XX.

* I refer here to the extraordinary breathing required for the ordinary physiological purposes of life. When an individual voluntarily expires to the utmost, as in blowing into the spirometer, the expiratory muscles are brought into considerable play; but such an expiration is, so to speak, ultra-physiological.

CHAPTER VIII.

THE RESPIRATORY FORCES.

While inspiration is essentially active, expiration, unless forced, is almost entirely passive, the only muscles taking part in it being the internal intercostals, triangularis sterni, and possibly also in very slight measure the abdominal muscles. The passive forces of tranquil expiration are the suction of the lungs on the ribs and diaphragm, and the positive intra-abdominal pressure which tends to force the diaphragm upwards directly the latter ceases to contract. In the upright position gravity also comes into play as an expiratory force by pulling the ribs down. These passive expiratory forces are, of course, greatest after an extraordinary inspiration, for the elastic recoil of the lungs is then increased, and, moreover, is supplemented by that of the thoracic cage, and in the vertical position of the trunk the influence of gravity also—especially if the shoulders and chest are bulky—is considerably augmented. In the fullest possible inspiration, however, one of the passive expiratory forces—*i.e.*, the positive intra-abdominal pressure—is diminished.

In forced expiration the expiratory recoil is helped by the contraction of special expiratory muscles—the abdominal muscles, quadratus lumborum, serratus posticus inferior, erectores spinæ, and others.

Passive recoil plays very little part in inspiration. In tranquil inspiration the ribs, which during expiration have been bent inwards beyond the neutral point, recoil outwards, and after an extraordinary expiration this outward recoil is, of course, much increased.

Inspiration being essentially active, we have next to inquire, What are the muscles engaged in the act? They are: (1) those which raise the ribs, and (2) the diaphragm.

1. In ordinary inspiration the ribs are raised by the external intercostals, the levatores costarum, and the diaphragm.* The action of the intercostals is assisted by the comparative fixity of the first ribs, which are attached by especially strong cartilages to the sternum, which, again, is supported by the clavicles. Hence, the first ribs afford purchase to the intercostal muscles below, and they are further fixed during inspiration by the contraction of the scaleni.

In extraordinary inspiration many other costal elevators come into play. These include all those muscles which directly raise the ribs, such as the serratus posticus superior (which passes from the spine to the second, fifth, and intervening ribs), the cervicalis ascendens, and (when the arm and shoulder are fixed) the serratus magnus, the pectorals, and that part of the latissimus dorsi which passes from the humerus to the last three ribs, and also those capable of raising the clavicles and scapulæ, such as the sterno-mastoids, the trapezius, and the levatores anguli scapulæ.

The various costal elevators can act independently, especially after practice, being thus able to raise a limited set of ribs more than, or even quite independently of, the others. Thus, it is possible to expand the upper part of the thoracic cage more than the lower, or *vice versâ*, and to raise the ribs on one side more than on the other.†

* See p. 51. † See p. 58.

2. The diaphragm arises from (*a*) the back of the ensiform cartilage; (*b*) the inner surface of the lower six costal cartilages, and sometimes from part of the corresponding bony ribs; (*c*) the internal and external arched ligaments, extending respectively from the body of the second to the tip of the transverse process of the first lumbar vertebra, and from the latter to the last rib; (*d*) the bodies of the first three lumbar vertebræ as the two fleshy crura. From this origin its fibres pass to the central tendon, the most anterior, especially those coming from the xyphoid, being short and nearly horizontal, and thus by their contraction tending to pull the lower part of the sternum and adjacent cartilages backwards; while the remaining fibres arch upwards to their insertion, those arising lowest down from the sides of the chest having the steepest ascent, and—in the expiratory position of the chest—running for some distance in close proximity to the ribs. The arch of these fibres is most pronounced when they are lax, the diaphragm being then dome-shaped, owing to its being thrust upwards by the excess of pressure on its under surface over that upon its upper. When they contract the dome flattens out, the thorax being thereby enlarged vertically; at the same time the central tendon and lower ribs are dragged upon, the former being somewhat depressed and the latter raised.

The central tendon is prevented from any considerable descent by its connection with the pericardium, which is continuous with the cervical fasciæ; the lower ribs are, moreover, under ordinary circumstances steadied during diaphragmatic contraction by the quadratus lumborum and serratus posticus inferior. When the diaphragm contracts under these conditions, the chief effect is a straightening of its arched fibres—*i.e.*, a flattening of the dome—the ribs being only slightly raised. I find that the girth of the lower chest is only increased half an inch after a full diaphragmatic breath, while that of the belly is augmented by 2 inches. By practice it is possible to prevent any raising of the ribs during diaphragmatic contraction, inspiration being then purely *abdominal*, a term which is not synonymous with *diaphragmatic* as applied to breathing. When, however, the diaphragm is firmly supported on its under surface, as happens when the abdomen is voluntarily retracted or firmly compressed, the chief effect of its contraction is to elevate the lower ribs, and thus to open out the costal arch and increase the girth of the lower chest.*

This expansion of the lower bony chest is, however, not solely due to the upward drag of the diaphragm upon the ribs. Some descent of this structure occurs even when it is firmly supported from below, and this tends to thrust the abdominal viscera downwards; but their downward movement being checked by the firm pressure upon them of the abdominal walls, the lower ribs are bulged outwards.

That the tendency of the diaphragm to elevate the lower ribs increases with the resistance which the anterior abdominal walls oppose to the viscera can be shown by a very simple experiment. Let the hands rest on the side of the lower chest, and then take a full diaphragmatic breath. It will be found that the hands suffer very little movement. Now, keeping them in the same position, stand facing a wall, and while pressing the abdomen firmly against it take a similar inspiration; the lower chest will then be found to bulge very appreciably on either side. On the other hand, when the abdomen is opened, and the support on the under surface of the diaphragm thus greatly diminished, it no longer acts as a costal elevator.

* It is, as we shall see, to this end that some teachers of singing advise that the belly should be retracted during inspiration, and that others advocate the use of an abdominal belt during singing.

I have said that the central tendon is only capable of limited movement in respiration. Its range of movement is a point of some interest, because it is evident that the heart must move with it. When a deep thoracic inspiration is taken, the heart can quite plainly be felt beating in the epigastrium, and this was thought by Sibson to prove an actual downward movement of the central tendon; but the epigastric pulsation under these circumstances might very well be due to the lifting upwards of the thoracic cage over the heart rather than to an actual descent of the heart within the thorax. In order to ascertain whether the heart descends, we should measure the vertical distance between the chin and the apex of the heart before and after a deep thoracic breath, and applying this test I do not get any evidence that the central tendon descends.

It is otherwise, however, when a full diaphragmatic breath is taken *with fixed clavicles;* the central tendon and the heart then actually descend, as may be shown by means of Röntgen rays.

The respiratory centre is automatic. It consists of an inspiratory and expiratory portion, the former alone acting during ordinary breathing. The automatic action is reinforced by impulses ascending the vagi from the lungs; the expansion of the lungs tends to inhibit through these nerves the inspiratory centre, and to excite the expiratory centre; and, on the other hand, the contraction of the lungs tends to check the action of the expiratory centre and to incite the inspiratory centre.

Most of the vagal fibres passing to the respiratory centre act upon its inspiratory portion, and the effect of the impulses ascending them is to quicken breathing; these fibres are in constant action. A smaller number, especially those belonging to the superior laryngeal nerves, act upon its expiratory portion. Hence it is that irritation of the larynx causes violent expiratory efforts. Impulses ascending these fibres tend to slacken the respirations.

While the respiratory nerves *par excellence* are the respiratory portion of the vagi, numerous afferent nerves are capable of affecting the respiratory centre. Witness the effect of cold suddenly applied to the back.

Not only is this centre influenced through the nerves, but also by the plasma bathing it. Apnœa is due to impulses ascending the vagi, and not to altered plasma, while dyspnœa is essentially due to the latter. In this condition the blood is deficient in O and surcharged with CO_2, but the excess of the latter plays only a small part, as compared with the deficiency of O, in causing the peculiar breathing of dyspnœa. The quickened breathing induced by muscle exercise is due to the stimulation of the medullary centre by certain unknown substances. The deficiency in O and the excess of CO_2 cannot be the sole causes of the acceleration in this case, since such alterations in the blood tend to deepen rather than to hasten the respirations, as is shown in dyspnœa.

CHAPTER IX.

MODES IN WHICH THE THORAX IS ENLARGED.

The thorax is enlarged by elevation of the ribs and descent of the diaphragm, the former increasing the sagittal and lateral diameters, and the latter the vertical diameter.

In ordinary tranquil breathing, there is comparatively little rib movement, especially in the upper part of the thorax, respiration being chiefly abdominal. It is true that in the civilized woman the ribs, notably the upper ones, often move freely, diaphragmatic action being correspondingly curtailed; but this type of breathing is not a natural sexual characteristic: it is due to the use of stays, which interfere with the free descent of the diaphragm and the expansion of the lower bony cage. In consequence of this, the cage in its upper part becomes expanded and abnormally mobile (hence the 'heaving bosom' of the woman), while, contrariwise, the growth of the lower chest is interfered with, its movements being correspondingly restricted. It is for this reason that, after the age of fourteen, the lower transverse diameter of the chest is less in the civilized woman than the upper, in man the reverse being the case (Sibson).

While normal tranquil breathing is chiefly abdominal, the part played by costal elevation must not be neglected. The increase in thoracic girth thus affected is only 2 to 3 mm.,* but the importance of this slight increase is

* Hutchinson gives 1 to 2 mm.; Burdon Sanderson, 1 to 6 mm.; Douglas-Powell, 2 to 3 mm.

shown by the fact that when, as from myelitis just below the origin of the phrenics, the individual has to depend upon pure diaphragmatic breathing, the respirations are laboured.* But that the diaphragm plays the more important part in tranquil breathing is evident from the great difficulty of breathing resulting from its paralysis.

Costal breathing is more developed in man than in any animal. If, for instance, we examine the thorax of an anthropoid ape, we find that the sagittal diameter is nearly as long as the transverse, and the same feature is observed in the human infant. It is clear that the capacity of such chests cannot be greatly increased by elevation of the ribs, but as the erect posture comes to be assumed, the chest flattens so as to throw the centre of gravity backwards, and thus keep it vertically above the narrow basis of support afforded by the feet, and in this way the capacity for costal breathing is increased. Nevertheless, as already observed, tranquil breathing is essentially diaphragmatic. This is even more the case in the horizontal position than in the upright, because the pressure of the ribs against the surface of support interferes with their movement. Even among women it will be found that in the horizontal position, when no stays are worn, tranquil breathing is chiefly diaphragmatic.

The mode in which the thoracic cage expands is best studied during an extraordinary inspiration. The clavicles, scapulæ, sternum, and ribs are then raised; the anterior extremities of the clavicles and ribs move forwards and upwards, carrying with them the sternum, which at the same time tends to become convex anteriorly, or to suffer an

* While writing this I have such a case under observation. The breathing is purely diaphragmatic and manifestly laboured, although the lungs are normal. It is, however, possible that this laboured action depends upon paralysis of the muscles which steady the lower ribs, and thus facilitate the inspiratory action of the diaphragm.

increase in its natural convexity, while the posterior costal extremities move backwards, carrying with them the spine. This may be easily demonstrated by placing the hand on the middle of the back while a deep inspiration is being made. The movement of the upper ribs is chiefly forwards, that of the lower ribs chiefly backwards, and Sibson points out, in connection with this fact, that the bulk of the upper part of the lungs is in front, while the bulk of the lower part is behind. The backward movement is most marked at that part of the spine which articulates with the sixth, seventh, and eighth ribs.

Were the spine as movable as the sternum, elevation of the ribs would cause it to travel as much backwards as it causes the sternum to move forwards, for the ribs passing obliquely from spine to sternum, any diminution in their obliquity must increase the distance between these two. The sternum being, however, less fixed than the spine, tends to move the more, but as it approaches its limit, *i.e.*, towards the end of inspiration, it offers considerable resistance to further movement, and it is then that the backward movement of the spine becomes most pronounced.

As the ribs ascend they undergo some eversion, and this tends to increase the lateral diameter of the chest, but the increase in the lateral diameter is chiefly due to a straighten ing out of the costal curves.

In the posterior movement of the ribs, their angles move backwards more than the spine, thus deepening the spaces for the lungs on either side of the spine. During costal ascent the upper ribs approach one another, while the distance between the remaining ribs, especially the last three, increases, as can be easily shown by placing the fingers between them.

In some the upper part of the sternum moves forwards more than the lower; in others the reverse occurs.

Sibson has shown that the third, fourth, and fifth costal cartilages move forwards somewhat beyond the sternum. When, however, the cartilages are rigid and welded to the sternum, the latter advances more than the cartilages.*

The movement of the fourth, fifth, and sixth cartilages, and of the sixth rib over the heart, is somewhat less than on the right side. This is even true of tranquil breathing.

It is possible completely to dissociate costal from abdominal breathing, for though contraction of the diaphragm tends to raise the lower ribs, it is, as already pointed out, possible to check all costal movement during diaphragmatic descent.

Costal breathing falls under two heads: (*a*) That in which the clavicles are raised, and with them all the ribs. When such an inspiration is carried to its extreme, the ribs are elevated to their utmost, and the chest cavity is increased to its maximum. I shall speak of this as the *pancostal* method. (*b*) That in which the ribs are raised without elevation of the clavicles. All the ribs may be raised in this method by allowing the inner ends of the clavicles to move forwards, but even then the chief expansion takes place in the lower part of the chest. I shall therefore speak of it as the *lower costal* method.

There are thus three primitive types of breathing in the normal chest: *pancostal*, *lower costal*, and *abdominal*. Much confusion may be avoided if we keep this fact clearly in mind. The so-called *clavicular* variety, about which so much has been written, is, as far as I can see, impossible under normal conditions. In it the clavicles are raised and the upper part of the chest is supposed to expand alone, or at all events greatly in excess of the lower part; but this appears to me to be absolutely impossible under normal conditions, since the lower ribs must ascend with the upper,

* The tendency of the upper costal cartilages to advance beyond the sternum is often well shown in the chest of hypertrophous emphysema.

and this implies expansion of the lower chest. When, however, the lower part of the chest is tightly bound with a rigid corset, it is necessarily incapable of proper expansion —if, indeed, of any expansion at all—and under these circumstances a costal inspiration causes an enlargement of the upper chest chiefly or only. This part of the chest undergoes in those who habitually tight-lace a compensatory enlargement and acquires increased mobility, and this undue mobility of the upper chest is observed in such even after the corset has been removed.

I do not deny that it may be possible by practice to gain such control over the elevators of the upper ribs as to cause them to be raised more than the lower during inspiration, and thus to bring about a relatively larger expansion of the upper than of the lower chest. The Italian teachers of singing lay great stress upon this expansion of the upper chest, and advise the singer to direct to it all his attention in breathing. To this end the shoulders are held back, in order that the scapulæ may afford *points d'appui* for the serrati magni, which under these circumstances become costal elevators, and there are, of course, other special elevators of the upper ribs. It must, however, be remembered that the lower ribs are compelled to follow the upper ones, and this necessitates a considerable expansion of the lower chest, unless the latter is compressed.

This is the proper place to refer to the retraction of the belly which accompanies a deep costal inspiration. Such an inspiration causes flattening of the belly, the upper part shelving suddenly away from the costal arch. This is especially noticeable in the epigastrium, which constitutes a pronounced hollow. Exactly the same thing is observed if, prior to the costal breath, the belly be bulged by a deep diaphragmatic inspiration: as the ribs are raised, it gradually recedes, finally becoming scaphoid.

This flattening or actual hollowing out of the belly is due to several causes. When the ribs are elevated to the utmost, the lungs are unable, by their fullest expansion, to fill the chest, unless the diaphragm lies high. With every increase in the size of the chest the suction of the lungs on the sides and base of the thorax increases. It is insufficient to draw in the ribs, which are held in position by powerful costal inspirators, but the diaphragm is unable to resist it, and is thus sucked upwards. So great is this suction at the end of a complete costal inspiration, that the most strenuous effort at diaphragmatic inspiration is powerless to cause any diaphragmatic descent; and it is this suction which determines the limit of costal inspiration. Small, ill-developed lungs are very soon stretched to their utmost, and therefore only permit of moderate costal expansion; but large, well-developed lungs (non-emphysematous) permit considerable costal elevation to occur before suction puts a stop to further expansion.

The effect of the upward aspiration of the diaphragm is to increase the vertical diameter of the abdominal cavity; the elevation of the costal arch acts in the same direction, and, moreover, puts the abdominal wall on the stretch, while the opening out of the costal arch augments the transverse diameter of the abdomen above. The abdominal cavity, being thus increased in its transverse and vertical diameters, necessarily suffers diminution in its sagittal diameter, this being favoured by a diminution in intra-abdominal tension. Hence a deep costal inspiration causes a flattening of the belly. The scaphoid appearance thus induced in a thin subject is rendered more pronounced by the throwing forward of the costal arch, which helps to cause the abdominal wall to shelve away from it, and also by the backward movement of the dorso-lumbar spine which accompanies a deep costal inspiration.

The flattening of the belly just described must be carefully distinguished from that which is due to a voluntary contraction of the transverse fibres of the abdominal walls. This is the kind of retraction advocated by those teachers of singing who advise costal as distinguished from abdominal breathing. Sir Morel Mackenzie and others have mixed up these two varieties of retraction. Mackenzie assumed that the retraction of the belly observed in divers before diving, and in those about to make a strong effort, is a primary event, akin to the retraction adopted by singers; whereas it is, in point of fact, a secondary event—the result of a deep costal inspiration.

Costal and abdominal breathing may be associated. After a full pancostal breath, it is, as we shall see, doubtful whether in the normal individual any additional air can be inspired by means of the diaphragm; the quantity must in any case be small. While, however, after such an inspiration abdominal breathing is, in the normal individual, practically impossible, it is, in a limited degree, possible after an incomplete inspiration of this kind.

Abdominal breathing may, in a similar way, be associated with lower costal breathing, and here also the abdominal breath is limited. The fact is that expansion of the lower bony thorax causes a flattening of the diaphragm which necessarily cutrails the range of abdominal breathing. Nevertheless, lower costal and abdominal breathing may be associated in varying degrees; thus, a complete lower costal breath may be associated with a moderate abdominal breath, and, again, an almost complete abdominal inspiration with moderate lower costal expansion.

The Quantity of Air that can be expired by Different Methods of Breathing.—The total quantity of air that can be expired after the fullest possible inspiration is termed the 'vital capacity.' This subject will be dealt with in a separate chapter. Here it will be convenient to note the quantity of air that can be expired by the different methods of breathing. The subjoined table gives the results obtained by the spirometer in my own case. I must mention, however, that it is extremely difficult to make accurate observation on this head, because it is by no means easy to breathe by any particular method without encroaching on another. Thus, in pure abdominal breathing we must be absolutely certain the ribs do not move; the result in this case, moreover, depends upon the degree of expansion of the bony thorax while the abdominal breath is being taken.*

TABLE SHOWING THE QUANTITY OF AIR WHICH CAN BE EXPIRED BY THE DIFFERENT METHODS OF BREATHING.

Pancostal		400 cub. in.
Lower costal		210 cub. in.
This can be extended by allowing the inner ends of the clavicles to move upwards, and by varying the elevation of the entire clavicles.		
Lower costal, supplemented by abdominal		210 to 270 cub. in.
According to the degree of diaphragmatic descent.		
Abdominal	Thorax kept fixed in its mean position	110 cub. in.
	Thorax kept fixed in position of costal expiration	170 cub. in.
	Thorax kept fixed in lower costal expansion	90 cub. in.
Abdominal, supplemented by lower costal expansion		110 to 270 cub. in.
According to the degree of lower costal expansion. 200 cubic inches are inspired by a full abdominal breath, making no effort to prevent expansion of the lower chest, nor to cause it, the ribs not passing beyond the mean in expiration.		

* For these and other reasons I cannot but receive the figures which have been published relative to this question with some reserve. To mention only one instance, Joal[1] gives the abdominal and costal respiratory capacities of three experienced singers as follows:

Abdominal.	Costal.
5,200 c.c.	5,300 c.c.
4,300 ,,	4,800 ,,
4,000 ,,	4,300 ,,

In the first case, that is to say, the proportion is as 52 : 53. I have no doubt whatever that in this, and indeed in all three cases, the abdominal inspiration was supplemented by a lower costal breath; otherwise the disproportion would be very much greater.

[1] 'On Respiration in Singers,' translated by Norris Wolfenden, p. 90.

It will be seen from the above that pure abdominal breathing gives a very small volume of air, but that if this method is supplemented by lower costal inspiration, as it practically always is, it may give as large a volume as the latter method.

It will also be observed that the quantity of air that can be inspired by descent of the diaphragm, *i.e.*, by abdominal breathing, varies according to the degree of expansion of the lower bony chest. The more expanded this is, the nearer are the circumferential attachments of the diaphragm to the level of the central tendon—*i.e.*, the flatter is the diaphragm, and the less is its inspiratory power. Contrariwise, the more contracted the lower bony chest, the more arched is the diaphragm and the greater its inspiratory power. Hence I find that when my thorax is fixed in full lower costal expansion I can only inspire 90 cubic inches by descent of the diaphragm, while by the same means I can inspire nearly double the amount (170 cubic inches) when it is fixed in a position of extreme costal expiration. When it is fixed in the mean position 110 cubic inches can be taken in by an abdominal breath. The 170 cubic inches represent the amount that can be inhaled when the circumference of the diaphragm is lowered down to the fullest possible extent below the central tendon, when that tendon is arched to its utmost, and when, therefore, the greatest increase in thoracic capacity can be effected by its contraction. The 90 cubic inches represent the quantity of air that can be inspired when the diaphragm is flattened by the extreme opening out of the costal arch and thus rendered less capable of increasing thoracic capacity.

If, after a complete expiration, a full diaphragmatic breath be taken, it will be found that it is still possible to take in a large draught of air. The same is true if a lower costo-diaphragmatic breath be taken instead of a diaphragmatic, though in this case the amount of air that can be subsequently inhaled is less. If, on the other hand, a full pancostal inspiration be taken after a complete expiration, no more air, or at all events only a small quantity, can be inhaled by means of the diaphragm.* In other words, the lungs in the normal individual are not large enough to fill the thorax at its potential maximum, *i.e.*, with the ribs elevated and the diaphragm depressed to their respective extremes. I say in the normal individual, by which I mean one with freely movable ribs and healthy lungs. If the ribs are not freely movable, so as to allow of a deep costal inspiration, the individual may be able to take an appreciable abdominal breath after he has raised the ribs to the utmost. Similarly, in large-lunged emphysema, the lungs may be large enough to admit of considerable abdominal breathing after a full pancostal inspiration.†

* This at once disposes of the view, held by some teachers of singing, that more air can be taken in by a diaphragmatic or lower costo-diaphragmatic breath than by the purely costal method. Further proof of the fallacy of this teaching is supplied by the spirometer.

† It has been suggested to me that the lungs *are* large enough to fill the chest when expanded to its potential maximum, and that the inability to take in an ample supply of air by means of the diaphragm, after a full costal inspiration, is not due to the lungs having been stretched to their limits, but to the diaphragm having been flattened to the utmost by the lower costal expansion. I cannot accept this view. Air can be inspired when the costal arch is opened out to its utmost by a lower costal inspiration. In emphysema, again, the bony chest may be in a state of superextraordinary inspiration, and the diaphragm yet retain considerable inspiratory power. It is true that in very advanced cases of hypertrophous emphysema the respiratory capacity of the diaphragm is greatly curtailed, and may possibly in some cases be quite annulled. Nevertheless, if we except such, I believe that the potential capacity of the chest is always greater than that of the lungs, and that the expansibility of these organs essentially determines the limit to which the thorax can be enlarged. This position is strengthened by what we observe in destructive pulmonary disease, which alway diminishes thoracic expansibility.

CHAPTER X.

BREATHING IN SINGERS.

The various methods of breathing which have been recommended for singers are not always very lucidly expounded, but they may, I think, be described under one or other of the following heads:

1. **Clavicular**: when the clavicles are raised, and the expansion in the upper part of the chest is in relative excess.
2. **Pure lower costal**: when the lower ribs are raised, without any protrusion of the belly, the clavicles being kept fixed. A subvariety of this is that in which the inner ends of the clavicles are moved upwards and forwards, thus securing an increased expansion of the upper part of the chest.
3. **Lower costo-abdominal**: when the lower ribs are raised, and the belly protruded, the former being the essential movement.
4. **Pure abdominal**: when the belly is protruded, the ribs being fixed.
5. **Abdomino-costal**: when the belly is protruded, and the lower ribs raised, the former being the essential factor.

1. **Clavicular Breathing.**—In this the clavicles are raised, and the expansion of the upper part of the chest is in relative excess.*

* Nothing better shows the obscurity which prevails regarding the various modes of breathing for singers than Joal's observations on clavicular breathing. See on this subject the author's paper in the *Journal of Laryngology*, etc., 1897, p. 35.

This mode of breathing is practically impossible for a man, but many women are undoubtedly, in the sense defined above, clavicular breathers, because the lower chest cannot expand adequately when the stays are worn tight. The quantity of air they inspire by this method is said to be less than by the others. In men, on the other hand, raising the clavicles necessitates a considerable expansion of the entire bony chest, not of the upper part only, and so it secures the maximum intake of air; but this is not the classical clavicular breathing. It might be described as the *pancostal* type. I conclude, however, that, under whatever name, it is the method adopted by singers of the old Italian school, for some of them executed passages exceeding ninety-five seconds, and I do not think it probable that any man could execute so long a passage in one breath except by the pancostal method, *i.e.*, by raising the clavicles and all the ribs to the utmost. Joal, however, is of the opinion that this school adopted the lower costo-abdominal method.

2. **Lower Costal Breathing.**—In this the clavicles are kept fixed, and the ribs are raised, expansion taking place chiefly in the lower part of the chest, the diaphragm not descending. This is the method, so far as I can understand, described by Mayo Collier, and recommended by him and by the late Sir Morel Mackenzie, though they are silent as to whether the clavicle should be raised or not.

In this method the abdomen is drawn in ('rendered concave') by a contraction of the abdominal muscles, and it is argued that thereby 'the vault of the diaphragm is supported by the front abdominal walls, and maintained in position by the liver, spleen, and great end of the stomach' (p. 94). In this way the central tendon of the diaphragm is fixed, and the contraction of the muscle fibres which pass more or less vertically from the central tendon above to the ribs below, spends itself in raising the lower ribs, and in expanding the lower bony thorax.

It should be observed that a very slight elevation of the clavicle during a lower costal breath adds considerably to the volume of air that can be inspired, and there can be no doubt that many singers who for the most part adopt the lower costal method, and who would indignantly repudiate the accusation of being clavicular breathers, do appreciably elevate the clavicles, especially when desirous of taking a more than usually deep breath.

3. **Lower Costo-Abdominal Breathing.**—In this variety the lower costal breathing is combined with varying degrees of abdominal breathing, but the latter is subsidiary to the former, and only occurs in comparatively slight degree, causing a moderate protrusion of the epigastrium. It should be mentioned that some degree of epigastric protrusion is apt to occur whenever a deep costal inspiration is taken. This may result from two causes: either from an active descent of the diaphragm, or from an elevation of the lower end of the sternum above the central tendon of the diaphragm, causing the heart to lie immediately under the epigastric wall.

This, as I understand him, is the method of breathing advocated by M. Joal, though he does not make it absolutely certain whether he recommends actual descent of the diaphragm, merely remarking that 'the convexity of the diaphragm tends to be effaced.'* The belly, he contends, should be retracted in the subumbilical region, and while the clavicles are kept fixed the ribs are elevated to their fullest extent and the epigastrium protruded (presumably from active descent of the diaphragm). The retraction of the subumbilical region he refers to a voluntary contraction of the inferior fasciculi of the abdominal

* 'On Respiration in Singers,' translated by Norris Wolfenden, p. 80.

muscles (p. 117),* and its object is to support the diaphragm below, so as to enable the entire force of its contraction to be devoted to the elevation of the lower ribs, as already described. To the same end some singers compress the belly by means of a band or belt. This form of breathing Joal somewhat ambiguously designates the 'costal' type, and he gives it his enthusiastic support. In it he assumes the upper ribs to be stationary; but it is certain that fixation of the clavicle by no means prevents expansion of the upper chest, as anyone may see for himself who will examine the bare chest while a full costal breath is being taken with fixed clavicles.

It is contended by Joal that this method of breathing secures a larger volume of air than the others by expanding the chest in its most roomy part. This is not my experience.

A method of breathing taught in Italy and described by Cathcart may be mentioned here, in that it is allied to Joal's method. The outer ends of the clavicles are fixed, the inner extremities moving upwards and forward. In this way not only is the superior entrance to the thorax enlarged, but the bony chest is enabled to expand amply in its upper as well as in its lower part. Indeed, what is aimed at is producing the maximum expansion above.

4. **Pure Abdominal Breathing.**—In this the breathing is, as far as possible, purely abdominal; *i.e.*, the diaphragm contracts with relaxed abdominal walls, and being thus only slightly supported on its under surface, the force of its contraction is chiefly spent in thrusting the abdominal viscera downwards, and in increasing the vertical capacity of the

* It is due, I believe, to a contraction of the transversely disposed muscle fibres of the anterior abdominal wall, as already described; a contraction of the lower portions of the recti would tend to pull down the ribs and sternum, which are required to be raised in the form of breathing under discussion.

chest, and to only a small extent in an upward tug on the ribs (which are probably prevented from being raised by a contraction of certain muscles, such as the quadrati lumborum and the serrati postici inferiores). At all events, while contraction of the diaphragm tends to raise the ribs, even with relaxed abdomen, there can be no doubt, as Mandl observes, that 'when the person is completely master of diaphragmatic respiration, deep inspirations can be taken without elevating the ribs in any manner, as Magendie had already said.'*

Abdominal breathing is closely associated with the name of Mandl, who in 1855 advocated this mode of breathing in an article which appeared in the *Gazette Médicale*, though it had already been largely practised. He obtained a wide following, and in schools of singing most strange devices were resorted to for the purpose of fixing the ribs and compelling pure abdominal breathing; thus, the 'pupils were made to sing while lying down on mattresses, sometimes with weights, more or less heavy, placed on the sternal region; masters were even said to make a practice of seating themselves familiarly upon the chests of their pupils. In the schools were to be seen gallows with thongs and rings for binding the upper half of the body, orthopædic apparatus, rigid corsets, and a kind of pillory which enclosed the frame and fixed the ribs.'†

Abdominal breathing is said to be rarely employed by women. Joal has not met with a single woman singer who adopts this method. Nor is this surprising, when we reflect that the corset interferes with the abdominal protrusion. But, indeed, this method is probably very rarely employed at all—I doubt if it ever is, pure and simple. I cannot believe that Mandl and his school confined themselves to pure abdominal breathing.

* Joal, *op. cit.*, p. 67. † *Ibid.*, p. 43.

5. **Abdomino-Costal Breathing.**—When abdominal is supplemented by costal breathing, we may term it 'abdomino-costal.' It is the method recommended by Lennox Browne and Behnke in their work on 'Voice, Song, and Speech.'

I now propose briefly to criticise these various modes of breathing, with a view to discover which is the most suitable for the singer. I must at once confess that I do not at present see my way to recommend very specially any one method to the exclusion of the others. What I have been most concerned to do is to define accurately the different modes in which breathing may be carried on, and to clear the ground for profitable discussion.

Practically, all writers condemn forced clavicular breathing in the case of the man, but there are some who justify its employment in the woman, on the erroneous assumption that it constitutes for her the normal type of breathing. Its evils are self-evident, necessitating as it does elevation of the shoulders, and, from the contraction of the cervical muscles, compression of the important structures entering the thorax from above. The effort of lifting with every inspiration the entire thorax and upper extremities is tiring; the interference with the return of blood from the head during a loud and long-sustained note may be so great as to cause turbidity, and even duskiness, of the face; and it is, moreover, doubtful whether expiration can be so nicely regulated as by the other methods. If pronounced clavicular breathing is ever justifiable, it should certainly only be employed on rare occasions, and as an extension of the more usual form of breathing.

It is otherwise, however, with modified clavicular breathing. I can see no objection to a moderate upward and forward movement of the inner ends of the clavicles, as recommended by Cathcart. This not only enlarges the superior opening of the thorax, but favours the expansion of the upper portions of the chest, where, it is contended, ample expansion should be aimed at on the ground that the nearer the resonating cavity is to the seat of voice-production, the better resonance does it give.

It is certain that moderate clavicular breathing is frequently employed by those who claim to be lower-chest breathers, and it seems at least doubtful whether the singer should rigidly adhere to the hard and fast rule never to raise the clavicles in the slightest degree.

Accepting, then, the dictum that pronounced clavicular breathing can only be justifiable on rare occasions, we have to inquire which of the other methods is the best. Is it (*a*) the pure lower costal; or (*b*) this extended by abdominal breathing (and if this form, how much abdominal extension is justifiable); or (*c*) the pure abdominal; or, finally, (*d*) the abdominal, extended by the lower costal (and if the latter form, how much lower costal is justifiable)?

In seeking an answer to our question, we of course attach some weight to the amount of air that can be inspired by the various methods, but not too much. The singer is not required to distend his chest to the utmost.* Were a large volume of air the great desideratum, then a pancostal breath, with extreme elevation of the clavicles, would be best, for by it half again as much air can be inspired as by any other method.

It is urged that the lower costo-abdominal method is superior to the abdominal, in that the work is shared by a larger number of muscles, for in abdominal breathing these are more or less confined to the diaphragm and the abdominal muscles. Speaking from my own experience, I should say that the very reverse is the case: an abdominal breath can

* Joal argues as if it were necessary to take in a very large volume of air. See *op. cit.*, pp. 72, 80, 134.

be taken with the utmost ease, while a lower costal breath involves an appreciable effort, seeing that the ribs have not only to be raised but also to be bent.

It is also argued that in the abdominal method expiration requires the expenditure of more energy than in the lower costal variety, in order to push up the viscera, which are displaced downward by the descent of the diaphragm—an argument of no weight, seeing that these organs are capable of resuming their normal position upon mere relaxation of the diaphragm without any contraction of the abdominal muscles, being drawn up by the elastic recoil of the lungs.

We have next to inquire whether the abdominal or the costal method enables the singer to regulate the outgoing blast of air with the greater precision and nicety. The air, as we know, has to be driven out slowly, steadily (*i.e.*, without jerks), and with varying degrees of intensity.

How is this regulation effected? Cathcart contends that in the case of costal breathing it is, or should be, effected by the mutual antagonism between the expiratory muscles and the false vocal cords, which approximate in order to oppose the outgoing blast of air, and he attaches great importance to this laryngeal impediment, seeing that without it (so he argues) it would be impossible to get that degree of condensation of pulmonary air necessary to bring out the best quality of tone. It is, however, more generally held that the regulation of the expiratory blast is essentially dependent upon the antagonistic action of the inspiratory and expiratory muscles, and this is probably the case in abdominal and in pronounced clavicular breathing. Cathcart holds that, in the form of breathing he recommends, the inspirators cease to contract when expiration begins, the air being held by the false vocal cords; but according to the prevailing view the inspirators continue in action, though with diminishing force, throughout the entire period of expiration, no matter what mode of breathing is adopted. Of the two sets of muscles, however, it is held that the expirators act the more powerfully, and thus expel the air, the force of expulsion and consequent loudness of note depending upon the degree of excess of inspiratory over expiratory action. In delivering a note fortissimo, for instance, the expirators act with full force, the inspirators undergoing considerable relaxation.*

Now, it is urged that much better control can be exercised over the expiratory blast by the costal than by the abdominal method, which, according to Cheval, Morel Mackenzie, and others, is apt to give a jerky note, from the inability of the diaphragm to undergo a gradual and even relaxation. This is, of course, a question for experience to decide, but I see no theoretic reason why the diaphragm should not be taught to relax gradually as well as other muscles. Indeed, this argument regarding the inability of the diaphragm to undergo gradual and even relaxation may be employed against the lower costal method, seeing that the supporters of it contend that the diaphragm is an important agent in expanding the lower bony chest.

Cathcart contends that by his method the air is driven out of the lower regions of the lungs faster than from the upper lobes, and that 'the upper ribs will only be pulled down when the lower lobes are nearly exhausted, and it is then time to renew the breath.' In this way, he argues, the high resonating properties of the expanded upper chest are maintained throughout expiration. I have not yet had the opportunity of testing the accuracy of this view; I will only here observe that the upper ribs must to a large extent follow the lower.

It has been further urged that abdominal breathing may induce serious disturbances in the abdomino-pelvic

* Joal, *op. cit.*, p. 97.

viscera. In this method the diaphragm descends to its furthermost limit, and remains contracted throughout nearly the entire period of expiration, during which time the abdominal muscles are contracted also, in order to expel the air. This leads to considerable compression of the abdominal and pelvic organs, and, according to Cheval,* all sorts of troubles may thus result, such as hernias, indigestions, and disorders of the abdominal circulation. Joal describes the case of a woman at twenty-two, who was in perfect health and 'able to sing with impunity up to the day when she fell into the hands of a fanatical professor of abdominal respiration,' after which dysmenorrhœa, which was found to depend upon retroversion of the uterus, set in (p. 74). In another case the most violent form of dyspepsia was similarly induced. He quotes from other authors to the same effect, and refers to a case of uterine prolapse as resulting from the abdominal method of breathing. Now, I can quite understand that this form of breathing might bring about some of these evils in women who tight-lace, but I find it hard to believe that it can be injurious to the normal woman who does not compress the waist and abdomen.

A further argument has been advanced in favour of costal breathing, whether the lower costal, as advocated by Joal, or that more extended form recommended by Cathcart, in which the upper chest is well expanded, *i.e.*, that it increases the resonance of the bony thorax; and if such is the case, it should go a long way to turn the balance in its favour. I am aware that theoretic considerations appear to support this view, and it is said to be borne out by practical experience, but I should like definite proof of this.

One word as to the desirability of voluntarily retracting the belly in lower costal breathing. I confess I am some-

* Joal, p. 74.

what doubtful as to the utility of it. I think it highly doubtful whether the diaphragm plays an important part in elevating the lower ribs in this type of breathing. In my experience the ribs can be equally well raised with flaccid belly. It does not seem to me improbable that abdominal retraction was originally advocated in order to render abdominal breathing impossible.

Note.—In response to a request, my friend Dr. George C. Cathcart has briefly set forth his views regarding the proper method of breathing for singers: 'Breathing for singing differs from ordinary breathing in that the chest has to be used not only as a reservoir for the air which vibrates the vocal cords, but also as a resonator of the voice. When we remember that the effectiveness of a resonator increases with its nearness to the sound it resonates, it will at once be seen what an important part the mode of breathing plays in proper voice production. The abdominal method originally introduced by Mandl makes no use of the chest as a resonator. This method, combined with lower costal, as advocated by Brown and Behnke, is little better. as it also ignores the use of the chest as a resonator. In the old Italian method the chest was raised as a whole, every effort being made to cause the maximum expansion of the upper part, the inner ends of the clavicles being raised and the abdomen retracted. In this way, not only can a large volume of air be taken in, but the resonator is brought as near as possible to the vocal cords. This method is in accordance with nature, science, and art.'

CHAPTER XI.

VITAL CAPACITY.

'Vital capacity' is the term which John Hutchinson employed to denote the amount of air that can be expired after the fullest possible inspiration. After testing the vital capacity of a large number of individuals, he estimated its average for persons 5 feet in height at 174 cubic inches, with an increase of 8 cubic inches for every inch above this. Arnold's estimate for 5 feet is about the same, but he gives the increase for every inch in height above this as about $9\frac{1}{2}$ inches. Hence, according to Hutchinson, a man of 6 feet should breathe 270 cubic inches, while according to Arnold it would be 288 cubic inches.

This relation between height and vital capacity is remarkable, since height is determined chiefly by length of legs, and not by the size of the trunk and the thorax. People of 5 feet 6 inches in height and those of 6 feet have much the same length of trunk, and therefore the same length of thorax; nor is there necessarily any increase in the chest circumference with increased height. Indeed, short men have often much greater thoracic girth than tall men. Hence, there is no necessary relation between chest capacity and height, but between vital capacity and height there practically always is.* This is due to the fact that *the mobility of the chest increases with the stature.*

* Hutchinson determined the cubical contents of the thorax by removing the heart and lungs through an opening sufficiently large to

Hutchinson further held that there is also no relation between the circumference of the chest and vital capacity, a tall man with a chest of 34 girth probably having a larger vital capacity than a short man with a 40 inch. But of course, with *equal* mobility, the greater the circumference, the greater the vital capacity.

Arnold, on the other hand, finds a definite relation between thoracic girth and vital capacity. He gives 160 cubic inches as the standard capacity of a thoracic girth of 26 inches, and 9 inches the increment in capacity for every increase of 1 inch in girth.

Other formulæ are given by which it is claimed that the normal vital capacity of an individual may be calculated. Thus, Wintrich has sought to find a coefficient which, multiplied by the height, should give the normal vital capacity; C. W. Müller calculates it from the length of the trunk and the circumference of the chest, and Arnold from the total height and the circumference of the chest. All such formulæ are untrustworthy.

For the same height the vital capacity is much less in women than in men. Waldenburg estimates the former at from three-quarters to two-thirds that of the latter, and Arnold found the increase with every inch of stature as two-thirds that of men.

According to Wintrich, vital capacity goes on increasing up to the age of forty; according to Arnold, up to thirty-five. Hutchinson found an increase up to thirty, and a diminution of 1½ inches with every subsequent year up to sixty. In old age vital capacity sinks to a very low level.

admit the hand, and subsequently injecting it with plaster of Paris. In this way he was able to obtain a cast of the chest, the cubical contents of which could then be readily ascertained, and by this means he claimed to show that vital capacity may be larger than the mean cubical contents of the chest.

Those leading sedentary lives have a much smaller vital capacity than the active. It is, indeed, surprising how fixed the chest becomes in the sedentary. Vital capacity is greater in the standing than in the sitting posture, and greater in the latter than when lying down. It is diminished by obesity, after a heavy meal, by pregnancy, and all other conditions curtailing the respiratory area or interfering with the respiratory movements.

The Practical Value of gauging Vital Capacity: Value in Diagnosis.—Spirometry is practically useless in diagnosis where other means have failed, though Hutchinson claimed by this means alone to have diagnosed a case of commencing phthisis. All tables which claim to give the normal vital capacity for different heights and different chest measurements are approximate only; at best they can only give an average quantity—a standard which, however correct it may be as the mean capacity of a large number, does not necessarily give us the normal capacity of the *individual*. Individual capacities vary on either side of this mean. Hence, one with healthy lungs may fall below it, while one with pulmonary disease may surpass it. If we possessed a record of the normal vital capacity of the individual founded upon spirometric examinations, the case would be different; then any decided falling away from this would unmistakably indicate disease.

But while spirometry is useless for diagnostic purposes, it is of value for ascertaining the extent and the progress of disease. If, for instance, the vital capacity in a case of phthisis is good, we know that there cannot be great destruction of tissue; and, similarly, the degree of emphysema present can be estimated with considerable accuracy. Waldenburg points out that when the emphysematous patient can breathe decidedly more into a chamber of rarefied air than into ordinary air, the prognosis is better than when such is not the case.

Spirometry is also decidedly useful in indicating the effect of treatment. By its means we are able to record accurately any increase in the expansibility of the lungs or the mobility of the chest.

The Quantity of Residual Air.—The air which remains in the lungs after the fullest possible expiration is termed the 'residual' air. Hutchinson estimates it at from 30 to 60 cubic inches, Vierordt at from 30 to 40. Waldenburg believes it to be much more than this—to be, indeed, nearly, if not quite, double the vital capacity. He points out that several pints of fluid may be drawn off from one pleura, even when the lung on the same side is by no means entirely collapsed, and when the other lung is quite unaffected. Apparently, however, he overlooks the fact that when a pleura is distended with fluid the corresponding side of the chest is in the inspiratory position, and not in that position in which the lungs contain residual air only, *i.e.*, the position of expiration.

CHAPTER XII.

SECONDARY EFFECTS OF THE RESPIRATORY MOVEMENTS.

There is a tendency to think of the respiratory movements as subserving one function only, namely, the aeration of the blood. The fact is, however, far otherwise. In the first place, the circulation of blood and lymph is profoundly affected by the thoracic movements; in the second, several important organs are rhythmically commoted, and their functions thus influenced in no small degree. These latter effects I will now briefly describe.

During diaphragmatic descent all the movable abdominal and pelvic viscera are pushed downwards, their dislocation during deep abdominal breathing being considerable.* This may be proved by placing the palm of the hand upon the perinæum and then taking a deep inspiration, when a descent and increasing fulness of the perinæum can be felt quite plainly; a sudden cough produces a strong impulse in the same situation. The extent to which the liver

* Sibson writes that, as a result of diaphragmatic descent, 'the liver, stomach, spleen, pancreas, kidneys, and all the abdominal organs, the uterus (the inspiratory descent of which has been felt by Dr. Frederick Bird), and all the pelvic viscera, are pushed downwards during a deep inspiration; at which time the perinæum protrudes more than it does in the tranquil state' (*Med. Chir. Trans.*, vol. xxxi., p. 363). I am not, however, aware that there is any proof that the kidneys and pancreas descend during inspiration.

descends in breathing has already been referred to, and there can be no doubt that these movements favour its functional activity by hurrying on the flow of blood, lymph and bile. The liver is, during inspiration, squeezed between the diaphragm—which grasps a considerable portion of its large convex surface—and the anterior abdominal wall, and it is manifest that this rhythmical compression must profoundly modify the hepatic functions. We must, indeed, assume that the functions of the abdomino-pelvic viscera are dependent for their normal activity upon this rhythmic compression and dislocation, so that any interference with the latter must injuriously affect the former.

The descent of the diaphragm causes a corresponding downward movement of the heart. 'The central tendon of the diaphragm, forming the floor of the pericardium, presents an inclined plane, upon which the heart glides forwards and downwards during inspiration under the combined influence of the descent of the diaphragm and the forward movement of the ribs and sternum' (Sibson). In so doing it stretches the pulmonary artery, the ascending arch of the aorta, and the great vessels coming off from the arch ; but it must be remembered that the pericardium is reflected on to the great vessels at the base, being thence continuous with the cervical fascia. Hence, the downward movement of the diaphragm tugs upon these vessels, and is limited by their fascial attachments.

CHAPTER XIII.

INFLUENCE OF THE RESPIRATORY MOVEMENTS ON THE CIRCULATION OF THE BLOOD.

Before considering how the circulation is modified by the respiratory movements, it is necessary to refer briefly to the influences of external pressure on the heart and bloodvessels.

The susceptibility of the bloodvessels to outside pressure depends essentially, I conceive, upon the blood pressure within them, and in only a small degree—not mainly, as Michael Foster makes it appear—upon the thickness of their walls: for were the pressure in a blood-capillary as great as that in the aorta, the compressibility of each would be practically the same. As it is, the arteries are comparatively incompressible, their walls being supported by a substantial internal blood pressure, while the veins are much more compressible, owing to the lowness of the pressure within them. We must think of the arteries as comparatively rigid rods, and of the veins as flaccid, and partly or completely collapsed.

It follows that the venous circulation is much more susceptible than the arterial to variations in extravascular pressure. A good instance of the differing compressibility of the arteries and the veins is afforded by (1) the intra-abdominal vessels, (2) the intra-thoracic vessels.

1. De Jager points out that even strong pressure upon the abdomen has very little effect upon the abdominal

arteries, while it serves to express a large quantity of blood from the splanchnic veins.* That the abdominal veins are very susceptible to pressure is well shown by the numerous experiments of Leonard Hill with reference to the influence of gravitation on the circulation. Thus, he has shown that whenever from failure in certain compensatory mechanisms blood gravitates into the splanchnic veins and the right heart is thereby bereft of its supply, simple pressure upon the abdomen suffices to squeeze the blood out of these veins into the right heart and so to re-establish the circulation.

2. Slight modifications in extravascular pressure are sufficient to affect appreciably the calibre of the cavæ and the pulmonary veins, especially of the former, in which the pressure is frequently negative, while considerable modifications of extravascular pressure are needed to modify the calibre of the aorta to an appreciable extent; the pulmonary artery, being much less tense, is more susceptible than the aorta, but much less so than the large intra-thoracic veins.

Unlike the bloodvessels, the susceptibility of the heart to external pressure depends not only on the intracardiac blood pressure, but also very largely upon the thickness of the cardiac walls. Thus, the right auricle is easily influenced by external changes in pressure, having both a low internal blood pressure and thin walls. On the other hand, the massive thick walls of the left ventricle render it comparatively independent of external pressure, especially during systole, when the internal pressure is very high. Modifications of external pressure affect the heart chiefly by favouring or retarding diastole.

We now turn to the respiratory movements in connection with these facts. The respiratory movements influence the blood-circulation in a threefold manner: (1) By modifying

* *Journal of Physiology*, vol. vii., p. 202.

the capacity of the intra-pulmonary portion of the pulmonary circuit; (2) by modifying the pressure upon the heart and such of the intra-thoracic bloodvessels as are outside the lungs, namely, the aorta and its branches, the pulmonary artery and its extra-pulmonary branches, the innominate veins and their branches, the venæ cavæ, the azygos veins, and the pulmonary veins; (3) by modifying the intra-abdominal pressure.

1. With every inspiration the vessels of the lungs expand, contracting again during expiration,* the degree of vascular expansion and contraction being, under ordinary circumstances, in direct proportion to the degree of inspiration and expiration.

That the intra-pulmonary vessels should open up when the lungs expand and shrink again when they contract, seems natural enough, but the exact reasons for these alterations in calibre are not so easy to determine. During inspiration the pressure in the alveoli falls, and that in the pleuræ, already negative, falls still further, so that the effect of inspiration on the lungs is much the same as that which would be produced by placing them in the reservoir of an air-pump and then exhausting the air, having previously ligatured the pulmonary artery and veins. We know that under these circumstances the intra-pulmonary vessels would dilate, and, indeed, the inspiratory increase in the vascular capacity of the lungs has been attributed to a species of dry cupping.† It must not, however, be supposed that this increase is due solely to diminution of the atmo-

* It has been experimentally shown that the pulmonary vessels are more capacious after inspiration than after expiration (see McKendrick's 'Physiology,' vol. ii., p. 290). 'If,' writes P. M. Chapman, 'at the termination of expiration the quantity of blood in the lungs is from $\frac{1}{15}$ to $\frac{1}{18}$ of the total quantity of blood in the body, at the termination of inspiration it will be from $\frac{1}{12}$ to $\frac{1}{13}$.'—*Lancet*, 1894, vol. i., p. 587.

† See Michael Foster's 'Textbook of Physiology,' sixth edition, Part II., p. 650.

spheric pressure upon the bloodvessels. Such a diminution can only directly affect the alveolar vessels, while the inspiratory expansion of the intra-pulmonary vessels involves the whole of them. This it does, I imagine, by a diminution in the circumvascular *tissue pressure.* As inspiration proceeds, the fibres—elastic and others—surrounding the vessels become stretched, and thus exert traction upon and expand them. During a complete expiration this circumvascular negative tissue pressure becomes converted into a positive pressure, when the vessels are actually compressed by the surrounding tissues.

These two pressures, namely, the intra-alveolar atmospheric pressure and the circumvascular tissue pressure, may be made to vary within wide limits. When a forced inspiration is taken with closed glottis, they both fall; hence the intra-pulmonary vessels suffer a considerable expansion, and blood is sucked in large quantities into the lungs. When, on the other hand, a forced expiration is made with closed glottis, each pressure increases; hence, the intra-pulmonary vessels are strongly compressed, and the blood is thus driven out of the lungs.

Were variations in the intra-pulmonary atmospheric pressure the sole cause of the variations in the calibre of the intra-pulmonary vessels, it would follow that the lungs could be made to contain more blood when contracted in full expiration than when expanded in complete inspiration: all that would be necessary would be to inspire forcibly with closed glottis in the former case, and similarly to expire in the latter; the contracted lung would then contain the maximum supply of blood, and the expanded lung the minimum.*

* Seeing that the inspiratory muscles can act to greatest advantage at full inspiration, the lungs, on the above assumption, should contain less blood if a forcible expiration with closed glottis be made at the end

But such is not actually the case, for though the intra-pulmonary pressure may be diminished in the contracted lungs, the circumvascular tissue pressure is necessarily increased. On the other hand, while the intra-pulmonary pressure may be greatly increased in the expanded lungs, the circumvascular tissue pressure is necessarily greatly diminished. It should be mentioned, in this connection, that the breath can be held twice as long when the lungs are expanded in full inspiration as when contracted in full expiration, and this, no matter how we modify the intra-pulmonary atmospheric pressure. No doubt this difference is largely, possibly solely, due to the larger quantity of intra-pulmonary air in the one case than in the other; but it at least suggests that it may also be partly due to the fact that the circumvascular tissue pressure is negative in the one case and positive in the other, the former favouring and the latter retarding the pulmonary flow.

In comparing the time during which the breath can be held when the lungs are fully expanded by inspiration with the time during which it can be held when they are fully contracted by expiration, it is well first to induce apnœa by breathing rapidly and deeply for, say, fifteen seconds. I find that if I then hold my breath in full expiration, nearly a minute elapses before dyspnœa becomes urgent; and, curiously enough, the period remains much the same whether, while thus holding the breath, I forcibly inspire, or expire with closed glottis, or do neither. On the other hand, if, after similarly inducing apnœa, I hold my breath in full inspiration, I can go two and a quarter minutes

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of a full inspiration than at the end of a full expiration. Contrariwise, the expiratory position being the most favourable for the action of the inspiratory muscles, the lungs should contain more blood if a forcible inspiration be made at the end of complete expiration than at the end of complete inspiration.

before there is an urgent desire to breathe. And here again, the pressure to which the intra-pulmonary vessels are subjected by forcibly inspiring, or expiring with closed glottis, makes no appreciable difference in the time during which the breath can be held.

The effect of the inspiratory expansion of the intra-pulmonary vessels is to lessen the resistance which they oppose to the blood-flow, and consequently to increase the rate of flow through the pulmonary circuit, thereby increasing the output from the right heart and the out-flow from the lungs. As against the increased rate of flow thus resulting we must set the diminution in its rate brought about by the widening of the pulmonary bed,* and a further circumstance has to be considered in this connection: not only does an increase in vascular calibre tend, by the widening of the bed, to diminish the rate of flow, but the *very process of vascular dilatation* itself tends in the same direction: for as the vessels open out, the extra vascular space thus created has to be filled with blood, and this process of filling detracts from the forward movement of the blood. By so much as the vessels open out and, as it were, *swallow up* the blood, by so much is the pulmonary output diminished; and it is conceivable that the vascular dilatation might be so rapid as temporarily to check the pulmonary outflow altogether—nay, actually to suck blood from the left heart into the lungs. How markedly this swallowing-up process detracts from the forward flow may be shown by taking a

* The influence of pulmonary expansion on the pulmonary 'bed' will be most marked where the bed is widest, *i.e.*, in the neighbourhood of the arterioles, capillaries, and venules, and consequently its effect on rate of flow will also be most marked here. The widening of the bed in this region must operate very decidedly in the direction of diminishing the rate of flow, and it should be noticed that an actual diminution in the rate of flow here is compatible with an increased pulmonary output.

very rapid and deep inspiration after a forced expiration with closed glottis, when the sudden change in the calibre of the pulmonary vessels from the minimum to the maximum diminishes the pulmonary output to such an extent as to cause the individual to grow pale and faint, and even destroy all trace of the radial pulse. This is especially the case in those with low tension. The exact converse of this occurs during effort, as in coughing or lifting a heavy weight. A deep inspiration is first taken, and then a powerful expiration with partly or completely closed glottis. In this way the calibre of the pulmonary vessels is suddenly changed from a minimum to a maximum, and as a result the pulmonary blood tends to be driven in both directions, *i.e.*, backwards towards the right heart, and forwards into the left heart. It is not able to regurgitate into the right heart owing to the pulmonary valves, but although checked in this direction, it is doubtful whether much can escape from the right heart during a violent effort. On the other hand, the way into the left heart being open, a large quantity of blood is expressed into it. In this connection it must be borne in mind that the venous portion of the pulmonary circuit is much more compressible than the arterial portion, owing to its comparatively low tension. The effect, therefore, of a sudden effort is to squeeze a large quantity of blood into the left heart, and thus to increase the aortic input.* It is in this way we can explain a phenomenon I have frequently observed, viz., a swelling up of the systemic arteries—the temporals, for instance—during cough. Even more effective in this respect is a sudden effort with *com-*

* It is true that the extra-pulmonary portion of the pulmonary veins and the left auricle are subject to great pressure during effort, and this must operate in the direction of diminishing the input into the left ventricle; but it must be remembered that the blood pressure in all of them must also rise very considerably, and that this heightened pressure will diminish their compressibility.

pletely closed glottis. It is probably for this reason that straining at stool and similar efforts are so liable to cause rupture of arterial aneurysms, whether of the small miliary aneurysms of the cerebral vessels or of the large aneurysms situated on the great bloodvessels. Another factor tending to send up arterial blood pressure in these cases is the powerful contraction of the abdominal muscles, and the consequent compression of the abdominal vessels. As I elsewhere point out, compression of the belly may increase the work of the heart 30 per cent. by squeezing blood from the splanchnic area into other parts of the vascular system. During effort such compression is probably not able materially to increase the input into the right heart owing to the increase of intra-thoracic pressure, but it tends, nevertheless, to send up the systemic arterial pressure by increasing the peripheral resistance in the splanchnic area.

Michael Foster* writes as though the swallowing-up process above referred to takes place during the beginning of inspiration only, but it is manifest that it must last during its entire period. It is quite possible, however, that it is greatest at the beginning of inspiration, and that in this way it may cause a delay in the increased output brought about by the diminished pulmonary resistance. It will be observed that, while it tends to diminish the pulmonary output, it increases the input by actually sucking blood out of the right heart.

2. In order to understand the influence of the second factor, the facts enunciated in Chapter I. must be borne in mind. It is there pointed out that the heart and its great bloodvessels are, under ordinary circumstances, subjected to pulmonary suction, this suction operating even at the end of an ordinary expiration, and increasing with every inspiration. It constitutes an important aid to the circulation, sucking, as it does, blood from the veins of the neck

* 'Text-Book of Physiology,' sixth edition, Part II., p. 650.

and upper extremities (on which the pressure is at least equal to the ordinary atmospheric pressure) into the innominates and superior cava, and from the abdominal veins (on which the pressure is likewise positive) into the inferior cava; also from the lungs into the pulmonary veins. Its influence on the heart also favours the circulation, inasmuch as it facilitates diastole (the degree of which largely determines the amount of blood flowing into the heart) much more than it retards systole. Ventricular systole must, indeed, be very little influenced by it.

The effects just considered are greatly increased when inspiration is made with closed glottis, by which means suction may be raised to —100 mm. Hg. Under these circumstances the blood is sucked with considerable force into the cavæ and right heart, and from the pulmonary veins into the left heart. On the other hand, such powerful suction must hamper systole, especially auricular systole; but any retardation of the circulation thus resulting is overbalanced by the acceleration of diastole.

Pulmonary suction ceases with a full expiration, the pressure on the heart and great bloodvessels then becoming positive, and if a violent expiration is made with closed glottis, it may amount to 100 mm. Hg or more. Such a pressure on the cavæ and pulmonary veins must tend to obliterate them, and to render cardiac diastole (notably of the auricles) very difficult. The heart and great bloodvessels may, indeed, be so firmly compressed in this way as almost to check the circulation altogether for a time.

Since pulmonary suction constitutes an important aid to the circulation, it follows that any loss of pulmonary elasticity is detrimental to the same. This is one of the reasons why in emphysema the blood tends to accumulate in the systemic veins.

3. With every descent of the diaphragm the intra-

abdominal vessels are compressed. The tense arteries are very little influenced by this pressure, but the flaccid veins yield to it, blood being squeezed out of them into the right heart, for though the intra-abdominal veins are not provided with valves, those of the lower extremities have them, and consequently the blood cannot regurgitate from the iliacs into them. Hence, as Marey observes, the pressures in the intra-thoracic and intra-abdominal veins run in opposite directions, the former falling during inspiration, and the latter rising, and *vice versâ*. (I refer to diaphragmatic inspiration.) In the portal veins the pressure may rise several millimetres of mercury.*

The effect of diaphragmatic inspiration in increasing intra-abdominal tension and thus squeezing blood out of the intra-abdominal veins into the right heart, is largely dependent upon the condition of the anterior abdominal walls. When these are lax and flaccid, tension is very little increased, even by extreme contraction of the diaphragm. On the other hand, when the abdominal walls are strongly contracted or firmly compressed, as by a belt, or by flexing the body on the thighs, forcible contraction of the diaphragm may cause considerable augmentation of tension.

It should be observed, however, that inspiration does not always augment intra-abdominal tension; it may produce the very opposite result. Thus, when the fullest possible thoracic breath is taken, abdominal tension falls, owing to the powerful suction of the lungs upon the diaphragm; and the fall becomes still greater if the breath be taken with closed glottis. The effect of this diminished tension is to draw the blood from the lower extremities and abdomino-pelvic viscera into the intra-abdominal veins.†

* Marey points out that the action of the abdominal muscles, which (in the dog, at least) tend to contract during expiration, and thus to compress the intra-abdominal veins, introduces a disturbing influence ('La Circulation du Sang,' Paris, 1881, pp. 417, 529).

† For a practical application of the above facts, see p. 151 *et seq.*

While intra-abdominal pressure tends to fall during ordinary expiration, it increases when expiration is forced, especially when the glottis is closed, as in effort; but the compression of the intra-abdominal veins thus resulting does not urge the blood onward, owing to the concomitant increase in intra-thoracic pressure.

It will probably be concluded from the foregoing observations that the ordinary respiratory movements favour the circulation, but it is doubtful whether in ordinary breathing they have any decided effect. While the rhythmic descent of the diaphragm aids the circulation, it is doubtful whether the rhythmic expansion and contraction of the lungs have the same result, seeing that the accelerating influence of expansion is neutralized by the retarding influence of contraction. We have seen that pulmonary suction is largely dependent upon the degree to which the very elastic lungs are stretched. During inspiration the elastic tension rises to a given point, and during expiration it falls again to the original point. Hence the mean tension is the same during both inspiration and expiration, and so far as pulmonary suction is dependent upon pulmonary tension, it is the same during both inspiration and expiration. Pulmonary suction is, however, also influenced by the intra-pulmonary air pressure. This latter falls during inspiration, and in so doing increases the suction upon the heart and extra-pulmonary bloodvessels, while it also causes an expansion of the intra-pulmonary vessels; but the accelerating influence of this diminished intra-pulmonary pressure is counteracted by the expiratory increase of intra-pulmonary pressure, which not only diminishes the suction upon the heart and great bloodvessels, but likewise the calibre of the intra-pulmonary vessels.

It would thus appear that if inspiration and expiration are of equal duration (as under ordinary circumstances they practically are), the respiratory expansion and contraction of the lungs will not aid the circulation. How, then, are we to account for the fact that the circulation is impeded when the breath is held? Marey has shown, by taking tracings of the right ventricle under these conditions, that its beats become slower and that it manifests an increasing difficulty in emptying itself, the amount of residual blood increasing with every beat. This latter fact is further attested by the increase of dulness to the right of the sternum, and by the distension of the veins of the head and neck. These phenomena certainly suggest that by holding the breath we remove a something which facilitates pulmonary circulation. It must, however, be remembered that when an individual is asked to hold his breath, he closes the glottis, and makes an unconscious expiratory effort, thus increasing the intra-pulmonary pressure; also that holding the breath checks the respiratory blood-change, the pulmonary circulation being hindered in consequence.*

But while the rhythmic movements of the lungs do not under ordinary circumstances aid the circulation, there are certain positions of the chest and certain modes of breathing which are favourable to it, and it behoves us thoroughly to understand what these are. Since pulmonary suction aids the blood-flow, it follows that *increase in mean pulmonary suction will favour the circulation.* Such an increase may be effected by inflating the chest to the utmost with every inspiration, and limiting the expiratory range. In this way the transference of blood from the veins to the arteries is facilitated. It may further be aided *by prolonging the inspiratory periods and shortening the expiratory*, for by this means the period of lessened becomes longer than the period

* See pp. 142-144.

of heightened intra-pulmonary tension; *i.e.*, the period of acceleration becomes longer than that of retardation. The mode of breathing, therefore, most favourable to the circulation is to take slow full inspirations (preferably through the nose), followed by short and somewhat shallow expirations (preferably through the mouth). This is, indeed, the method often instinctively resorted to when there is need of facilitating the transit of blood from the cavæ to the aorta. In running, for instance, the blood is diverted in large quantities from the splanchnic area to the muscles, whence it is pumped with great rapidity into the right heart, which has some difficulty in disburdening itself of this large access of blood. Now, the mean size of the chest is manifestly increased in running, full inspirations being taken, while expirations stop short of their ordinary limit. Further, as breathlessness becomes marked the expirations get distinctly shorter than the inspirations. A ready way of demonstrating this disproportion is to notice how many paces can be taken during the one and the other respectively. Legrange found that when breathlessness became decided he took thirteen paces during each inspiration, and only five during an expiration. When the breathlessness has become pronounced it will be found quite impossible to make the two acts equal: inspiration may be voluntarily prolonged, but not expiration, which is always cut suddenly short by the imperious demand to inspire. Hence it is that expiration does not proceed to the ordinary limit, the mean size of the chest being in consequence increased and the circulation through the lungs thereby facilitated.

Legrange, who was, I believe, the first to point out the alteration in rhythm just referred to, explains it, as I have done, by reference to the favouring influence on the circulation of deep inspirations, and the retarding influence of deep expirations, the individual in consequence instinctively prolonging the one and shortening the other. The altered rhythm cannot, he argues, be due to mechanical causes, seeing that it occurs in exercises of the arms as well as of the legs, and that it lasts for some time after the exercise which has induced it.

In all forms of dyspnœa there is the same difficulty in getting the blood through the lungs and the same tendency to take full inspirations and short incomplete expirations. Hence, in dyspnœa we find the inspiratory muscles more active than the expiratory.

Influence of the Respiratory Movements on Arterial and Venous Tension.—We are now in a position to consider this influence.*

Inspiration favours the flow of blood into the cavæ and right heart, from the latter into the lungs, and from the lungs into the left heart. In short, it favours the transference of blood from the systemic veins into the systemic arteries, and its effect is most marked when the glottis is closed. Hence, inspiration causes a fall of venous blood pressure, especially in the superior cava (the cranial fontanelles and veins of the neck collapsing),† and a rise of pressure in the systemic arteries.‡ Expiration, on the other hand, impedes the flow of blood from the veins into

* The influence of the respiratory movements on arterial tension has been skilfully treated of by De Jager. See *Jour. Phys.*, vol. vii., No. 2, p. 130; also Plüger's *Archiv.*, Bd. 20, 27, 33, and 36, and *Arch. Neerl. T.*, 19 and 20, which contain copious references to the literature of the subject.

† The effect of inspiration upon the pressure in the inferior cava varies according to circumstances: a deep abdominal breath increases it; a deep costal breath diminishes it.

‡ Inspiration, by increasing the amount of blood in the lungs, tends to cause a fall in arterial as well as in venous pressure; but by diminishing pulmonary resistance it tends to cause a rise in arterial pressure, the latter effect preponderating. See De Jager, *Jour. Phys.*, vol. vii., No. 2, pp. 196-198, 206-208.

the arteries, its effect being greatest when forced and with closed glottis. Hence, venous blood pressure rises during expiration, the fontanelles and cervical veins swelling up, while arterial blood pressure falls.

These respiratory alternations in arterial blood pressure do not exactly synchronize with the respiratory movements. Thus, the expiratory fall continues into the beginning of inspiration, possibly because the first effect of inspiration is to diminish the pulmonary output; indeed, this inspiratory fall may, as we have seen, be very marked if a deep and rapid inspiration be taken after a forced expiration with closed glottis. On the other hand, the inspiratory rise continues into the beginning of expiration, the first effect of which is to augment the pulmonary output by expressing blood into the left heart. If expiration be made powerfully with partly or completely closed glottis, this expiratory rise may, as already observed, be decided. It is, however, only momentary, the final effect of a protracted expiration of this kind being a considerable lowering of arterial and a corresponding rise of venous pressure, for not only is the circulation through the lungs and great veins entering the heart impeded, but the action of the heart itself. Eduard Weber pointed out that even a moderate expiratory effort, while the mouth and nostrils are closed, renders the pulse slow and small and the heart-sounds indistinct, more forcible expiration causing the radial pulse to disappear completely, an effect which Oertel attributes to the 'compression of the subclavian artery by the strongly raised upper ribs.'*

Whatever augments intra-thoracic pressure, such as coughing, vomiting, straining at stool, lifting a heavy weight with closed glottis, has similar effects. These different kinds of

* Von Zeimssen's 'Handbook of General Therapeutics,' vol. iii., p. 468.

effort and their influence on the circulation are more particularly considered in Chapter XVI.

It has been shown by Leonard Hill and Barnard that external compression of the thorax affects the circulation in the same way as expiration with closed glottis, and they insist that whatever raises intra-pulmonary air pressure causes a fall in arterial and a rise in venous pressure, 'the diastolic filling of the heart and the passage of blood through the lungs being thereby impeded,' so that the effect on the circulation is the same as that produced by obstructive lung disease and cardiac failure.

Tight-lacing causes external compression of the thorax, and therefore impedes the pulmonary circulation, damming it back upon the systemic veins.

These two physiologists have also brought out a point in connection with the radial pulse which has hitherto been strangely overlooked, namely, that the radial artery has two venæ comites, and that the quality of the radial pulse is affected by the degree to which these two veins are distended. When examining the radial pulse, we feel in fact three vessels, and these we may speak of as the radial band.

Now, Blake observed that forced expiration increased the size of the radial pulse. This was proved by careful observations with the arteriometer, and by the fact that the base line of the sphygmographic curve rises with forced expiration. How to reconcile this fact with the fact that increased intra-thoracic pressure lowers arterial tension was a problem which Blake presented to Leonard Hill for solution. By a series of ingenious experiments Hill and Barnard have conclusively proved that the increase in the size of the radial pulse produced by forced expiration is due to distension of the venæ comites,* and that anything which causes

* Such an expiration may, as we have seen, produce a distension of the arteries, but this is momentary only.

the blood to be dammed back upon the great veins produces the same effect. They insist that it is impossible to differentiate between the venous and arterial aspects of the radial pulse, and that the fulness of the venæ comites gives a distinct character to the radial pulse, whether tested by the finger or the sphygmograph. For this reason they hold that the quality of 'fulness between the beats' does not necessarily signify high arterial tension. Sir William Broadbent attaches great importance to this phenomenon as evidence of high arterial tension, but by 'fulness between the beats' he evidently means a sense of fulness *when a fair degree of pressure* is applied to the pulse. Now, a vein when under a high venous pressure is quite easily compressible, and hence the physician would be very unlikely to mistake overdistension of the radial venæ comites for high arterial tension.

Influence of the Respiratory Movements on the Pulse-Rate.— In man, the dog, and certain other animals, the rate of the pulse increases during inspiration, diminishing again during expiration. This phenomenon is due to cardiac inhibition taking place with every expiration, for if in the dog the vagi be cut, the respiratory variations in pulse-rate cease. The modifications in pulse-tension, however, continue, and this shows that these latter are not dependent upon the rhythmic alteration in rates.

But while the act of inspiration quickens the pulse and that of expiration slows it, holding the breath in extreme inspiration slows the pulse while holding it in extreme expiration quickens it. Thus, the following results were obtained in my own case :

Ordinary pulse	53, 52, 50, 52, 53.
With chest fixed in expiration	58, 54, 56, 58, 58.
With chest fixed in inspiration	52, 48, 51, 52, 51.

Dr. Edward Blake, who directed my attention to these effects, has obtained much wider divergences than I give. Thus, in one of his observations a pulse of 80 was reduced to 64 by holding the breath in extreme inspiration, while in another case a pulse of 65 was increased to 76 by holding it in the expiratory position.*

The Effects of the Respiratory Movements on the Cerebral Circulation.—These effects are so important from the therapeutical point of view that it is necessary to describe them, if only briefly.

The skull after infancy being a closed cavity, the volume of its contents must always remain the same. Now, the brain-substance is incompressible, and the researches of George Elder† would appear to prove that the quantity of cerebro-spinal fluid within the skull remains constant. It therefore follows that the quantity of blood within the closed cranium always remains the same (Munro-Kellie doctrine). This does not, however, imply that the calibre of the intra-cranial vessels can never alter, for the brain-matter, though incompressible, must not be regarded as a rigid substance, but diffluent rather, and capable of altering in position in response to alteration in the calibre of the cerebral vessels. With every beat of the heart the cerebral arteries dilate, thus displacing the brain-substance and causing a corresponding contraction of the cerebral veins; similarly, as the arteries recoil, the brain-substance closes in about them, thus allowing the veins to dilate; there is, in fact, an alternate pulsation of the arteries and veins. Elder concludes that the respiratory movements are

* *The Medical Times and Hospital Gazette*, March and April, 1897.

† 'The Intra-cranial Circulation in some of its Aspects': *Brit. Med. Jour.*, 1897, vol. ii., p. 1414.

likewise capable of modifying the calibre of the cerebral vessels. The effect of inspiration is to cause a depression, and of expiration to cause a bulging, of the anterior fontanelle. There can be no doubt that the former is due to a collapse of the cerebral veins (not the sinuses, which are said to be incompressible) owing to the suction of the thorax, and the latter to a distension of them from the effect of expiration in hindering the return of venous blood. Now, Elder is inclined to believe that the same thing occurs in the closed skull, but seeing that he also believes the volume of intra-cranial blood always to remain the same, he is compelled to assume that the supposed inspiratory venous collapse is accompanied by a corresponding arterial dilatation, and the expiratory venous distension by a corresponding arterial collapse, the modification in arterial calibre being effected through modifications in the pressure of the brain-substance, this latter being always the same as that of the intra-cranial venous pressure. I cannot accept Elder's conclusion. In order that the supposed inspiratory venous distension should cause arterial contraction, the venous pressure would have to be greater than the arterial pressure, which it never is. Assuming, therefore, that the quantity of intra-cranial blood is constant, we must conclude that the effect of inspiration on the cerebral circulation is to hurry on the venous flow, without causing these vessels to diminish in calibre, and as they do not alter in calibre, it is clear that the suction action must extend along the entire cerebral circuit, accelerating the arterial and capillary as well as the venous circulation, the cerebral flow being further favoured by the inspiratory rise of arterial pressure. Hence with every inspiration blood is drawn out of, and pumped with increased force into, the brain. By taking deep inspirations, followed by short and shallow expirations, we can so quicken the cerebral circulation as to induce temporary unconsciousness. When we reflect that the intra-cranial lymph-flow is at the same time quickened, it is manifest that we have thus at our command a means of profoundly modifying the cerebral processes.

CHAPTER XIV.

THE INFLUENCE UPON THE CIRCULATION, ETC., OF MODIFICATIONS IN THE DENSITY OF THE OUTER AIR.

There are various ways of modifying the pressure of the external atmosphere, and since these have a profound influence upon the circulation, they must be considered here. Thus, the entire body can be immersed in a condensed or a rarefied atmosphere by condensing or rarefying the air in an air-tight chamber. It is further possible, by means of suitable apparatus, to modify intra-pulmonary tension without altering the general atmospheric pressure. Thus, the patient can be made to—

(*a*) Inspire into condensed air.
(*b*) Expire into condensed air.
(*c*) Inspire rarefied air.
(*d*) Expire into rarefied air.

These various methods are practically unknown in this country, but they have been carefully studied and largely employed on the Continent. The reader will find a detailed account of them in Waldenburg's* and Oertel's† works. I shall therefore only very briefly touch upon the subject here.

* 'Die Pneumatische Behandlung der Respirations- u. Circulations-Krankheiten.'

† Van Ziemssen's 'Handbook of General Therapeutics,' vol. viii. Translated by J. Burney Yeo, M.D., F.R.C.P.; London, 1885.

The Effects of immersing the Body in Compressed Air.—The blood is expressed from the lungs and the surface of the body, and driven into the abdomino-pelvic viscera. Hence, the secretions of the lungs and the skin are diminished, while those of the stomach, intestines, kidneys, and uterus are increased. The heart and great bloodvessels are compressed, the extent of cardiac contractions diminished; the pulse gets slower, and its absolute tension higher than usual. The respiratory movements are deeper, slower, and more easily performed. Vital capacity increases; there is augmentation of thoracic capacity, chiefly, it would seem, from compression of the diaphragm. Absorption of O and elimination of CO_2 are increased. This shows that increased metabolism occurs, a fact which harmonizes with the great capacity for sustained muscle-effort among workers in compressed air, and with the rapid loss in weight which they undergo.

By means of a contrivance in the wall of the compressed-air chamber, the patient is enabled to expire into the external atmosphere, the expiratory range being thus increased and the quantity of residual air diminished.

The Effects of Rarefied Air.—These are sought for, not by means of the rarefied-air chamber, but by residence in mountainous districts. The lungs and skin become hyperæmic, and their secretions correspondingly augmented, the reverse being the case with the abdomino-pelvic organs. The heart beats more rapidly, and the absolute arterial pressure is lowered. The chest expands, the respirations get deeper and slower; the vital capacity, however, diminishes, from the expansion, it is thought, of the intestinal gases and consequent elevation of the diaphragm. The absorption of O and the elimination of CO_2 are diminished, while the temperature of the body tends to fall.

The Effects upon the Circulation of varying the Density of the Air inspired and expired into, the General Atmospheric Pressure remaining the same.—In explaining these effects, I shall make no reference to the influence of modifications of intra-pulmonary pressure on ventricular systole and diastole. Inspiration of condensed air favours systole and interferes with diastole, while inspiration of rarefied air favours diastole and interferes with systole, in either case the favouring influence on the one being more or less balanced by its interfering influence on the other.

(*a*) Inspiration of condensed air interferes with the induction of the negative intra-pulmonary pressure during inspiration. There may, indeed, be a brief phase of negative pressure at the very beginning of inspiration, especially if sudden; it soon, however, becomes positive, and at the end of inspiration is practically the same as that of the air in the apparatus used. The effect of this heightened intra-pulmonary pressure is much the same as that produced by effort. The pulmonary vessels are compressed, so that the lungs become pale; the auricles and the great veins entering the heart are also compressed, and hence the circulation through the lungs is impeded, the blood being dammed back upon the right heart and systemic veins, and, indeed, if the degree of condensation be sufficiently great, it may actually be stopped. If now expiration be made into an atmosphere of ordinary density, the heightened intra-pulmonary pressure gradually diminishes, but it is not until towards the end of expiration, when the condensed air has freely escaped, that the pressure in the lungs attains its normal expiratory level.

It will thus be seen that, so far as its immediate effects on the circulation are concerned, no good purpose can be served by the inspiration of condensed air, in spite of Waldenburg's argument to the contrary. Whatever good may come of it is indirect, and traceable to the larger volume of oxygen thus introduced, and to the influence of condensed air in opening out collapsed vesicles.

(*b*) Expiration into compressed air has a similar, but even more marked, effect on the circulation, the result being strictly comparable to that of effort, or to what happens in Valsalva's experiment. The increase of intra-pulmonary pressure does not cease with the beginning of inspiration, for the pulmonary air being then condensed, the normal degree of inspiratory rarefaction cannot at once be attained.

(*c*) Inspiration of rarefied air causes the inspiratory negative pressure to become still more negative, and thus increases inspiratory suction, the blood flowing more abundantly into the right heart, and from the right heart through the lungs into the left heart, for which reason it is especially indicated in passive engorgement of the lungs and systemic veins. Its effect does not end with inspiration, the negative pressure not being effaced until expiration is somewhat advanced.

(*d*) Expiration into rarefied air may be employed in similar cases, reducing as it does intra-pulmonary tension during expiration, and causing it to remain negative even at the end of a deep expiration, when under ordinary circumstances it is decidedly positive. Hence, a marked suction action is established during expiration, when normally it is all but absent. The effect continues into inspiration, the initial expansion of the lungs causing the rarefied air to become still more rarefied; gradually, however, the influx of air at the ordinary density establishes the normal inspiratory pressure.

Excessive rarefaction of the air breathed does not favour the flow into the right heart. The greater the rarefaction, the greater is pulmonary suction, and when this has become sufficient to produce an extreme degree of negative pressure in the great veins of the neck and abdomen, these became flattened by the atmospheric pressure, the supply of blood to the right heart being thus diminished. In engorged right heart, whether from disease of the lung or left heart, such curtailment in its blood-supply is beneficial. In such cases, however, the blood-pressure in the large systemic veins is considerable, attaining, it may be, several millimetres of mercury, and it is not easy to render it negative.

We must be careful not to produce too great rarefaction of the air in the lungs, since extreme rarefaction may cause rupture of the capillaries lining the air-passages by lessening the support they receive from the intra-pulmonary air-pressure.

Of the above modes of breathing, the inspiration of condensed, and the expiration into rarefied air have been most frequently employed for therapeutical purposes. These two methods may with advantage be combined, the patient alternately inhaling condensed air and expiring into rarefied air. The high pressure at which the air streams into the lungs causes a complete expansion of the vesicles, and thus many vesicles may be expanded which are habitually in a state of semi-collapse. On the other hand, expiration into rarefied air causes a more complete removal of the air than is otherwise possible. By the combined methods we, in short, increase the expansion and contraction of the vesicles, and thus augment the absorption of oxygen and the elimination of carbonic acid.

CHAPTER XV.

INFLUENCE OF THE RESPIRATORY MOVEMENTS ON THE CIRCULATION OF LYMPH.

A word as to the course of the pulmonary lymphatics. The radicles of the pulmonary lymphatics originate in the septa between the alveoli and in the bronchial mucous membrane, those from the superficial alveoli passing into the subpleural lymphatics, which also receive the radicles of the pleura, while those from the deeper alveoli pass into lymphatic vessels running in the adventitia of the larger bloodvessels (perivascular lymphatics). The bronchial lymphatic radicles empty themselves into the lymphatic vessels situated in the bronchial adventitia (peribronchial lymphatics). All three groups of efferent vessels—subpleural, perivascular, and peribronchial—traverse the roots of the lungs and pass into the bronchial glands, whence the lymph is conveyed into the thoracic ducts.

The alveolar radicles communicate with the alveoli through certain inter-endothelial spaces, and in a similar manner the radicles in the bronchial mucous membrane have communication with the interior of the bronchi. Hence it is that particles of carbon or other substances in the air-passages are able to work their way into the pulmonary lymphatics, and thence into the bronchial glands. Hence, also, inflammatory exudations into the air-passages are capable of being absorbed by the lymphatics. Just as the bronchial and alveolar lymphatic radicles communicate with the air-passages, so the pleural radicles communicate with the pleural cavities, the communication in this case being established by means of *somata*.*

We are now in a position to explain the influence of the respiratory movements on the flow of pulmonary and pleural lymph. During inspiration the openings of the pleural stomata become widened, and the pleural lymphatics expanded; hence any fluid there may be in the pleuræ tends to be drained off into the pleural lymphatics. During expiration the lymph is pressed inward in the latter vessels. Similarly as regards the lymphatics which take their origin in the bronchi and alveolar septa; inspiration tends to suck fluid from the air-passages, expiration to accelerate the pulmonary lymph-flow. Inspiration, be it noted, expands all the pulmonary and pleural lymphatics, large and small; its effect, therefore, must be to suck fluid from the radicles into the larger lymphatics. It must further be observed that all the pulmonary lymphatics, save the capillaries, being provided with valves,† expiration must force the lymph along these vessels in the same way as rhythmical muscle-contractions drive the blood along the muscle-veins.

The above considerations prepare us for the conclusion that respiratory exercises are useful in promoting the absorption of fluid from the pleuræ and air-passages. Their potency in the former respect is shown by injecting a fluid into the pleura of an animal, and observing the effect of artificial respiration. This is found greatly to increase the rate of absorption.

The central tendon of the diaphragm contains an elaborate system of lymphatics, and the effect of diaphragmatic move-

* See on the above subject 'The Anatomy of the Lymphatics.' E. Klein, London, 1875.

† Thus differing from the pulmonary veins, which have no valves.

ments is to pump lymph from the peritoneal cavity into the pleuræ, as can be shown by injecting a coloured fluid into the former. The more active the diaphragmatic movement, the more rapidly does absorption occur. In my belief, ascites is often prevented by active movement of the diaphragm.

Inspirations favour the flow of lymph along the thoracic ducts by diminishing the pressure in the veins into which they respectively enter. On the other hand, regurgitation of blood into the ducts during expiration is prevented by the valves situated at their venous openings.

I would lay particular stress on the fact that by means of respiratory movements we are able to promote the flow of lymph, for in this way we can influence the nutrition of the entire body. Consider, for instance, the case of the brain. The more active the breathing, the more rapid is the flow of cerebral lymph, and when we consider that by means of suitable respiratory movements we can also hasten the return of the cerebral blood, it is clear that we have at our command a ready means of massaging the brain. Bearing upon this subject is the observation of a German writer, who says: 'Rise from your table, take deep inhalations, move your arms in rhythm with them, and your ideas are clarified and your conclusions become logical.'*

These considerations led me to expect that much good might be done by respiratory exercises in functional nervous diseases, and such I have found to be the case.†

The movements of respiration further promote the flow of lymph in the pericardium, heart, and chest-walls.

* *Brit. Med. Jour.*, 1895, vol. i., p. 93.

† See Chapter XXIV.

CHAPTER XVI.

PHYSIOLOGICAL MODIFICATIONS IN THE RESPIRATORY MOVEMENTS.

We have seen that the respiratory movements have wide-reaching effects: that while primarily serving for the inflow and outflow of the breath, they also profoundly influence the circulation of blood and lymph, and further, by rhythmical compression and dislocation affect the functions of the abdominal and pelvic viscera.

Such being the case, the various modifications in respiratory movements become of interest, and demand our careful study. These modifications may be physiological and pathological. I shall deal first with the former.

The respiratory movements are diminished in depth and frequency during sleep and when the attention is deeply engaged, and probably in both cases, but certainly in the former case, the mean thoracic capacity is diminished. On the other hand, muscle-exercise tends to increase their depth and frequency, and to augment the mean capacity of the chest. The respirations are also modified in coughing, vomiting, and during muscle-effort, in all of which intra-thoracic pressure is increased and the wonted respiratory rhythm interfered with. The rhythm is also modified, and intra-thoracic pressure increased, though in a less degree, in shouting, singing, crying, yawning.

Diminution in the Frequency and Depth of the Respiratory Movements.—The blood normally tends to accumulate in the splanchnic veins during sleep, but the peculiar condition of the respiratory system at that time also favours its accumulation in the right heart and systemic veins. The mere diminution in the frequency and depth of the breaths probably does not directly interfere with the circulation, since the respiratory movements in tranquil breathing do not appreciably augment the flow; but this diminution possibly does, by favouring dyspnœa, impede it indirectly, especially when, from heart or lung disease, there is a tendency in that direction. Not only, however, are the respiratory movements shallower and slower during sleep than during the waking state, but the mean size of the chest is diminished, and this diminishes not only the respiratory area, but pulmonary suction also, thereby lessening an important aid to the circulation.

This tendency for the circulation to stagnate during sleep helps to explain the frequent occurrence of dyspnœa at night-time. In cases of pulmonary engorgement from mitral disease, for instance, the respiratory movements are, during the waking state, voluntarily amplified, while the mean thoracic capacity is increased, the tendency to engorgement being thereby diminished. During sleep, however, this voluntary help is not forthcoming, and the respirations becoming comparatively quiescent and the chest capacity diminishing, it is not surprising that the patient should be at times awakened by dyspnœa. The best way of guarding against this difficulty is to instruct him to take several deep breaths before sleep and whenever he awakes.*

* 'The sufferer from dilatation constantly supplements his reflex respiration by voluntary deep breaths.'—Sir William Broadbent.

'Take away the necessity for the voluntary effort indispensable to

When the mind is deeply absorbed, the respiratory movements are inhibited—they may, indeed, be temporarily suspended, as, for instance, during the 'breathless attention' that awaits the announcement of some momentous news or follows the course of an interesting narrative. More frequently, however, the breathings simply become slower and more shallow than usual. In such cases the defective respirations are apt to be interrupted ever and anon by a long sigh, which not only makes up for arrears in blood-aeration but helps to unload the engorged right heart. There is, therefore, some physiological foundation for the old saying that 'with every sigh a drop of blood leaves the heart.'

All patients with mitral trouble, but especially those engaged in close intellectual work, should be warned against this tendency to shallow breathing during deep attention.

Increased Frequency and Depth, and Altered Rhythm from Muscle-Exercise.—Muscle-exercise causes an acceleration and deepening of the respiratory movements, and an increase in the mean thoracic capacity, these effects being due to alteration in the blood bathing the respiratory centres, to deficiency of oxygen, and to excess of carbonic acid and certain unknown muscle-excreta.

As the breathlessness of muscle-exercise becomes pronounced, expiration tends, as we have seen, to become shorter than inspiration. The individual experiences an increasing difficulty in adequately emptying his lungs. Hence, especially in the untrained runner, expiration is apt to be unduly restricted. This evil, as well as the tendency to breathe too rapidly, may be corrected by training.

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respiration (in certain cases of bronchitis), and the patient would soon be so sound asleep it would be difficult to wake him: suspend the voluntary effort by an opiate, and the sleep is the sleep of death.'—Hyde Salter.

After exercise, respirations resume their average rate before the heart-beats.

The breathlessness induced by muscular activity is in direct proportion to the amount of work done in a given time, and is due to the blood-changes thereby induced, these being more pronounced the greater the amount of work. The more adequately the individual breathes during active exercise, the less is the breathlessness, whereas muscular efforts which lead to fixation of the chest cause great breathlessness.

The augmented activity of the respiratory movements consequent upon muscle-exercise, favours the exhalation of CO_2 and the absorption of O, the increased muscle-metabolism leading to a greater production of the one and a greater demand for the other, while the increase in the mean size of the chest and the altered rhythm favour the transit of blood through the lungs.

Modifications in the Respiratory Movements leading to Augmented Intra-pulmonary Tension.—Such modifications occur in talking, shouting, singing. These and kindred acts are considered in the following chapter. Here I shall refer only to those acts which cause considerable augmentation of pressure within the lungs.

In coughing, and to a less extent in sneezing, the lungs are suddenly compressed by the contracting chest, and the free escape of air being impeded, intra-pulmonary tension rises. During the expulsive phase of vomiting, the glottis is completely closed, and the lungs may be compressed with very great force. In both coughing and vomiting, especially the latter, there is considerable compression of the abdominal veins from contraction of the abdominal muscles, and the blood is in consequence squeezed out of them towards the right heart. On the other hand, the circulation through the lungs is impeded owing to the heightened intra-pulmonary tension. Hence these acts engorge the right heart, and conduce to dilatation of its cavities. We should therefore use every endeavour to diminish the tendency to them, especially to paroxysmal coughing, which is, unfortunately, only too common in heart disease. An attack of vomiting not infrequently gives the last blow to a failing heart. Both in syncope and shock the blood tends to accumulate in the abdominal veins, and it seems probable that the vomiting which sometimes accompanies these conditions may do good by driving the blood thence into the right heart.

The essential features of cerebral concussion are loss of consciousness and shock, the pulse being very feeble and rapid and the patient blanched. Now, it is well known that the stage of 'reaction,' or return to a more active circulation, is ushered in by vomiting. Sir William Savory used to teach in his lectures that the vomiting did good by directly stimulating the heart, but it seems much more probable that it benefits by compressing the great splanchnic veins and thus replenishing the right heart, the inability of which to drive the proper quantity of blood through the lungs is not due to any primary failure of its own, but to dearth of blood-supply.

Muscular 'effort' causes fixation of the chest, generally in the position of inspiration. Thus, in straining at stool, a preliminary inspiration is taken, and the glottis being closed, the abdominal muscles contract, and, as a result, not only the abdominal but the thoracic contents are compressed, for it must be remembered that the abdominal muscles are powerful expirators. Hence, the circulation is affected very much as in coughing and vomiting, the blood being squeezed out of the portal system and inferior cava into the right heart, while its passage through the lungs is greatly impeded.

This fixation of the chest tends to occur whenever the large muscles attached to it are called upon to make powerful contractions, the object being to provide fixed points of attachment, without which they would act at great disadvantage. Thus, in lifting a heavy weight on to the shoulders, fixation of the thorax facilitates the action of the deltoids, pectorals, and other muscles more immediately engaged in the process; while it also facilitates the action of the muscles occupied in maintaining equilibrium and in rendering the vertebral column rigid—above all, the great muscles of the back and of the anterior abdominal wall, which will be found to be powerfully contracted. Free movement of the chest is, indeed, quite impossible under the circumstances. This remark applies as much to the muscular floor as to the bony walls of the chest, for it is impossible for the diaphragm to descend when the anterior abdominal muscles are powerfully contracted.

It follows that in all powerful efforts it is necessary to fix the chest, and it will generally be found fixed in the position of inspiration. Why is this? One great advantage is that a deep inspiration secures an extra supply of oxygen to compensate for the failure of supply during the period of fixation. Another advantage lies in the diminished resistance to the pulmonary flow afforded by the expanded lungs, this being especially serviceable at a time when the pulmonary circulation tends to be obstructed by a very high intra-pulmonary tension. (It would not be surprising if it were discovered that the pulmonary vessels undergo a vaso-motor dilatation at the same time, in order further to facilitate the pulmonary flow.)

In the act of defæcation a full *diaphragmatic* inspiration is taken. This is manifestly for the purpose of increasing intra-abdominal tension. In most cases of effort, however, it will be found that the chest is fixed in *costal*, not diaphragmatic, inspiration. More than one advantage attaches to this. In the first place, more breath can be taken in by a costal than by a diaphragmatic inspiration. Again, descent of the diaphragm would have the disadvantage of unduly augmenting intra-abdominal tension during effort: with the diaphragm low, and the glottis closed, a sudden and violent contraction of the abdominal muscles might cause such an increase of tension within the belly as to lead to hernia, not to mention lesser evils, such as the discharge of fæces. It is possible, also, that the abdominal muscles, especially the recti, can act to greater advantage in maintaining equilibrium when the ribs are raised and the origins and insertions of these muscles thus more widely separated than when they are low.

The greater the resistance to be overcome the more powerful is the contraction of the balancing muscles and the greater the instinctive desire to fix the chest. Even the comparatively gentle 'resisted movements' employed in the treatment of heart disease are sufficient to fix it. The tendency is less in carrying than in lifting weights, but in violent spasmodic efforts, as in jumping and in wielding the sledge-hammer, the chest is almost invariably fixed; in hundred-yards' sprinting it is by some fixed during the entire race; mountain-climbing, also, is liable to cause its temporary fixation.

That *fixation of the chest with partially or completely closed glottis interferes with the circulation, is a fact of great practical importance.* It shows that fixation should be avoided as far as possible, and especially by those with heart or lung disease. A farther reason for its avoidance is that it tends to stretch the alveoli, and thus to diminish pulmonary elasticity.

Hence it is that in the various exercises which we prescribe we are careful never to allow the breathing to stop.

During 'resisted movements,' for instance, we direct the patient to continue to breathe steadily all the time, and in order to ensure this it may be necessary to make him count aloud. Similarly, we must warn him never to fix the chest when using the dumb-bells. If the glottis is closed while the dumb-bells are being energetically employed, an unconscious expiratory effort is sure to be made, and thus while strengthening the muscles of the arm and chest we may be damaging the lungs and interfering with the circulation.

CHAPTER XVII.

NORMAL MODIFICATIONS OF THE RESPIRATORY MOVEMENTS (*continued*): TALKING, SHOUTING, SINGING, COUGHING, CRYING, SIGHING.

The respiratory movements are liable to constant modification in the physiological acts of talking, shouting, singing, laughing, crying, sighing. These acts are more far-reaching in their effects than would at first sight appear. Not only do they affect the body by modifying the respiratory movements and thus producing the effects already mentioned, but by involving the expenditure of a considerable amount of neuro-muscular energy, and by inducing definite psychic phenomena which themselves have their physical accompaniments. In brief, any one of these acts, *e.g.*, singing, causes (*a*) a modification in the circulation of blood and lymph, (*b*) an alteration in the functions of the abdominal and pelvic viscera; and further leads to (*c*) a considerable discharge of nerve and muscle energy, and to (*d*) numerous changes (muscular, glandular and other) throughout the body, in consequence of the attendant psychic change.

Seeing, then, how far-reaching are the effects of these several acts, and remembering how large a part they play in normal life, we may safely conclude that they influence the functions of the body beneficially, and that an undue interference with them is injurious. One is apt to forget how strong is the instinct to shout and sing, laugh and cry. It is especially noticeable in the savage and in the child. If this instinct is unduly repressed in the child, it is sure to suffer. Crying should certainly be restrained within limits, but there can be no doubt that it is primarily physiological, not only favouring the proper expansion of the lungs and accelerating the circulation, but deadening the effects of pain and relieving nerve-tension (especially in women).

Rosbach thinks it not improbable that many evils which manifest themselves in later life, such as chlorosis, contracted chest, and the phthisical habit, may take their origin in the practice of mothers ‘stopping their infants from screaming by soothing them to sleep in their arms, or by stupefying rocking in the cradle.’*

It is well known that children show a strong instinct to chatter and sing the first thing in the morning, and it should be allowed full vent, as far as is practicable. The shouting which young people indulge in during their play is quite remarkable, and is manifestly physiological. The same tendency to shout is observed in young adults, especially among the poorer classes, in holiday time. Though from the physiological point of view justifiable and even beneficial, the noises they make are certainly not always pleasing, especially to the over-sensitive nerves of the cultured, among whom this instinct is consequently suppressed, though whether altogether to the gain of the individual is questionable.

The various acts referred to will now be considered individually.

Talking. — As regards the psychic aspect of talking, thought becomes much more vivid if it finds expression,

* Von Ziemssen's ‘Handbook of General Therapeutics,’ London, vol. iii., p. 581.

whether in speech, writing, music, or artistic production, than if it remains unexpressed. The physical effects of thought are more pronounced in talking than in writing. The cortical nervous discharges underlying it send a stream of energy towards the muscles involved in speech and gesture, and both voice and gesture can be modified to convey subtle shades of thought and feeling which cannot find expression in writing. The very expression of these subtleties enhances the vividness and intensity of mentation. Talking is for this reason stimulating, and its influence in this respect is, in a measure, proportional to the gesture accompanying it. Few things are more calculated to stimulate the body, to rouse it from lethargy, than 'animated' conversation.

In talking, as in laughing, shouting, singing, and crying, inspiration is short while expiration is prolonged, the exit of air being checked partly by obstruction in the glottis and partly by the action of the inspiratory muscles.

The actual amount of work done in talking is far more than might at first sight be supposed, and should always be taken into account in reckoning up the quantity of 'exercise' taken during the day. The talking done by barristers, politicians, teachers, and others, enables them to dispense largely with exercise as ordinarily understood. For not only do they in this way expend a considerable amount of muscle energy, but they experience the manifold advantages of active respiratory movement continued for long periods together. Indeed, I believe talking to be distinctly conducive to longevity.

That talking involves a considerable expenditure of energy is shown by the exhaustion which it induces in those who are nervously run down. Such are often greatly exhausted even after a moderate day's talking. This exhaustion is due to mental as well as to muscle expenditure. Indeed, in the very neurasthenic the bare process of thought may be an effort, and the mere effort to think may alone cause exhaustion ; and if such is the case, how much more likely is the putting of thought into speech to do so, seeing that, apart from the muscle expenditure involved in speech, thought is so much more intense when spoken than when unexpressed.

Talking may be classified under the heads of colloquial speech, public speaking, and recitation, under which we may include reading aloud. In all three the breathing should be as much as possible of the lower thoracic type. The amplitude of respiratory movements required in colloquy is much less than that needed in public speaking and recitation, in both of which it is necessary to make the voice travel a considerable distance, and it is for this very reason that they constitute very effective respiratory exercises. Broadbent has remarked upon the beneficial influence of preaching in heart disease. The good effect is here doubtless due to the increased amplitude of the respiratory movements, and to the help thus afforded to the pulmonary circulation. It is for this reason that I always encourage talking in those suffering from passive engorgement of the lungs.

The breathlessness due to dilatation of the heart 'is often relieved,' observes Sir William Broadbent, 'by exercise of the voice. I have met with numerous instances in which a clergyman has climbed into the pulpit with the utmost difficulty, and has not only preached a sermon comfortably, but has been all the better for it.'* The good result, I take it, in these cases, is attributable to the deep inspirations necessitated by the loud voice required to fill a large building.

* See letter by the writer, *Lancet*, 1891, vol. i., p. 798.

For those not engaged in public speaking, and in whom it is hopeless to attempt to cultivate the singing voice, I recommend recitation, and, if that does not seem practicable, simple reading aloud. I believe that all, save the mentally deficient and those having some serious defect of speech, are capable of being taught to recite fairly well, but a belief to the contrary being deep-rooted in some, we may be unable to persuade them to learn. In such cases we can generally get the patient to read aloud a quarter of an hour, or ten minutes, every day. In reading, the individual should stand, and the book should either be supported on a rest a little below the level of the head, or it should be held out at arm's length at the same level, the voice being directed above the book. This should never be allowed to rest with its lower edge against the chest, as is the custom with some clergymen at certain parts of the service.

Voice-production should be taught by a competent teacher. It is well to inspire as much as possible through the nose, especially in speaking in crowded assemblies. The vast importance of breathing through the nose whenever possible, has been so much insisted upon of late years, especially by throat and nose specialists, that it needs no further insistence here. It is now fully recognised that habitual mouth-breathing is productive of untold evils, and that any obstruction to adequate nose-breathing should be promptly removed.

Shouting.—The psychic accompaniment of shouting is essentially emotional. Emotion is not only expressed but sustained, and indeed intensified by it. Thus the shouting of children at play, itself the outcome of exuberant emotion and pent-up neuro-muscular energy, enhances the emotional outburst. In like manner, the hurrahs of an applauding multitude, the cry of the huntsman, the war-whoop of the savage, the yells of an attacking force, may so exalt emotionality as to induce a condition bordering upon ecstasy.

A further effect of shouting is to dull sensibility, the emotional exaltation which it provokes and the voluminous discharge of neuro-muscular energy accompanying it, inducing a corresponding depression in the sensorial sphere. It is on this principle that groaning, and still more the shriek of acute agony, brings relief; the mere sound produces a similar effect by violently energizing the acoustic centres.*

The shouting and gesticulation which accompany an outburst of passion act physiologically by relieving nerve tension, and indeed, as Hughlings Jackson has suggested, swearing may not be without its physiological justification. Passionate outbursts are generally succeeded by a period of good behaviour, and, it may be, improved health. One frequently notices this in children, and I have also noticed it in the adult. It is possible that the outbursts of irritability observed in disease, as for instance in gout, have their physiological as well as their pathological aspect.

As regards the modifications in the respiratory movements caused by shouting, the important practical point to notice is that they are increased in depth. Hence, shouting favours the development of the lungs and accelerates the circulation of blood and lymph.

Singing.—Singing, like shouting, is more emotional than intellectual, the degree of emotion called forth depending upon the extent to which the individual throws himself into the spirit of the song. The nature of the attendant emotion varies, of course, considerably, and there is a corresponding variability in its physical correlatives. If

* A famous quack extracts his patients' teeth to the blare of trumpets and the boom of a big drum.

the theme of the song be joyous, the proper rendering of it is highly stimulating.

In singing there is a great disproportion between inspiration and expiration, the latter being much the longer. Moreover, during these long expirations, the glottis is constricted, and the free egress of air thus being prevented, ntra-pulmonary air-tension rises, and consequently the flow of blood to and from the right heart is impeded; but this temporary retardation of the blood-flow is reduced to a minimum by the expert singer, whose notes flow out without appreciable effort, and is more than compensated for by the acceleration which takes place during the succeeding deep inspiration. The obstruction at the glottis increases as the scale is ascended, and seeing that the expiratory force employed in the delivery of the upper notes is, for the most part, greater than that employed in the production of the lower, it follows that high singing, especially if fortissimo, impedes the circulation more than low singing.

I am not as a physician greatly concerned with the method of breathing employed, provided it be not the exaggerated collar-bone type, which I emphatically deprecate. On the whole, I am inclined to recommend the costo-abdominal type. It should be observed that when the diaphragm is actively used, the effect on the abdomino-pelvic viscera is greater than is otherwise the case.

From the medical standpoint singing is a most important exercise, both by virtue of its influence on the emotions, on the respiratory movements, and on the development of the lungs. Nothing better shows the beneficial effect of singing in developing the chest and warding off lung disease than the great pulmonary development and freedom from pulmonary disease among professional singers. Their general health is, moreover, exceptionally good, and this is probably in large measure attributable to the mere exercise of their calling.* Such therapeutic importance do I attach to singing that I recommend it wherever opportunity affords. It is especially useful in defective chest development and in chronic heart disease. Provided the patient can sing with comfort, I know of no condition in which singing is contra-indicated, unless it be a tendency to tubercular or aneurysmal hæmoptysis. It is scarcely necessary to say that the singer should be so clad as to allow absolute freedom of the chest-movements: there should be no constriction of the neck or waist, the collar should be low and ample, the stays (if worn) pliant and loose.

Oertel speaks enthusiastically of the beneficial influence of singing on the general health, and especially on the lungs, and he refers to the fact that almost all eminent singing-masters can tell of serious cases of lung disease which have been cured by their particular method of singing. He thinks there can be no doubt that weak chests of various kinds can be greatly improved by it, and he would even appear to include phthisis. 'In consequence of the reports sent in from various quarters on the healthy influence of singing on the respiration and circulation, and on the strengthening and nutrition of the lung, the practice of singing has been introduced even into prisons, in order to antagonize pulmonary consumption, which generally develops in a short time among the convicts. The method of singing devised by Fried. Grell is especially adapted for our national schools, and ought to be generally introduced, like gymnastics, from a sanitary point of view.'†

The invigorating effect of singing is well shown by the

* The splendid chest development of public singers is, of course, not entirely attributable to the constant exercise of the voice, since no one can attain a high excellence without having a good chest development in the first instance. It must also be observed that every singer who attains to fame is careful to lead a healthy life.

† Von Ziemssen's 'Handbook of General Therapeutics,' vol. iii., p. 583.

following extract from a daily paper: 'The Artists (Volunteers) have a collection of marching choruses which are peculiarly their own, and from long practice they are able to get every ounce of effect out of them. This system of singing is one which helps many men to keep going when they have no band to back them up, and it is astonishing to see the change in the bearing of the men when, perhaps towards the end of the day, and they are a bit done, someone strikes up a song with a rousing chorus. The lagging steps become elastic, backs straighten up, and with a soldierly swing the men go on, and forget for the while that they have a blistered heel or the uncomfortably heavy equipment.'

Laughter.—The psychic accompaniment of laughter being joyous emotion, its effect is stimulating, and it has been truly said that the man who makes us laugh is a public benefactor. Its beneficial effect on the body is illustrated in the saying, 'Laugh and grow fat.' The expiratory act in laughter is greatly prolonged, and the glottis being partly closed, intra-pulmonary tension is increased, and thus in excessive laughter there may be considerable impediment to the flow of blood through the lungs, as shown by the turgid head and neck. This disadvantage—for in most cases of heart-disease it is a disadvantage—is far more than compensated for by other effects, foremost among which must be reckoned the deep inspirations which separate the individual paroxysms.

Crying.—In thinking of the term crying, one must distinguish between the mere shedding of tears and the weeping accompanied by sobbing. In the one the effects are limited, while in the other the entire body may be violently convulsed.

I have already referred to the beneficial effects of crying in children.

The crying of the infant is peculiar. Expirations are prolonged, sometimes for as much as half a minute, and are interrupted by short inspirations. During the expirations the glottis is contracted, and the intra-pulmonary pressure rises considerably. Not only is the pulmonary circulation thereby greatly impeded, as shown by the swollen veins of the head and neck, but bronchial mucus, flatus, and other noxious matters are evacuated. The paroxysm is succeeded by rapid deep respirations, which restore the equilibrium of the circulation. Women, likewise, often derive benefit from 'a good cry'; the profuse flow of tears lessens blood-pressure within the cranium; the voluminous discharge of nerve-energy relieves nerve-tension; the sobbing movements of respiration influence in a very decided and doubtless beneficial way the circulation and the movements of the abdomino-pelvic viscera; while the widespread contraction of the muscle system has probably also a good effect. How pronounced are the dynamic effects induced by completely abandoning one's self to a fit of crying is shown by the exhaustion which it entails. It is, perhaps, partly through this exhaustion that crying induces sleep—we hear of 'crying one's self to sleep'—though this must be but a very crude explanation of the phenomenon.

The tendency of women to cry should, of course, be kept within proper bounds, but certainly harm may result from its complete suppression, as Tennyson recognises in the line, 'She must weep or she will die.' (It is said that women who are able to find relief in tears keep their youth longer than those who repress them.) The cankering action of a long-continued pent-up emotion has been likened to a 'worm i' the bud.' This is no mere poetic conceit, but expresses a profound physiological truth. In short, strong emotion should find expression. 'Give sorrow words.'

The sigh of syncope is comparatively rare. A much more common cause of sighing is shallow breathing, however induced. Thus, sadness and a sense of weariness or boredom are wont to be attended by shallow breathing, and in all of them sighing is frequent. In consequence of this shallow breathing blood-aeration lags behind, and the blood tends to accumulate in the right heart and systemic veins. The sigh benefits by promoting the aeration of the blood and by quickening the pulmonary circulation. It is for similar reasons that sighing is apt to occur during 'breathless attention'—when the attention, *i.e.*, is so strained that one forgets, as it were, to breathe adequately.

Yawning.—It is difficult to describe accurately this act. A deep and prolonged inspiration is taken through the mouth and nose, the mouth being widely opened and the nares dilated. The opening of the mouth is effected by a strong tonic contraction of the depressors of the lower jaw, and by the extension of the head and consequent elevation of the upper jaw. At the same time the limbs and trunk are 'stretched.' There is, in short, a wide-spread tonic contraction of the muscle system. This continues, and indeed reaches its climax, during the expiratory portion of the act, the mouth being kept open till towards the end of it. The expiratory current is directed solely through the mouth owing to elevation of the soft palate, and the vocal cords approximate, a characteristic sound being produced in the larynx, while there is a peculiar contraction of muscles at the back of the throat, the nature of which I do not understand.

There can be little doubt that one of the objects of yawning is the exercise of muscles which have been for a long time quiescent, and the acceleration of the blood- and lymph-flow, which has in consequence of this quiescence become sluggish. Hence, its frequency after one has remained for some time in the same position, *e.g.*, when waking in the morning. Co-operating with this cause is sleepiness, and the shallow breathing which it entails. This factor, as well as muscle-quiescence, is apt to attend the sense of boredom. Hence it is that the bored individual is apt to yawn. As in the case of sighing, the deep breath which attends the act of yawning compensates for the shallow breathing which is so apt to excite it.

I am unable to offer any explanation of the yawning, or rather gaping, which is induced by exhaustion from want of food. This mere gaping is, however, quite distinct from yawning, which is a much more complex phenomenon.

Allied to yawning is a modification of the breathing which is apt to occur during sleep. A deep breath is taken more or less suddenly, and this is followed by a long - drawn - out expiration with partially closed glottis, accompanied by a groaning sound. This kind of breathing has certainly some physiological import, but what it is I cannot say.

CHAPTER XVIII.

IMPEDIMENTS TO THE RESPIRATORY MOVEMENTS.

Defective expansibility of the lungs is a potent cause of restricted respiratory movements, and since all diseases of the lungs diminish this expansibility, they all curtail the respiratory movements. Phthisis, emphysema, and pneumonia are instances in point. Effusions into the pleura and pleuritic adhesions also limit pulmonary expansion, the latter by interfering with the movement of the lungs within the chest.*

Affections of the heart, pericardium, and aorta may likewise impede the movements of respiration. Amongst these may be mentioned pericardial effusion, agglutination of the heart to the chest-wall, aortic aneurysm, and enlargement of the heart. The latter produces its effect by encroaching upon the lungs, and in a child especially, this encroachment may be considerable.

It will be convenient to consider the impediments to costal and diaphragmatic breathing individually.

Impediments to Costal Breathing.—(*a*) The intra-thoracic diseases above referred to. The limitation of costal breathing thus induced tends to be most marked in those ribs

* John Hutchinson (*op. cit.*) refers to a case in which post-mortem examination disclosed complete adhesions of both pleuræ, and in which the vital capacity during life was above the average. It is difficult to explain such a case.

which overlie the disease. Thus, in phthisis the impaired movement may involve one apex only, and in enlarged heart and distended pericardium it may be confined to the superjacent ribs, costal cartilages, and sternum.

(*b*) Changes in the thoracic wall. Among these may be mentioned pleurodynia, disease of the ribs and contiguous parts, such as fracture of the ribs, or of the arm, and inflammation of the axilla, in all of which the limitation may be unilateral. After amputation of one arm, the motion of the ribs on the same side is restrained.

Lateral and angular curvature materially interfere with costal movement, especially the latter, and it is for this reason that subjects of angular curvature are so prone to pulmonary disease and to dilated right heart.

Obesity, especially in the woman, may hamper costal breathing, for though the ribs may glide up and down under the overlying fat, this has, in some degree, to be lifted, especially in the upright position of the body.

Rigidity of the chondro-osseous cage also interferes with costal breathing, and, as we have seen, this rigidity increases with age. Hence, altogether apart from the loss of pulmonary expansibility which takes place with advancing years, there necessarily occurs a diminution in the extent of costal movement; and it is not always easy to say how far thoracic immobility in the aged is due to senile rigidity, and how far to defective pulmonary expansibility.

(*c*) Affections of the muscle-system. Weakness of the muscle-system, whether from fever, chronic wasting disease, or what not, tends to render costal breathing sluggish. Hence the advantage of a well-developed muscle-system in facilitating costal movement. Oertel believes that the beneficial effect of mountain-climbing in heart-disease is largely due to its influence on the respiratory muscles, and I have no doubt that such is the case.

(*d*) Abdominal conditions. The movement of the lower ribs may be restricted by peritonitis, ascites, abdominal tumours, etc.

(*e*) Posture. The ribs cannot move as freely in the horizontal as in the vertical posture.

(*f*) Unsuitable clothing. It would be difficult, if not impossible, to devise any kind of dress which would leave the respiratory movements absolutely unembarrassed. The two objects to be aimed at are lightness and looseness. There should be a minimum of weight on the shoulders and chest, and sufficient looseness to admit of the fullest possible chest expansion—that is to say, the measurements should be taken, not while the chest is in a state of mean expansion, but during extreme inspiration. It is scarcely necessary to say that these requirements are practically never complied with. In women the bodice is often made to fit the chest tightly, like a glove, the measurement across the chest *being several inches less than it should be.* This was especially the case a few years ago, when it was the fashion for women to be flat-chested; and even to-day it is, I am told, well-nigh impossible to get a fashionable dress-maker to allow ample room across the chest, although the increasing prevalence of bicycling is undoubtedly leading to an improvement in this respect.

A special evil to be guarded against is the accurate fitting of the chest garments to a misshapen chest. Suppose, for instance, that a coat or bodice is accurately fitted to a stooping figure, it is clear that any attempt to straighten the body and expand the upper part of the chest will be hampered by the clothes.

In the endeavour to minimize the evils arising from the weight of the clothes, they must not only be made as light as possible, but regard must be had to the points from which they are suspended. 'Children, especially girls, have to wear stockings, and to keep these stockings up an elastic suspender is attached, this being fastened either to a light, stiff jacket or a corset, which is kept up by shoulder-straps over the shoulders. Then, other articles of clothing are also kept up, more or less, by shoulder-straps, and these straps are not placed close to the neck, where they would be less harmful, but to the apices of the shoulders, where they constantly tend to bear the latter downwards and forwards, giving rise to stooping shoulders and to a poking head, depressing the chest, and acting as a constant source of irritation to the wearer.'* To be ideal the clothes should be partly suspended from the hips and partly from the shoulders, the attachment being in the latter case close to the neck.

The injurious effect of heavy accoutrements on costal breathing is sufficiently manifest.

I have reserved to the last the effect of the corset in restricting the movements of the ribs. Even the most pliant and loose stays, such as Jaeger's, though permitting ordinary breathing, prevent full thoracic expansion, and ordinary stays are practically always tightened up somewhat—their very name implies this—and they are decidedly tight to many who would not be regarded as tight-lacers. Unless the hand can, without being in the slightest degree compressed, be placed beneath them during the fullest costal inspiration, it is clear that they must interfere with the expansion of the lower chest. As a matter of fact, the thorax of all corset-wearers is distorted, the lower part of the chest being unduly contracted and immobile, and the upper part unduly expanded and mobile; so that no woman who has habitually worn stays can be employed as an undraped model.

We may here stop to consider the evils of tight-lacing in

* Noble Smith, *Clin. Jour.*, February 27, 1895.

a general way. The practice interferes with the movements of the diaphragm as well as of the ribs, with several evils as a result. (*a*) Respiration is diminished. (*b*) One of the most important accessory forces of the circulation is interfered with, the blood being no longer sucked and squeezed out of the large veins into the right heart with the normal force. (*c*) The respiratory area being diminished, the resistance opposed to the right heart is increased ; as a consequence, dilatation of the right heart is favoured, pressure in the pulmonary circuit rises, and there is accentuation of the second sound. This I find very frequent in women. (*d*) The limitation of diaphragmatic movement interferes with that rhythmical compression and dislocation of the abdominal and pelvic viscera which are intimately bound up with the normal carrying on of their functions. The worst indictment has yet to come : (*e*) The compression of the abdominal vessels drives the blood which they should contain into other parts of the vascular system, and arterial pressure and the work of the heart are, in consequence, augmented. The effect on the heart is, in fact, the same as that which would be produced by increasing the quantity of blood in the body.* (*f*) Stays also induce atrophy of the muscles of the chest, back, and anterior abdominal wall, and it is largely on this account that pendulous belly, with its many secondary evils, is so common in women.† Were stays never worn, and were the abdominal muscles properly exercised, this affection would be seldom met with.

It is not surprising that women, and even sensible ones, should defend the use of stays. Their chief argument is that 'the figure requires support,' that 'they feel the need

* Roy and Adami have shown that pressure on the abdomen may increase the work of the heart by 30 per cent. *Brit. Med. Jour.*, 1888, vol. ii., p. 1321.

† See Chapter II.

of support.' Precisely. This need is inevitable when the muscles of the chest, back, and abdomen are imperfectly developed, as they cannot fail to be when stays have been habitually worn. The corset, in short, creates the demand which it supplies.

It is only among the obese that the physiologist can sanction the use of stays, and then merely as a temporary and remedial measure. When the abdominal walls are very flabby the firm support of the corset may render service by keeping up intra-abdominal tension, and thus preventing an undue accumulation of blood in the splanchnic veins, and also by enabling the diaphragm to play its proper part in promoting the abdominal circulation (see p. 90). Exercises calculated to develop the abdominal muscles will, however, enable the woman to dispense with this artificial support after a time, longer or shorter according to the extent of the mischief.

Now, if tight-lacing is harmful even in the normal individual, how much more so must it be in the diseased, above all, in sufferers from cardiac and pulmonary disease. The only wise course for such is to discard stays altogether. Even loose stays are hurtful in their case, for it is impossible to get them so loose as not to hamper the respiratory movements; and yet I have over and over again examined women with severe heart-disease who laced tightly. I can recall one young woman with a pre-systolic mitral murmur who was suffering as much from constriction of the waist as of the mitral orifice.

When we consider the evils of tight-lacing, the wonder is that it can be continued for any length of time without leading to fatal results. It must, however, be remembered that stays are only worn during a portion of the twenty-four hours; that during that portion they are not always tightened up to the extreme limit; and that when they are loosened (above all, when they are removed) the breathing becomes more natural again, the circulation tending to readjust itself. I have satisfied myself that even in extreme tight-lacers the diaphragm acts freely in the horizontal position after the stays are removed. Further, we may reasonably assume that some provision is made in the woman against impediments to diaphragmatic descent, seeing that such normally exist during pregnancy. Finally, there is the fact that an individual rarely lives up to his full physiological capabilities, and that there is normally a considerable pulmonary and cardiac reserve power. Were it not for this, tight-lacing would be impossible. A tight-lacer is not only compelled to curtail her activities, but she draws upon her entire reserve, and since the sufferer from heart or lung disease needs the full measure of reserve power, tight-lacing in her case is slow suicide.

Impediments to Diaphragmatic Breathing. — (*a*) Intra-thoracic disease. The extent to which the diaphragm is capable of moving is, of course, largely dependent upon the expansibility of the lungs. Thus in phthisis its movements may be greatly limited; also in emphysema, which may cause such flattening and descent of the diaphragm as, so it is said, to nullify completely its inspiratory power, though it is certain that in many cases of emphysema the work of inspiration is thrown almost entirely on the diaphragm, owing to the immobility of the ribs. Extensive adhesions of the lower portions of the lungs necessarily interfere with diaphragmatic descent, for if the lungs cannot move bodily downwards, they can only expand vertically by an excessive vertical stretching of the air vesicles.

Pleural and pericardial effusion may, of course, also impede diaphragmatic action. It should be observed that when the intra-thoracic disease is on one side, the movement on the corresponding side of the diaphragm is limited.

(*b*) Disorders of the diaphragm itself. The diaphragm may be paralyzed in diphtheria and spinal disease; it may share in the weakness of the muscle-system generally; it may be degenerated in typhoid and other fevers; also in emphysema, bronchitis, and heart-disease*; it may become inflamed in association with pleurisy and peritonitis; and it may be infected with trichinosis and malignant disease.

(*c*) Impediments referable to the abdomen. Acute peritonitis may cause the diaphragm to remain practically stationary. The abdominal muscles become tense in this condition, so as to protect the inflamed surfaces, and possibly also to oppose the descent of the diaphragm (Hutchinson). Their contraction, it should be noted, continues even during inspiration, thus opposing the action of the inspirators.

An enlarged liver does not generally impede the action of the diaphragm to any great extent, as this organ tends to increase in the downward direction. When a tumour occupies its upper part, it may be thrust upwards, and limit the action of the right half of the diaphragm. This is especially the case in hydatid of the liver.

Other abdominal tumours, such as a pregnant uterus, fibroid, ovarian cyst, or hydronephrosis, may interfere with the descent of the diaphragm; so also may obesity, flatulent distension, and ascites. These latter demand a special notice. They all three tend to thrust the diaphragm upwards, and thus to diminish the pulmonary area and dislocate the heart. That they should do this is not surprising, seeing that they cause a considerable increase of intra-abdominal tension, and that pulmonary suction is ever tending to draw the diaphragm upwards. They also necessarily offer a considerable obstacle to the normal flattening of the diaphragm during inspiration.

* Consult 'Virch. Arch.,' B. 73, s. 166-180, for an instructive article on 'The Degenerations of the Diaphragm: their Causes and Consequences.'

Although the movements of the diaphragm are restricted when the walls of the abdomen are overladen with fat, the restriction may be much less than one might expect. It is astonishing what resistance a powerful diaphragm is capable of overcoming. I have seen a belly as tight as a drum from excessive accumulation of fat and fluid rise an inch or more with every descent of the diaphragm, and this when the patient was moribund. In such cases the diaphragm must be greatly hypertrophied.

Since obesity restricts both costal and diaphragmatic movement, and at the same time curtails the respiratory area, it necessarily impedes the circulation, causing the blood to flow with increased difficulty through the lungs. Hence the tendency to hypertrophy and dilatation of the right heart in the obese,* and for the blood to be dammed back upon the great veins. The circulation being sluggish, and the respiratory action curtailed, the further formation of fat is favoured. Thus fat begets fat. Moreover, the circulation both of pulmonary and systemic blood being sluggish through the lungs, these organs are predisposed to inflammation, and it is for this reason that the obese are so liable to bronchitis. Acute bronchitis and pneumonia are very dangerous when they occur in the stout, on account of (*a*) their restricted respiratory area, (*b*) their restricted respiratory movements, and (*c*) their sluggish circulation.

These considerations prove the necessity of reducing the quantity of fat in the very obese. This is, above all, necessary in cases of pulmonary and cardiac disease. With me it is always a first consideration. I place the patient on a lean-meat diet, and under a graduated system of exercises. The beneficial influence of respiratory exercises and others

* Cohnheim has observed great hypertrophy of the right heart in association with extreme corpulence.

calculated to develop the abdominal muscles cannot be exaggerated.

Flatulent distension of the stomach and intestines is a recognised cause of breathlessness. Such distension not only impedes respiration and interferes with the action of the heart in the manner indicated, but causes a reflex disturbance of cardiac action. It is, indeed, especially in heart-disease that we should be on our guard against this condition. An over-loaded stomach may act in the same way. In such cases I am in the habit of giving the food in a very concentrated form.

In some cases it may be advisable to feed the patient for a time by the rectum alone. In so far as weakness of the abdominal walls predisposes to flatulent distension, exercises calculated to strengthen these muscles should be resorted to (see p. 160). Of drugs, turpentine is perhaps the most useful. It should be administered per rectum, or by means of a cloth applied to the belly. In extreme cases of distension puncture may be called for, or relief may be got by means of the rectal tube.

In all diseases of the heart and lungs we should strenuously guard against the accumulation of fluid in the peritoneum. It should be drawn off directly any distension of the abdomen is observed. No harm can result from the operation if skilfully performed, while many evils may result from its omission. Apart from those already mentioned, it is needful to remember that in pronounced ascites (and the same is true of extreme flatulent distension) the blood is expressed from the splanchnic veins into other parts of the vascular system, and the work of the heart thus increased. Further, the impediment to diaphragmatic action favours the ascitic accumulation, inasmuch as the diaphragm normally pumps the lymph from the peritoneum into the pleuræ. Indeed, it has seemed to me that ascites is rare when the diaphragm acts vigorously. I can recall the case of a man dying from cardiac failure in whom there was a great accumulation of fluid in the tissues, considerable enlargement of the liver, but no evidence of ascites. Now, in this man the breathing was almost confined to the diaphragm, which was acting with great vigour.

(*d*) Unsuitable clothing. Any constriction about the waist or compression of the abdomen tends to interfere with the free play of the diaphragm. The corset is, of course, the greatest offender in this respect. Nevertheless, it is astonishing to what extent the diaphragm can descend even with tightly-laced corsets.

CHAPTER XIX.

HYPEROXYGENATION OF THE BLOOD—DYSPNŒA.

Hyperoxygenation of the Blood.—In previous chapters I have shown how widespread and complex are the effects of the respiratory movements on the organism, and how profoundly therefore it may be influenced by respiratory exercises. One important effect of such exercises has yet to be mentioned—*i.e.*, their influence upon blood-oxygenation and upon the elimination of respiration excreta. By means of deep breaths we can produce a hyperoxygenation of the blood, and we can further the elimination of CO_2, and of the solid organic substances which are normally given off from the lungs, as well as of certain volatile toxines, and this without increasing in a notable degree the work done by the organism. It is probable that much of the good derived from respiratory exercises is referable to the changes thus brought about in the blood.

That the brain is profoundly affected by deep breaths is shown by their tendency to cause giddiness, and it is not a little remarkable that this tendency wears off in those who practise deep breathing regularly, proving that it must produce a lasting effect upon the organism. Some of these effects have been studied by W. Marcet, and I will now epitomize his observations.

The time during which an individual can sustain a voluntary muscle-contraction is determined by the endurance of the cerebral centres engaged in the act of volition rather than by that of the muscles themselves. Directly these centres are exhausted the muscle-contraction gives way.

This act of volition entails a considerable absorption of oxygen by the centres engaged in it, and the more the quantity of oxygen available for absorption, the longer can the voluntary effort be made without exhaustion of these centres, and the longer therefore the possible duration of the muscle-contraction.

After several deep breaths, an excess of oxygen is absorbed ; an unusually large quantity is thus available for the centres engaged in voluntary effort, and it is then possible to continue a voluntary contraction an unusually long time. Thus a given weight can be raised a greater number of times after a succession of forced breaths than ordinarily. To quote a specific instance—a man 'who after ordinary breathing lifted a weight of 4 lbs. 203 times in succession, after a rest and forced breathing for two minutes lifted the same weight the same height no fewer than 700 times.'

It is a remarkable fact that the mere act of volition—as when an individual in imagination directs his will towards lifting a heavy weight, or running to catch a train—causes an augmentation of respiratory movement, and an increase in the volume of air breathed.

Another fact of interest is that volition can be fatigued when exerted in imagination as well as in actual muscle-effort.*

In reference to the above observations, I would observe that Marcet seems to have fairly proved that deep breaths increase the power of sustained cortical action. This effect, I would suggest, may be due not only to the augmented supply of oxygen to the brain, but also to the increased elimina-

* 'The Croonian Lectures,' Lecture iii. (W. Marcet, M.D., F.R.S.), *Brit. Med. Jour.*, vol. ii., 1895 (p. 6).

tion of its waste-products, which are known to have a paralyzing influence on cell-activity, this increased elimination being brought about by an acceleration in the flow of blood and lymph, coupled with an augmented output of poisonous substances from the respiratory tract, without that extensive increase in the production of waste-products which happens when the deep breaths are produced by muscle exercise. But, whatever the explanation, the fact remains that deep breaths increase the power of sustained nervous effort, and it is perhaps owing to this that they are useful in cases of neurasthenia and as a means to increase will-power, a fact which I have myself independently observed.

Dyspnœa.—I have already pointed out that dyspnœa tends to cause over-action of the inspiratory muscles, and thus to increase the mean size of the chest (see p. 93). This is well shown by a simple experiment suggested by Wilson Fox: Let the breath be held at the end of a moderately deep inspiration, or let successive moderately deep inspirations be taken with imperfect expiration: it will be found that the tendency in either case is to recommence inspiration.* This shows that the need for a fresh supply of oxygen is more imperative than the need for removing the respiration excreta. The resulting expanded state of the lung benefits by increasing the respiratory area and by favouring the passage of blood from the right to the left heart.

The breathlessness induced by muscle-activity tends to make expiration shorter than inspiration (see p. 93), but in the breathlessness of disease, *e.g.*, in emphysema and asthma, the reverse is generally the case.

Cardiac dyspnœa is largely due to imperfect blood aeration

* 'Diseases of the Lungs,' by Wilson Fox, edited by Sidney Coupland, p. 158, *note*.

from failure in the circulation, but it is also in part due to nervous causes. Indeed, Alexander Morison maintains that the essential cause of cardiac dyspnœa is 'neither pulmonary congestion nor defective aeration, but a reflex transmitted from the stimulated heart to the accelerant fibres of the pneumogastric nerve,' an opinion shared by D. B. Lees.*

I would call especial attention to the breathlessness attending functional palpitation, 'flushes of heat,' and high arterial tension, as interesting clinical varieties.

Let us now consider the vascular phenomena observed in asphyxia.

There is first an aortic rise of pressure, followed by a gradual fall. The pulmonary pressure begins to rise with the aortic, but does so more gradually, reaching its maximum when the latter is falling. The pressure in the left auricle is little affected till the aortic fall begins, when it rises to a great height, remaining high till death.

These phenomena are interpreted by Bradford and Dean† as follows: The initial aortic rise is due to vaso-motor constriction of the systemic arteries; the final fall, to paralysis of the left ventricle. The latter cannot be due to emptiness of the pulmonary veins, since the pressure in the left auricle is actually increased;‡ nor is the rise due to systemic obstruction, for it occurs after division of the cord below the fifth dorsal nerves. It is largely due to vaso-motor constriction of the pulmonary vessels, for when the cord is divided below the medulla, thus cutting off the vaso-motor fibres to the lungs, the pulmonary pressure only rises 4 mm., whereas before the division the pressure is

* *Brit. Med. Jour.*, 1896, vol. i., p. 661.

† *Jour. Phys.*, vol. xvi., Nos. 1 and 2.

‡ This opinion harmonizes with Cohnheim's, who attributes the final pulmonary œdema of asphyxia to paralysis of the left ventricle, which he avers ceases to beat before the right. 'The Pathology of the Circulation,' vol. i., p. 528.

actually doubled. Bradford and Dean suggest that this slight rise is due to the direct action of the venous blood on the pulmonary arterioles, but I think we can better explain it by reference to the cessation of the respiratory movements, which normally aid the pulmonary circulation.*

Sir George Johnstone believes that contraction of the pulmonary arterioles constitutes the essential vascular phenomenon of asphyxia. To this he attributes the engorgement of the right heart and systemic veins, and the emptiness of the left ventricle. It is difficult to harmonize this view with the fact pointed out by Bradford and Dean, that there is a great rise of pressure in the pulmonary veins in dyspnœa.

* Bradford and Dean induced the asphyxia in their experiments by causing a 'cessation of artificial respiration in curarized animals after division of both vagi.'—*Op. cit.*, p. 74.

CHAPTER XX.

ON THE VARIOUS KINDS OF BREATHING EXERCISES.

HITHERTO we have been occupied for the most part with theoretical considerations. We now come to their practical application. In this chapter I shall describe the various exercises which I have found useful; in subsequent ones, the conditions in which they should be employed. For the convenience of the reader I append a reference to previous chapters treating of important practical points: Chapter I. —Means for preserving pulmonary elasticity. Chapter II. —Method of testing the tone of the abdominal muscles. Chapter V. — Method of testing thoracic mobility. Chapter XII.—Respiration of condensed and rarefied air. Chapter XIV.—Therapeutic aspect of talking, singing, etc.

Preliminary Observations.

When a patient comes before us, our first concern (from the point of view of this work) is to discover if there are any impediments to the free movement of the chest. The most common are unsuitable clothing (*e.g.*, very tight corsets) and obesity, and it may need considerable perseverance to remove either of these. It should be remembered that they are both essentially removable, and that failure to obtain their removal will generally mean failure in our patience and tact. In regard to tight-lacing, it is well not to demand too much at once; we must be content to gain our end little by little.

It is important that the air which enters the lungs during the breathing exercises should be as pure as possible, more especially since in deep breaths (which these exercises frequently demand) any impurities that may be inhaled will be drawn deeply into the lungs. Nature makes every effort to protect the vesicles from the inhalation of nocuous matters. In the first place, normal breathing takes place through the nose, the ingoing air being thereby warmed, moistened, and filtered. Then, again, the air which rushes in with every inspiration, *i.e.*, the tidal current, does not pass further than the trachea and large bronchi, gaseous diffusion taking place between the new air thus introduced and that in the smaller bronchi and alveoli. The tidal current being thus confined to the trachea and larger bronchi, solid particles are largely prevented from passing into the smaller air-passages, inasmuch as they do not come under the law of gaseous diffusion. Hence those which do not pass out in the expiratory current are deposited in the mucous membrane of the larger passages, and becoming entangled in the mucous secretion which they excite, are for the most part removed by expectoration. This removal is further favoured by the ciliæ lining the entire bronchial tree down to the ultimate bronchioles. These lash outwards, and thus act as scavengers.

Seeing what an important part the nasal passages play in preparing the inspired air, it is imperative that there shall be no nasal obstruction, and therefore every patient should be carefully examined for this very common condition.

I have said that the air inhaled should be as pure as possible. It is, unfortunately, not always easy to secure pure air, especially in the dwellings in large towns. The room should contain a minimum of furniture, and should be well ventilated. In many cases the exercises may be done with advantage before the open window.

If the patient has a delicate chest, it may be advisable to dry, purify and medicate the air. This may be done by Hartnett's antiseptic dry-air exhaler, 'so constructed that it dries and filters the air, and impregnates it with volatile medicaments which impart to the air oxidizing and antiseptic properties equal to, if not exceeding, those to be found in pine and eucalyptus forests.' The substances to be employed are eucalyptol, menthol, pinol, guaiacol, sanitas oil, terebene, and camphor, all of which are freely volatile, and thus gain access to the remotest vesicles, unlike such substances as creosote and carbolic acid, which, as Hartnett points out, are much less likely to travel beyond the large bronchi. There is another advantage gained by employing these highly volatile substances, viz., their ready absorption by the respiratory tract. Such a substance as turpentine is highly penetrating, so much so that a small amount of wet paint in a house will speedily cause the urine of its inmates to smell of violets.

When all impediments to breathing in the shape of unsuitable clothing and obesity have been removed, when the nasal passages are quite free, and when the patient is provided with suitable air in which to practise the exercises, difficulties may yet exist in the shape of a rigid thorax and of weak respiratory muscles. The means of increasing thoracic mobility are considered in Chapter XXI. In order to strengthen weak respiratory muscles we should attend to the general nutrition, giving, if need be, cod-liver-oil, malt, iron, arsenic, and so forth, and seeking to develop the respiratory muscles by special exercises. These muscles are, of course, brought into play in breathing exercises, but the larger muscles of costal respiration may be more effectually strengthened by dumb-bell and similar exercises.

The dumb-bells should not weigh more than 3 lbs. Largiadèr's apparatus supplied by Krohne and Sesemann will be found very useful for the purpose of developing the muscles, and it has the great advantage of allowing the force employed to be precisely regulated.

The diaphragm may be strengthened by being made to contract against resistance in the shape of pressure applied to the anterior abdominal wall. This may be obtained by a sheet of lead of varying degrees of thickness, fitted to the belly in the horizontal position of the body.

Preliminary Exercises.

The patient must be taught to obtain complete control over his respiratory movements. He should first learn to dissociate costal and abdominal breathing, since each produces its own peculiar effects. Thus, in deep abdominal inspirations the bases of the lungs are expanded more than the apices, while intra-abdominal tension is increased, and the blood squeezed out of the abdominal veins. Moreover, the abdomino-pelvic viscera are compressed and dislocated, their functions being thereby altered, while lymph is pumped from the peritoneum into the pleuræ. On the other hand, in a full costal inspiration, the upper regions of the lungs are more fully expanded than by any other means, while intra-abdominal tension is diminished, and the flow of blood from the digestive viscera into the splanchnic veins, and from the kidneys, pelvic viscera, and lower extremities into the inferior vena cava, accelerated.

Diaphragmatic breathing is best learned in the supine position. All impediments to the free play of the diaphragm being removed, the individual should concentrate his attention on the abdomen, seeking to protrude it to the utmost with every inspiration, and to keep the bony thorax fixed. After a little practice, complete control over the diaphragm in all postures will be acquired. In diaphragmatic breathing the lower ribs tend to be raised, and it requires some practice before one can contract the diaphragm without raising the ribs—before, *i.e.*, pure abdominal breathing can be acquired.

The diaphragm, after its contraction, returns to the expiratory position under the united action of the pulmonary suction above and the positive intra-abdominal pressure below. When, however, pulmonary suction is slight, as in emphysema, or when the intra-abdominal pressure is low, as happens when the anterior abdominal walls are lax, the expiratory movement of the diaphragm may be sluggish and limited. In such cases it may be accelerated and amplified by voluntarily retracting the belly by means of the transversales. It may, indeed, be amplified in this way even when normal in range, for air can be expressed from the lungs by retracting the belly, after the diaphragm has assumed the position of ordinary expiration. Hence it is a good plan to alternate diaphragmatic contractions with abdominal retractions, protruding and retracting the belly to the fullest possible extent. This constitutes an admirable system of abdominal massage. Abdominal expiration may also be favoured by pressing upon the belly in the various ways described under the passive exercises (pp. 157-159).

The augmentation of intra-abdominal tension resulting from descent of the diaphragm may be increased in various ways—*e.g*, by applying a weight to the belly in the supine position, by flexing the body on the thighs in the sitting posture, or by wearing a broad belt. If a powerful abdominal breath be taken under any of these conditions, the tension in the abdomen may be made to rise considerably.

Next as to the purely costal type of breathing. This may be practised both in the horizontal and upright postures, the attention being concentrated on the ribs, and these should be raised to the utmost, while every effort is made to keep the anterior abdominal wall stationary. Lower costal breathing may then be practised. It is somewhat difficult, especially to the civilized woman, in whom the movement of the lower ribs is generally limited, owing to the use of stays. In order to acquire it, let the palm of each hand be placed on the corresponding half of the lower chest, and while care is taken not to raise the clavicles nor protrude the belly, an attempt should be made to separate the hands as far as possible by expanding the lower chest; the lower ribs should then be depressed, so as to allow the hands to come as close together as possible. It will be found difficult to do this without resorting, to some extent, to abdominal breathing.

The patient may be taught to expand the upper part of the thorax more than the lower. In the case of the man this is a difficult feat, and I do not set great store by it as a therapeutic measure. It is far more useful to be able to dissociate the movements of the two sides of the chest, for we are thus enabled to exercise one lung more than the other, and also to increase the mobility of the chest, notably of the chondro-sternal joints. Unilateral breathing is less difficult than would appear. It may be facilitated in the following way: One hand is placed in the corresponding axilla, and firm pressure is made on the same side of the chest, so as to check its movements as far as possible. The opposite arm is then gradually raised from the side until the wrist rests on the head. While the movement of this arm is in progress, an attempt is made to expand to the utmost the corresponding side of the thorax at the same time that the body and head are inclined to the opposite side.

It need scarcely be said that the physician must himself acquire perfect facility in these various kinds of breathing, so as to be able personally to instruct his patients in them.

Having mastered these elementary types of breathing, the patient is in a position to undertake various kinds of breathing exercises. These we may divide into:

Active breathing exercises.

Active breathing exercises conjoined with other exercises.

Passive breathing exercises.

Exercises for developing the abdominal muscles.

Before describing them, let me reiterate the following important principles: The transit of blood from the venæ cavæ to the aorta, and the flow of lymph into the thoracic ducts, may be facilitated (*a*) by increasing the mean size of the chest, an end best effected by taking deep inspirations and limiting the expiration range; and (*b*) by prolonging the period of inspiration and shortening the expiratory period. In other words, the flow of blood and lymph can be most effectually stimulated by taking long and deep inspirations (preferably through the nose), followed by short and shallow expirations (preferably through the mouth).

All expirations with closed glottis impede the circulation along the cavæ and through the lungs, and hinder the flow of lymph into the thoracic ducts. While performing the various exercises recommended, it is therefore most important to keep the glottis open.

Deep thoracic inspirations cause a lowering of the intra-abdominal pressure, and thus determine a flow of blood to the abdominal vessels.

On the other hand, deep abdominal breaths increase intra-abdominal pressure, especially if pressure be made on the abdomen at the same time, and thus tend to squeeze the blood out of the abdominal vessels.

Active Breathing Exercises.

1. Take the fullest possible thoracic inspiration,* followed by an ordinary expiration.

2. Expire to the utmost, bending the body somewhat forward, and then take an ordinary inspiration, resuming the vertical position.

3. Take the fullest possible thoracic inspiration, and then expire to the utmost, bending the body forwards.

4. Take a deep lower thoracic inspiration followed by a deep lower thoracic expiration.

5. Stand with the legs well apart, and take a deep abdominal inspiration, followed by a passive expiration—*i.e.*, one resulting from recoil merely.

6. Stand with the legs well apart, and take a deep abdominal inspiration, followed by a deep abdominal expiration. This latter is effected by retracting the belly by means of the transverse muscle-fibres of the anterior abdominal wall.

7. Take a deep abdominal inspiration, then a lower thoracic inspiration, and finally complete the breath by a deep thoracic inspiration, lifting the clavicles to the utmost. Expire in the reverse order.

8. Take a lower thoracic inspiration, and follow this up by a deep abdominal inspiration; make a deep abdominal expiration, and finally a deep thoracic expiration.

9. Assume the sitting posture; fold the hands on the lap; flex the body as far forward as possible. Now take the deepest possible abdominal inspiration with closed mouth, and then gradually raise the body, lift the arms

* Some authorities assert that the lifting of the ribs may be aided, and the intake of air increased, by resting the hands behind, or on the top of, the head, so as to bring the pectoral and other extraordinary muscles of inspiration into play, but I do not find this to be the case.

over the head, and take the fullest possible thoracic inspiration. After this, passively expire—*i.e.*, by recoil merely—with open mouth, allowing the arms to drop suddenly. Expiration should not proceed beyond the limit of ordinary expiration, and should not occupy more than one second, inspiration occupying not more than six.*

10. This exercise is recommended by Dr. Ed. Blake for expanding the chest: 'The patient is requested, while standing erect, to blow out quickly through a small opening produced by the pursing of the lips. At the same time he bends the head, and then the dorsal portion of the spine, whilst with his outspread fingers he compresses the sides of the thorax. Having done this, the fingers are enlaced behind the neck, the mouth is closed, and a very, very slow and prolonged inspiration taken through the nostrils, whilst at the same time the spine is slowly extended. The object in placing the hands behind the neck is to bring into play all the muscles of extraordinary inspiration. . . . The breath should not be held unless the ventricles are too vigorous.'†

The subjoined breathing exercises were employed by the late Surgeon-Captain Hoper-Dixon 'for developing the chest and otherwise strengthening the body.'‡ They are chiefly designed to educate the diaphragm, constituting, in fact, a species of diaphragmatic drill.

* During the first stage of this exercise the abdomino-pelvic viscera are firmly compressed, the outflow from the femoral veins is diminished, and the blood is squeezed from the intra-abdominal veins into the right heart, and also sucked in the same direction. During the phase of thoracic inspiration, blood is aspirated into the abdomino-pelvic cavity, and from the latter into the right heart and lungs.

† 'Lip Chorea and Paresis of External Pterygoids' [Stammering]. Bale, 1890.

‡ 'The Art of Breathing,' etc., pp. 22-24. London: Gale and Polden.

1. Recumbent position, head slightly raised, arms close to the side; gentle abdominal and lower costal breathing is employed, the abdomen being covered with some plastic material accurately fitted, the total weight not exceeding $3\frac{1}{2}$ lbs.

2, 3. The same sitting and standing respectively, without the weights.

4. Recumbent position; a deep abdominal and lower costal breath is taken—the abdomen being weighted—and the breath held in full inspiration, after which a sudden forcible expiration is made.

5, 6. The same sitting and standing respectively, without the weights.

7. Recumbent position. The same as No. 4, the first four to eight letters of the alphabet being repeated while the breath is held.

8, 9. The same sitting and standing, without the addition of weights.

10. Recumbent position. A deep lower costo-abdominal inspiration is taken at the same time that a dumb-bell is raised from each side over the head; inspiration is then completed, and followed by a forcible expiration, the dumb-bells being then returned to their original position.

11. The same practised on a form; the head should be well raised.

12. Recumbent position. A slow lower costo-abdominal inspiration is taken through the nose, followed by a similar expiration through the mouth. The exit of air should be so gradual as not to warm a finger held close to the mouth.

13. Inspiration as in the last, followed by a forcible expiration.

14. The reverse of the last, inspiration being hurried and expiration slow.

15. A series of light respirations are taken at the rate of

about 360 to the minute in the recumbent, sitting, and standing positions.

16. Hurried respirations are taken for about five seconds, after which a deep breath, followed by a gradual expiration.

Breathing Exercises conjoined with Active Exercises.

Breathing exercises may be conjoined with various active exercises. In this way groups of muscles may be strengthened at the same time that the patient derives the special advantages resulting from enhanced respiratory activity, which is in considerable excess of what the exercises themselves would induce. By these means the circulation is doubly stimulated, for not only is the heart excited to increased activity, but the transfer of blood from the systemic veins through the lungs into the systemic arteries is facilitated, the blood meanwhile being kept in a high state of oxygenation, and with a low percentage of CO_2. The flow of lymph is likewise doubly stimulated, being affected by both the exercises. A further advantage of this combination lies in the fact that the muscle-exercises may actually aid the respiratory movements, and conduce to increased amplitude of breathing.

In all the following exercises the patient stands. Inspiration should be taken through the nose, expiration through the open mouth. The former, with its accompanying movement, should be long, the latter and its movement short. All the exercises except No. 7 may be performed with dumb-bells of from 1 lb. to 3 lbs.

1. The arms, held stiff, are swung round as far as possible in the sagittal direction. Inspiration accompanies the upward movement, expiration the downward.

2. The arms, held stiff, are moved from the side of the body outwards in a lateral plane to the vertical, and then

returned to the original position. Inspiration accompanies the upward movement, expiration the downward.

3. The same as the last, except that the arms move forward in the sagittal plane.

4. The arms are flexed at the elbows, and held close to the sides. They are moved upwards, and extended to the vertical with inspiration, being returned to the original position with expiration.

5. The arms hanging down by the side of the body, the hands are moved upwards into the axillæ as far as they will go, the elbows moving outwards in the lateral plane; they are then returned to the original position. Inspiration accompanies the former movement, expiration the latter.

6. The arms, held horizontally in front of the body in the sagittal plane, are swung backwards in the horizontal plane as far as they will go, and then returned to the original position. Inspiration accompanies the former movement, expiration the latter.

7. While the hands rest upon the hips, with the thumbs behind and the fingers in front, the elbows are moved backwards as far as they will go, and are then returned to the original position. Inspiration accompanies the former movement, expiration the latter.

8. The arms, held horizontally in the sagittal plane, are moved downwards and backwards in this same plane as far as they will go, the body meanwhile bending forwards, the original position being then resumed. Expiration accompanies the former movement, inspiration the latter.

9. The arms are made to swing in the lateral plane, and in the same direction, so as to reach the highest possible point on either side, and are then returned to the original position. Inspiration is taken with the ascending movement, expiration with the descending.

Passive Respiratory Exercises.

Passive respiratory exercises are adapted to increase the expiratory range. They are therefore especially useful when the chest is permanently fixed in the inspiratory position, and when it is desirable to get rid of as much of the residual air as possible, the inspiratory input being thus increased. I find it generally much more difficult to get my patients to breathe out than to breathe in properly.

The patient should lie supine on a form or narrow couch. If neither of these is available, a table or bed should be substituted.

1. The operator stands behind the patient's head, which should project slightly beyond the couch; the upper arms are then grasped by the assistant, his thumbs looking upwards; the arms are then brought above the head, so as to form a **Y** with the body, and strong traction made upon them, the patient meanwhile taking a deep inspiration. They are then brought towards the thorax, and firmly pressed against it, while the patient takes a deep expiration.

2. The operator stands at the side of the patient, and grasps the arms as they rest at each side of the body, just above the elbows, his thumbs being uppermost, and looking towards the patient. He then moves the limbs in a horizontal plane until the hands meet beyond the head of the patient, who meanwhile takes a deep inspiration. This is followed by a deep expiration, while the limbs are moved back to their original position, the elbows being firmly pressed against the sides.

3. The patient's upper arms are held parallel with the body, the forearms crossing over the chest. The assistant stands on a level with the patient's hips, and, grasping the arms just below the elbow (his thumbs looking towards the ulnar bones), raises them in this crossed position beyond the head of the patient, who meanwhile takes a deep

inspiration. A deep expiration follows, the arms being returned to the original position, the assistant making firm pressure on the thorax. In this exercise the arms can be returned to, and pressure made upon, (*a*) the upper part of the sternum, (*b*) the lower part of the sternum, (*c*) the epigastrium, according as we wish to increase expiration in one or the other region.

4. The arms are held supine, at right angles to the body, and are allowed to fall backwards. The assistant stands on a level with the patient's lower thorax; and, grasping the limbs above the wrist (his thumbs being upwards, and looking toward the patient's head), presses them back as far as they will go without causing pain, the patient deeply inspiring the while. They are then brought in a folded position across the upper sternum, lower sternum, or epigastrium, against which firm pressure is made, while the patient takes a deep expiration.

5. The assistant rests the palms of his hands on either side of the lower sternum, the fingers pointing towards the axillæ; he then bears his weight upon the patient with every expiration, the degree of pressure being regulated by the needs of the case. If considerable pressure be desirable he may bear his whole weight.

6. The thorax may also be compressed by means of a broad belt or stays, which can be tightened up with every expiration. External compression of the lower chest, however, is not often required in the woman; the lower chest generally gets too much of it in her case.

7. The operator stands at the side of the patient, level with the abdomen, and, resting the palms of the hands across the belly, makes firm pressure upon it with every abdominal expiration.

8. The patient lies on one side, with the arms held above the head, and the operator, standing behind, places the

palm of each hand over the uppermost part of the thorax, so that the roots of the fingers correspond with the axillary line, the thumbs pointing towards the spine. The side of the thorax is thus grasped between the fingers and thumbs. With every expiration the operator makes firm pressure on the thorax, and endeavours to make the fingers and thumbs meet.

The same with the patient lying on the other side.

9. The patient assumes the same position as in 8. The assistant places his hands longitudinally to the patient, one in front of, and the other behind, the upper half of the thorax, the fingers pointing towards the head. With every expiration firm pressure is made, so as to bring the hands nearer to one another.

The same with the patient lying on the other side.

10. Position as in 8. The assistant places one hand across the belly, and the other across the back, firm pressure being made with every abdominal expiration.

11. Position as in 8. The assistant places one hand on the uppermost side of the lower thorax, the fingers pointing towards the sternum and the thumb towards the spine. The other hand is placed on the uppermost shoulder, the fingers resting on the clavicle and the thumb on the scapula. With every expiration the one hand presses against the lower thorax, while the other firmly presses the shoulder down, each hand squeezing the chest between the fingers and thumbs as much as possible.

The same with the other side.

12. Another means of increasing the expiratory range is to apply pressure on the shoulders with every expiration, the patient sitting.*

* Otto L. Holst employs exercises for developing the thoracic muscles and the lungs in phthisis. I have found some of these of undoubted benefit. ('A Contribution to the Rational Treatment of Phthisis,' etc., *St. Bart.'s Hospital Journal*, September, 1896, p. 187.)

Exercises for developing the Abdominal Muscles.

When the abdominal wall is very flabby, we may begin treatment by a course of massage and electricity. The muscles should be rubbed and kneaded for half an hour, and gently faradized for fifteen minutes, both operations being repeated twice daily. When they have by these means sufficiently recovered tone, we may commence a series of graduated exercises. These should be begun very tentatively, their duration and number being regulated by the age and strength of the patient.

The following will be found to strengthen the transversales:

1. Firmly retract the belly, and gradually increase the duration of the retraction from a few seconds to one minute, or even longer. It is not advisable that the period of retraction should in the first instance last longer than a few seconds, especially in the case of a very weak patient.

2. Repeatedly retract the belly at the rate of from ten to sixty retractions per minute, keeping the ribs fixed. A deep abdominal breath should alternate with each retraction.

3. Firmly retract the belly, and then, while the retraction is kept up, inspire and expire to the fullest extent. Time from ten to sixty seconds.

4. Take the deepest possible lower costo-abdominal inspiration by means of the abdomen and lower ribs. Close the glottis; then repeatedly retract and protrude the belly by alternately contracting the transversales and the diaphragm. (This is an advanced exercise, and can seldom be advantageously employed for more than thirty seconds.)

5. Alternately expand and contract the costal arch to the fullest extent. The upper portion of the transversales is thereby exercised.

All these exercises should be performed in the standing, sitting, and lying postures in turn.

The subjoined exercises act more generally on the anterior abdominal muscles:

6. A complete expiration is taken from the position of ordinary inspiration.

7. The patient stands with his legs two or three feet apart, and, the knees being kept fixed, the trunk is moved forwards as far as possible and then brought back to the vertical.

8. The patient stands with his legs apart, and flexes the trunk as far as possible, first on one side and then on the other.

9. The patient stands, and the body is bent backwards, the knees being at the same time gradually bent and the arms slowly extended over the head, and then separated. After the body has been bent backwards as far as possible without upsetting the equilibrium, it is gradually brought back to the vertical position.

10. The patient sits on a low stool, and bends his body alternately backwards and forwards, the forward movement being resisted by an assistant, who grasps the shoulders from behind.

11. The patient sits on a stool with his back to the wall. On either side of him is a ring firmly fixed into the wall. Through each ring there passes a cord, to the ends of which weights are attached. The portion of cord between the two rings is passed round the waist. The body is then repeatedly flexed on the thighs, and the weights thereby raised. This exercise has the great advantage that the work put upon the abdominal muscles can be regulated with nicety by altering the weights to be raised.

12. The supine position is assumed, and while the legs are being held by an assistant, the body is gradually moved

towards the vertical. If an assistant is not available, the patient may lie on the floor, and place the feet under some resistant object. If the abdominal muscles are weak, the patient may be unable to attain the vertical, and in this case he should not attempt to do so, but only lift the body so far as can be done without strain. When beginning this exercise, the patient may be allowed to help himself with his arms. When the arms are not used in this way, it is well for the patient to make firm pressure with his fingers against the inguinal rings, so as to obviate an unpleasant sensation which is often felt in these regions during this exercise, and to avert the possibility of a hernia. In some cases, though this is not often desirable, one may increase the weight which the anterior abdominal muscles have to lift by causing the patient to hold weights of varying amounts. It is most important that the breathing should be carried on naturally during the performance of these exercises. It should be of the costal type.

13. When the abdominal muscles have acquired sufficient strength, the patient may repeat Exercise 12, sitting on a hassock, and alternately lowering the head backward until it touches the ground, and assuming the sitting posture. Or he may sit on a couch or low table with his legs up and his buttocks slightly projecting beyond the edge; and while the legs are held down by an assistant, the body is gradually lowered over the edge as far as it will go, and then gradually brought back to the vertical. During this procedure it is advisable that the inguinal rings should be supported as directed.

14. The rope-hauling exercise is a very valuable means of strengthening the abdominal muscles. It may be performed indoors in the following way: Two strong elastic cords, about 2 feet in length, are fixed by one end into the floor, their free ends being provided with rings which can be

grasped by the hands. These cords are alternately stretched by first pulling with one hand and then with the other, as in rope-hauling.

15. The hands grasp a horizontal bar or rings suspended from the ceiling; the body is then suspended in space, and allowed to swing backwards and forwards.

Rowing, it may here be remarked, does not especially tend to develop the anterior abdominal muscles. The forward movement certainly is effected through them, but they take no part in the backward movement, since the necessary antagonism to the dorsal muscles is afforded by the resistance of the oars.

It will be well in this place to make some observations on the subject of cycling.

One of the advantages of cycling is that it renders possible a great deal of outdoor exercise without fatigue. How are we to explain the wide difference in this respect between it and the natural modes of progression? There are, I suggest, two chief reasons: In cycling (*a*) the legs have not to support the body, and (*b*) the vascular column is shortened. (*a*) The legs, having no work of support, can devote themselves entirely to that of propulsion, whereas in walking and running much of the energy expended by the muscles of the lower extremities is spent in supporting and balancing the body. Even the mere act of standing involves a considerable expenditure of muscle-energy both by the leg and trunk muscles; while in cycling not only are the leg muscles wholly freed from the work of support and balance, but the trunk muscles also are largely relieved from the latter function if the proper sitting posture be assumed. What do I mean by the proper sitting posture? If a person sits so as to ride at ease, he should hunch the back somewhat, since this involves the expenditure of much less muscle-energy than the bolt-upright position. This is one reason why the back should be well arched in cycling. (*b*) Man is distinguished from all other mammals by his erect posture. This, while securing him the great advantage of being free to devote the upper extremities to other purposes than propulsion, has also more than one disadvantage. If an intelligent extra-mundane being were to see man for the first time in the horizontal posture, it would surely never occur to him that it is natural for him to be erect. There is something incongruous in an animal built on the longitudinal plan standing and progressing upon one end of its long axis. Yet this is what man is and what he does, and it places him at a twofold disadvantage: first, in the matter of progression, it leaves him with but two legs to walk with, and the muscles of these two, as already observed, have to expend a great deal of their energy in balancing the body, which from its upright posture is much more difficult to balance than in the case of the quadrupeds; secondly, the height of the blood column is increased, the influence of gravity on the circulation being correspondingly increased. In particular, as Leonard Hill has so ably shown, there is a tendency for the blood to gravitate into the splanchnic area when the erect posture is assumed, and I cannot but think that the fatigue of standing and walking is largely due to this tendency. It is normally counteracted by the contraction of the splanchnic arteries, by the pressure of the firmly-contracted abdominal muscles on the splanchnic veins, and by the negative intra-thoracic pressure, and in cycling it is much reduced, and for at least three reasons: (1) The mean distance between the head and feet is diminished, and here we have an additional reason why the body and head should incline well forwards; (2) the splanchnic veins are compressed by the rhythmic flexions of the thighs on the abdomen, and this compression is increased by the forward attitude; (3) the aspiratory action of the thorax is increased, owing to its increase in mean size, this occurring in all active exercises. That the forward attitude tends to contract the chest is an altogether fallacious notion.

CHAPTER XXI.

RESPIRATORY EXERCISES IN DISEASES OF THE LUNGS.

Respiratory exercises will be found of great use in the prevention and treatment of pulmonary diseases. They benefit in many ways, but chiefly by stimulating the flow of blood (pulmonary and systemic) through the lungs, and in this and other ways favouring the development of these organs. They also benefit by increasing the mobility of the thoracic cage. That they are capable of developing the lungs is shown by the increased thoracic girth that can be brought about by their means. The way in which this increase is effected is described in Chapter IV.

As a Preventative of Pulmonary Disease.—The more perfectly developed the lungs, and the more mobile the thoracic cage, the less is the tendency to such diseases as phthisis, bronchitis, and pneumonia. This is a well-recognised fact. Nothing is more certain, for instance, than that small, ill-developed lungs are prone to tuberculosis. The so-called *phthinoid* chest, indeed, owes its characteristics to the smallness of the contained lungs, and it is in consequence of their smallness that the thorax assumes the position of super-extraordinary expiration.

Here let me observe that an ill-developed chest is not infrequently overlooked. Many a person, who when dressed appears to have a normal chest development, discloses, when stripped and carefully examined, some marked thoracic defect. A common cause of this deceptive appearance is an abundant deposit of fat about the thorax. In the tall, slim youth we easily recognise the phthinoid chest by the sloping shoulders and the small sagittal measurement; but when he becomes a stout man he may appear, on casual observation, to have a well-formed chest. In such a case acute pneumonia or bronchitis is always serious, although the apparently good development of the chest may suggest a favourable prognosis.

Not only do good pulmonary development and free thoracic mobility tend to prevent lung disease, but they place the individual at an advantage should he happen to develop it, both on account of the high resisting power belonging to the well-grown lungs, and on account of the large margin of reserve that goes with them. It is because of the smallness of this reserve in those with ill-developed lungs that they are so liable to succumb when attacked by acute pulmonary disease, and it is very largely for this same reason that the danger from it increases with every year after middle life, the reserve diminishing as emphysema and thoracic rigidity advance.

Respiratory exercises are more suitable for developing the lungs than gymnastics, much of the increase in thoracic girth obtained by the latter means being due to development of the thoracic muscles, and not infrequently to emphysema, induced by violent effort with closed glottis. By means of respiratory exercises we are able to develop the lungs without any danger of producing emphysema, and without putting the patient to the trouble of bringing about an altogether needless hypertrophy of the arm and chest muscles. The great development in these muscles which gymnastics tend to bring about serves no good end. It is perhaps amusing to see a professed gymnast walk on his upper extremities, but it is physiologically ridiculous. Feats of strength are wholly useless from the physiological point of view ; nay, they may even be harmful, and actually lead to a diminution in vital capacity.

Respiratory exercises are very useful in favouring the expansion of collapsed lung after pleural effusion. They should be assiduously employed in empyæma after the external wound has healed, and may even be begun before this. They may also be of considerable service to patients who are compelled to remain for a long time in bed, promoting as they do the general health, and preventing the tendency to hypostatic congestion of the lungs. Take as an example the case of chronic tubercular disease of the hip or knee, in which the patient is compelled to lie for weeks or months on his back, or, again, the tedious convalescent stage of typhoid.

It is unnecessary to particularize the class of bedridden patients for whom such exercises are unsuitable ; this may safely be left to the judgment of the reader.

In considering the influence of respiratory exercises in warding off pulmonary disease, the importance of always inspiring through the nose must be insisted upon. The fact is not yet properly appreciated that nasal obstruction, by compelling inspiration through the mouth, is a potent cause both of bronchitis and phthisis. I have seen several instances of both these diseases thus induced. In all diseases of the lungs the nasal passages should be carefully explored, and any obstruction immediately removed.

As a Means of treating Pulmonary Disease.—(*a*) Bronchitis. I have obtained some good results in bronchitis from respiratory exercises. This is not surprising, for inflammation of the bronchi is favoured by sluggish movement of the chest, with the consequent sluggishness of the circulation (pulmonary and systemic) through the lungs, and hence anything that accelerates the pulmonary flow is beneficial. Wherefore it is of the utmost importance to remove every impediment to free respiratory movement in this disease. I have already observed that obesity constitutes such an impediment, and that is, I believe, one of the reasons why bronchitis is so common in the obese. Now, respiratory movements are useful in reducing obesity, and they are therefore clearly indicated for stout bronchitic patients. I have seen cases of chronic bronchitis benefit most remarkably by cycling, the result being doubtless largely due to the increased activity of the respiratory movements.

Otto L. Holst recommends the following procedure for clearing the air-passages of mucus. The patient assumes a semi-reclining position, and an assistant stands in front of him, and lays both hands flat upon his chest. 'The patient is told to take a deep breath, and during the expiration a vibratory movement is given by the operator's hands as long as the expiration lasts, and a little longer ; then the hands are moved lower down on the chest, and the same performance is gone through till the operator's hands have covered consecutively the whole surface of the chest, front and back.'*

(*b*) Phthisis. In all but the very acute forms of phthisis I advocate the employment of respiratory exercises ; the more abundantly the lungs are flushed with blood, the more capable are they of resisting the bacillus. We should, of course, proceed cautiously if the tendency to hæmoptysis is great, but a small degree of hæmorrhage does not contraindicate this treatment, for, as pointed out by a writer in the *Lancet*, pulmonary hæmorrhage does not show a special tendency to follow upon exertion, being, on the contrary, comparatively frequent at night and in the early hours of

* 'A Contribution to the Rational Treatment of Phthisis in its Earlier Stages,' Otto L. Holst, *St. Bart.'s Hospital Journal*, September, 1896.

the morning.* I have myself been asked by a patient suffering from slight hæmoptysis whether singing would be injurious to him. In most such cases we may not only sanction, but should actually encourage it, provided we are sure that the patient adopts the proper mode of breathing and does not unduly exert himself. Much of the good effect obtained by sending patients with phthisis to cold mountainous districts is due to the increased freedom of the respiratory movements which this entails.

In connection with breathing exercises proper, other exercises, chiefly of the muscles of the trunk and thorax, as described by Otto Holst, may be resorted to.†

Jacoby ‡ employs a method of treating phthisis which may be referred to here. Starting upon the assumption that the predisposition of the pulmonary apices to phthisis results from the tendency of the blood to gravitate away from the apices in the erect position of the body, he seeks to determine a flow of blood to them by mechanical means. The patient is placed on a bed with the shoulders dependent, and hot water (from 30° to 45° C.) is allowed to play over the thorax through a series of tubes, four behind and four in front, the whole being enveloped in an air-tight gutta-percha vest. The patient then gets up, and, after being dried, his shoulders are wrapped in a moist bandage; thereupon the recumbent posture is assumed for two to three hours, the legs and abdomen being elevated above the chest. This routine is performed twice daily.

(*c*) Spasmodic asthma. The effect of respiratory exercises in this disease is often little short of miraculous. The following is an instance:

F., æt. 21. Both parents highly neurotic; not menstruated for eight months. During the last six years has been subject to stuffy breathing

* *Lancet*, 1895, vol. ii., p. 535. † *Opus cit.*

‡ *Münch. med. Wochenschrift*, 1897, Nos. 7 and 8.

at night, and to attacks of spasmodic asthma. Is very irritable, inclined to cry, suffers from flushes, giddiness, and other symptoms incidental to menstrual suppression. Wears Jaeger's stays, and although these are what most women would describe as 'quite loose,' they prevent free expansion of the lower costal chest, which is much narrower than the upper part. Sleeps with the window shut in a bedroom overcrowded with furniture.

Treatment.—Mag. sulph., sod. sulph., āā ʒi., in warm water every morning. Excess of furniture to be removed from bedroom, and window to be kept open all night. To sleep with the mouth shut. Respiratory exercises for half an hour twice daily.

The effect of this treatment was very marked. Menstruation came on very soon. Every unpleasant symptom disappeared, and there has been no return of the asthma.

Marcet has noticed the beneficial influence of deep breaths in asthma. He refers to the case of a physician in whom, 'at 2.30 a.m., loud wheezing and tightness of the chest came on, when a succession of forced inspirations had the immediate effect of arresting both the wheezing and the tightness; a second attack the same night was averted in a similar manner.'* He also mentions a case in which the tendency to asthmatic seizures was greatly reduced by cycling, and he attributes the good effect in both these cases to the extra supply of oxygen, brought about by the heightened activity of the respiratory movements. A deficiency of oxygen in the blood he regards as an important factor in the causation of asthma.

Metcalfe has obtained good results in asthma from massage of the chest muscles.

Chronic bronchitis, phthisis, and spasmodic asthma have all been markedly benefited by treatment in the compressed-air chamber; also by inspiring compressed, and expiring into rarefied, air. By both these means dyspnœa can be relieved in a remarkable way, and it is surprising

* *Lancet*, 1895, vol. ii., p. 78.

that so valuable a therapeutic agent should have been so entirely neglected in this country.

(*d*) The absorption of pleural effusions may be aided by means of respiratory exercises. It has been experimentally shown that if fluid be injected into the pleura its absorption is hastened by artificial respiration. It is, however, only in the chronic forms of effusion that breathing exercises are called for. They are not practicable in the acute forms with fever. Indeed, in such cases the opposite plan of bandaging, and thus fixing the affected side, has been practised.

(*e*) Emphysema. The treatment of emphysema by respiratory exercises opens up so many questions of interest that I propose to devote a separate chapter to the subject.

This is a convenient place for referring to *the means of increasing the mobility of the thoracic cage.*

All exercises in costal breathing tend to increase the mobility of the cage, and the younger the subject, the more potent are they to do this. They should, however, not be violent, seeing that great muscle-development tends to increase the rigidity of the thoracic bones (see p. 34). It may not be practicable to prevent a man from following a laborious calling, but we can at least forbid gymnastics and all athletic pursuits which tend to induce undue muscularity. Similarly, all exercises which cause marked dyspnœa should be avoided, inasmuch as this conduces to fixity of the cage by bringing about contracture of the costal elevators.

On the other hand, the sedentary and those with feeble muscle-systems should be encouraged to lead a muscularly active life, and special means, in the shape of dumb-bell and other exercises, should be resorted to in order to develop the muscles and to increase the amplitude of respiratory movement. It is among such that we can do most good, especially if the lungs are healthy. When the chest has become fixed from old age or chronic emphysema, our efforts are less successful.

A useful means of increasing thoracic mobility is the inhalation of compressed air and the breathing into rarefied air.

In seeking to increase thoracic mobility, we must be careful to observe the position in which the chest is fixed. If, for instance, we are dealing with a small phthinoid chest in which the mean position is that of super-extraordinary expiration, our efforts should be directed to increasing the inspiratory range, and similarly in regard to the contracted lower thorax in women who wear stays. Here we give exercises for increasing the inspiratory range of this part of the chest. When, however, the thorax is fixed in the position of super-extraordinary inspiration, as in large-lunged emphysema, our chief aim should be to increase the expiratory range, and a patient should be put through a systematic course of expiratory exercises. This is not only useful in increasing the mobility of the thoracic joints, but in counteracting the contracture of the costal elevators. For if this contracture is due, as I suggest, to overaction of these muscles, which are thus not properly antagonized by the costal depressors (notably by the great abdominal muscles), it follows that we should seek to bring about the normal antagonism. We cannot, as in talipes, divide the contractured muscles.

In the latter class of cases some help may be got from pressure applied externally to the chest. Thus, the patient may forcibly compress the sides of the chest during expiration by resting the palms of the hands on the lower part just in front of the axillary line, the fingers pointing forwards.

CHAPTER XXII.

RESPIRATORY EXERCISES IN EMPHYSEMA.

In order to understand the treatment of emphysema by means of respiratory exercises, it will be needful to consider the mechanism of thoracic expansion in hypertrophous emphysema.

In a typical instance of large-lunged emphysema the thorax is permanently enlarged, being in a condition of super-extraordinary inspiration; in other words, the mean size of the chest is greater than, were the lungs normal, it would be after the fullest possible inspiration, and, furthermore, the entire thorax is permanently elevated. Thus, the clavicles are raised, their anterior ends being carried forwards and their curvatures exaggerated; the sternum is moved forwards and upwards, its anterior aspect being markedly convex from above downwards, the manubrium and gladiolus forming the so-called *angulus Ludovici;* the dorsal spine is similarly carried backwards, and is convex posteriorly; the ribs are more horizontal than normally, and their curves more opened out; the costal arch is abnormally wide, and the diaphragm flattened.

How is this great expansion of the chest to be accounted for?* One is apt to assume that it is secondary to enlarge-

* It is remarkable how little attention has been given to this subject by physicians. Neither Hilton Fagge nor Bristowe even refer to it in their text-books; and how vague are the ideas prevailing on it is

ment of the lungs, and that the latter actually thrust the chest-walls outwards; but this explanation a little reflection shows to be wrong, seeing that the lungs exercise suction upon the thorax. It is true that this suction is diminished in emphysema, owing to diminution in pulmonary elasticity, but except possibly in very advanced cases, when 'the lungs may even appear to project on opening the thorax' after death (Wilson Fox), they retain some degree of elasticity, and must therefore habitually exercise some suction, however slight, upon the chest-walls.

Another view, that of Freund, assigns the chest-expansion to overgrowth of the ribs and sternum, whereby they are altered in shape and position; but such overgrowth, there can be little doubt, takes place in consequence of thoracic expansion, and is not the cause of it.

In Chapter IV. I have dealt with the factors which determine the size of the chest, and have prepared the way for an explanation of its progressive enlargement in hypertrophous emphysema. The two essential factors contributing to this enlargement are defective pulmonary elasticity and dyspnœa. In consequence of the former, pulmonary suction is diminished, and the thoracic elevators, being no longer properly antagonized, gain the ascendency and expand the chest, which may thus go on enlarging for many years before any decided symptoms develop, and before the individual has any notion of his lungs not being perfectly normal. Sooner or later, however, dyspnœa develops, and inasmuch as this excites the inspiratory, more than the expiratory, muscles, there is now a still greater preponderance of the expanding forces. This protracted overaction of the thoracic elevators gradually leads

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sufficiently attested by the following quotation from the article on 'Emphysema' in Quain's 'Dictionary of Medicine': 'The lungs being the seat of general expansion, the thorax is kept abnormally distended.'

to their hypertrophy and shortening, in consequence of which the thorax gets fixed in the expanded position, the fixation being also favoured by changes in the thoracic bones and joints. The expiratory muscles are also brought into forcible play. Thus, the abdominal muscles are tense, and the powerful contraction of the transversales may give rise to one or two grooves in them. This of course tends to retard the process of expansion, but does not prevent it, because the inspiratory muscles act still more powerfully.

The marked hypertrophy and shortening of the thoracic elevators are evident from an examination of the cervical muscles in old-standing cases of this disease; not only do they stand out prominently, but they may be felt to be hard and tense; and when we reflect that the sternum and clavicles are permanently raised, considerably in some cases, it is evident that there must be very considerable shortening, for how otherwise could they remain tense? This view receives further confirmation from the fact that the inspiratory force in emphysema predominates over the expiratory, as can be shown by the manometer. It is found that the inspiratory force remains normal, or is even increased, while the expiratory force is diminished.* This we may explain by reference to the hypertrophy of the inspiratory muscles, which enables them to maintain a high level of inspiratory force in spite of the fixity of the chest, which, however, diminishes expiratory force.†

* 'Die Pneumatische Behandlung der Respirations u. Circulations Krankheiten,' L. Waldenburg, 1880, p. 56.

† The important part which loss of pulmonary elasticity and over-action of the inspiratory muscles play in the production of the large emphysematous chest suggested itself to me when thinking over the mechanism of the expansion. This view was, however, I find, advanced by Dr. Budd nearly sixty years ago, when he expressed himself thus: 'The want of elasticity in the lungs is the real cause of emphysema. The powerful muscles of inspiration are continually tending to dilate

The degree to which the chest expands in emphysema depends upon its mobility at the onset of the disease, and also upon the vigour and activity of the muscle-system. Thus expansion is facilitated by free mobility of the chest. Little enlargement takes place in senile emphysema—*i.e.*,

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the chest, and hence . . . the air-cells. This agency is not counteracted as it should be by the natural elasticity of the lungs; and the air-cells, as well as the cavity of the chest, are permanently dilated' (*Med. Chir. Trans.*, xxiii., 1840, p. 52).

Cohnheim attributes emphysema in a large number of cases to a congenital defect of the pulmonary elastic tissue ('Principles, etc., of Medicine,' 3rd edit., vol. i., p. 967, C. H. Fagge).

Sir Richard Douglas-Powell also alludes to the loss of pulmonary elasticity as a factor in the pathology of hypertrophous emphysema, though I am not able to accept all his deductions. He argues thus: the elasticity of the lungs is greatly diminished, and may be lost in this disease, and pulmonary suction thus being inadequate, the chest-walls are no longer sucked in and bent beyond the neutral point at the end of an ordinary expiration; wherefore the thorax will have the same circumference at the beginning of inspiration as normally it has at the end thereof [it is not explained *why* the chest expands considerably beyond this point in emphysema], and inspiration is no longer aided by the passive recoil of the ribs, which have in consequence to be lifted with every inspiration ('Diseases of the Lungs,' 4th edit., chap. x.). This explanation does not appear to me to be satisfactory, for I do not see how inspiratory recoil *aids* inspiration, since it is neutralized by pulmonary suction, upon which, indeed, it depends. Suppose the latter to be represented by six, the inspiratory recoil of the ribs operating in the opposite direction will be represented by the same numeral, and the resultant, as far as inspiratory movement is concerned, is *nil*. Disappearance of pulmonary suction implies the disappearance of inspiratory recoil, but such disappearance will make no difference in the amount of inspiratory force needful. The need for increased inspiratory force, referred to by Douglas-Powell, is, I believe, due to that expansion of the chest which is a feature of the disease; for the more the chest is enlarged, the more difficult does it become to enlarge it further.

Jenner develops Budd's idea, and refers to the (possible) influence of diminished costal elasticity in the pathology of hypertrophous emphysema, contending that this interferes with proper costal recoil during expiration, which therefore is imperfectly performed.

the so-called 'atrophous' variety—because it does not come on until the chest has acquired the fixity peculiar to old age; but when the disorder begins in early or middle life, while the thorax is still mobile, considerable thoracic expansion may occur. Similarly, expansion tends to be more pronounced the more muscular the individual. It is therefore apt to be small in those with feeble muscles. Hence an additional reason why the chest should not expand in senile emphysema. On the other hand, those of powerful muscular build are apt to get very large chests if they develop emphysema, and it is not therefore surprising that the most pronounced cases of large-lunged emphysema are generally met with in those following laborious occupations.

The expansion of the chest is usually most marked in its upper part. This may be explained by the effect during cough of the sudden contraction of the abdominal muscles and uplifting of the diaphragm in driving the air from the lower regions of the lungs into their apical portions, which thus tend to thrust the upper part of the chest outwards. The powerful contraction of the abdominal muscles that then takes place leads to an actual contraction

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Wilson Fox, who gives the most masterly account of emphysema that I have met with, supports Budd and Jenner, and supplies, as I think, a most important link in the chain of argument, viz., the tendency of dyspnœa to excite the inspiratory muscles more than the expiratory. He observes that the emphysematous chest, 'especially under exertion, is expanded to its fullest limits by the muscles of inspiration, while the subsequent retraction necessary for the proper performance of respiration is hindered by the want of elasticity in these structures. As a consequence, a potential dyspnœa is produced, the immediate reflex effect of which is to create a tendency to further deep inspirations, and the inspiratory muscles become as a consequence hypertrophied.' (*Op. cit.*, p. 158.)

Neither Budd, Jenner, nor Wilson Fox, however, explain satisfactorily why the chest is kept *permanently* expanded and fixed.

of the lower chest, which therefore cannot be distended during the cough ; but the upper chest, not being so immediately under the control of the expiratory muscles, may suffer temporary expansion, and this frequent repetition may render permanent. It is on these lines that Jenner and Mendelssohn explain the frequent occurrence of emphysema at the apices.

I have laid stress upon the mechanism of thoracic expansion in hypertrophic emphysema because the process is largely an injurious one, and should, as such, be combated. It is harmful because it leads to excessive stretching of lung tissue, and this, as Budd insists, is alone sufficient to induce emphysema. Let us suppose healthy lungs to lose their elasticity, and the chest to assume in consequence the position of super-extraordinary inspiration. The continuous stretching of the alveoli thus induced will not only diminish pulmonary elasticity still further, but will so interfere with alveolar nutrition (which is dependent upon the ample rhythmic relaxation of the alveoli) as to give rise to so-called compensatory emphysema. It would appear therefore that mere loss of pulmonary elasticity is, by inducing thoracic expansion, sufficient of itself to bring about emphysema.

The loss of pulmonary elasticity in emphysema has a further injurious effect in that by diminishing pulmonary suction it interferes with an important accessory force of the circulation.

The progressive enlargement of the chest in emphysema tends to produce another evil—its fixation, and thus to diminish the expiratory range. In extreme cases the bony thorax may indeed be bereft of respiratory power, being either immobile, or admitting only movement as a whole without any alteration of capacity. Respiration is then practically confined to the diaphragm, which, however, does not move with its normal freedom on account of its flatness, due to the expansion of the lower chest and the diminished suction on its upper surface. It has, in fact, been said that in some extreme cases it is altogether incapable of enlarging the thorax, its contraction causing, on the contrary, an actual drawing-in of the ribs.* I have not, however, met with a case of emphysema in which the diaphragm had entirely lost its inspiratory power, and it is certain that in most cases a fair quantity of air can be inspired by its means, expiration being chiefly effected by a forcible contraction of the expiratory muscles, whereby the diaphragm is thrust upwards. If in cases of this kind the hand be placed upon the belly, it will be felt to obtrude during diaphragmatic descent, and to become hard during expiration from contraction of the abdominal muscles.

The immobility of the thorax is one of the worst aspects of emphysema, and has not received the attention it deserves. The diminution in respiratory area is serious enough, but this would be largely compensated for if only the patient could expire adequately. The breathlessness is due far more to the meagreness of the tidal current than to the limitation of the respiratory surface, and be it noted, as Walshe long ago pointed out, the emphysematous patient does not make up for deficient depth in breathing by increased rate.

That the diminished expiratory range in emphysema is due to the fixity of the thorax I have no doubt. I can find no other adequate cause. It is frequently attributed to loss

* Thus Wilson Fox writes: 'The contraction of the diaphragm may in some cases even appear to retract the lower ribs, acting as it sometimes does from a lower level, which in expiration may even be below that of the ribs The epigastrium may thus sink during inspiration and bulge during expiration, owing to the slowness with which the air escapes, while the chest is compressed by the accessory muscles of expiration.' *Op. cit.*, p. 171.

of pulmonary elasticity* ; but though such loss prevents ordinary expiration from taking place by simple elastic recoil, as happens under normal conditions, it cannot account for the inability of the patient to expire freely by means of the most powerful expiratory effort. Nor can the limited expiratory range be attributed to impediment in the air-passages. It has been argued, for instance, that the loss of pulmonary elasticity in emphysema 'interferes with that condition of permanent patency in which the small bronchi are normally held by the constant traction upon them of the elastic lung from all sides. In emphysema this traction becomes, in expiration at first, entirely neutralized, and in marked cases collapse of the bronchioles must occur during expiration.'† It seems, however, doubtful whether this loss of pulmonary elasticity leads in any marked degree to such collapse, seeing that in this disease the alveolar walls are considerably stretched. Be this as it may, it is certain that any obstruction thus arising is insufficient to account for the limited expiratory range, seeing that air can be expressed from the lungs by the thrusting upward of the diaphragm as the result of the contraction of the abdominal muscles. In extreme cases the breathing may be almost wholly abdominal, and this indicates that fixation of the chondro-osseous thorax is the cause of the diminished range.

Treatment of Emphysema.—From the foregoing observations it is manifest that in the treatment of emphysema we should seek (*a*) To preserve the elasticity of the lungs and cartilages; (*b*) by preventing overaction of the costal elevators to check thoracic expansion ; (*c*) to maintain the normal mobility of the thorax.

(*a*) I have already dealt with the means of preserving

* See Wilson Fox, *op. cit.*, p. 171.

† Sir Richard Douglas-Powell, *op. cit.*, pp. 194, 195.

pulmonary elasticity (see p. 7). I would here only insist upon the importance of avoiding strong muscle-efforts* and all exercises calculated to induce great dyspnœa.†

(*b*) In order to prevent overaction of the inspiratory muscles, and thus to check thoracic expansion, the patient must guard against all causes likely to induce dyspnœa, which, as we have seen, excites the inspiratory muscles more than the expiratory. We should further seek to antagonize the former by calling the latter into play. From the earliest phase of the disease recourse should be had to systematic expiratory exercises. Thoracic expansion begins long before the recognised signs of emphysema show themselves, and it is in this early phase of the disease that the expiratory exercises should be begun. Unhappily the patient does not often come under the physician's notice for emphysema until the disease has made considerable progress, but it may frequently be observed when he is consulted for some other condition.

The expiratory exercises I adopt are very simple. They consist in the deepest possible expirations. Starting from

* I have now under observation a man, æt. 20, whose chest is very emphysematous and fixed. There is no history of bronchitis, but inquiry elicits the fact that for the past six years, *i.e.*, since the age of fourteen years, he has been engaged in an occupation which requires him constantly to lift heavy weights. It is no unusual thing for him to have to lift two hundredweight! In this case there can be little doubt that the emphysema is due to loss of pulmonary elasticity resulting from heightened intra-alveolar tension, coupled with excessive inspiratory action consequent upon dyspnœa.

† Waldenburg cites the case of a student who became emphysematous in consequence of rapidly mounting several flights of stairs daily. Waldenburg attributed, and I think correctly, the loss of pulmonary elasticity and resulting emphysema in this case to the long-continued over-expansion of the lung resulting from great dyspnœa. He also refers to an interesting case of emphysema similarly induced in a professional lady swimmer who used to remain three minutes under the water. (Waldenburg, *op. cit.*, pp. 50-52.)

the position of ordinary inspiration the patient should expire to the utmost with mouth wide open, the body being bent forward the while, so as to favour compression of the diaphragm from below. These exercises should be practised for at least half an hour twice daily. Special exercises of the abdominal muscles should also be resorted to. Thus the patient, lying supine, is directed to raise his body, the legs being held by an assistant if necessary. In this way the great depressors of the thorax may be considerably developed. Retraction of the belly, by which the transversalis is exercised, should be frequently practised, and thus the tendency to undue opening-out of the costal arch prevented. Massage and faradisation of the abdominal muscles may in some cases be called for.

Apart altogether from the advantage gained in thus antagonizing the costal inspiratory muscles, it is of the greatest advantage to the emphysematous patient to have firm and well-developed abdominal muscles, since a lax state of these predisposes to many evils which tell against him, such as flatulence, costiveness, dislocation of the abdominal viscera, and the accumulation of blood in the portal area.

(*c*) By means of the expiratory exercises just described we may also check the tendency to fixation of the thorax, indeed, we can in this way generally increase thoracic mobility considerably. Defective thoracic mobility in an apparently healthy man is always suggestive of commencing emphysema. Here the use of the spirometer comes in. If we find a man of forty with no apparent lung disease to have a chest measurement of 38 inches, and a vital capacity of only 230 cubic inches, we may be pretty sure that he is on the road to emphysema. I would utter a word of caution against the assumption that thoracic girth is a safe measure of pulmonary efficiency.

Vital capacity is a much more accurate test. The spirometer often shows a chest of 34 inches to have a greater vital capacity than one of 38 inches.

When the chest is very fixed it may be necessary to resort to special means to promote the expiratory movement. In addition to those already described (p. 157), we may cause the patient to expire forcibly into a chamber of rarefied air, so as to reduce the 'residual' air to a minimum, or he may sit in a chamber of compressed air, and expire into the external atmosphere.

The inhalation of condensed air would theoretically appear to be wrong, seeing that it promotes thoracic expansion. As a matter of fact, it may prove of great service when dyspnœa is great, by favouring the oxygenation of blood. The patient may sit either in the compressed air chamber, or inspire compressed air, in either case expiring into rarefied air. It need scarcely be said that the inhalation of rarefied air is hurtful, and hence emphysematous patients should not reside in mountainous districts.

The chief drawback to the treatment just sketched out is getting the patient to persevere in it long enough. It involves a considerable sacrifice of time, and is apt to grow irksome. Few good results in this world, however, can be obtained without both pains and patience, and certainly the end gained in this instance is worthy the cost.

CHAPTER XXIII.

RESPIRATORY EXERCISES IN HEART DISEASE.

Respiratory exercises are valuable adjuncts in the treatment of heart disease, for they favour the development of the lungs, and thereby diminish their tendency to disease—a tendency it is most important to check, owing to the extra work lung disease casts upon the right heart. The importance of securing the fullest possible development of the lungs in heart disease has been strangely overlooked. The more completely the lungs are developed, the more capacious is the pulmonary vascular system, and the less is the resistance which it opposes to the right heart, pulmonary resistance being in inverse ratio to pulmonary capacity. This fact is, indeed, instinctively taken advantage of in heart disease, in which we may frequently observe over-action of the inspiratory muscles and an increase in the mean size of the chest. Not only is the breathing area in this way increased, but the pulmonary vascular capacity also; and hence the work of the right heart is diminished. Now, all organic cardiac disease, but especially mitral affections and primary disease of the right heart, tend to cast extra work upon the right side; and it is, therefore, of the utmost importance in all cases of heart disease to secure the maximum development of the lungs. Consider, for instance, what happens in mitral disease. In both obstruction and leakage at the mitral orifice the pressure in the pulmonary circuit is increased, a fact which proves that the resistance which the right heart has to overcome is augmented. This increased pressure obtains throughout the entire pulmonary segment, both in the pulmonary artery itself and in the pulmonary veins as they open into the left auricle. The augmented pressure in the latter is obviously compensatory, tending, as it does, to minimize the evil effect of the valvular disease. Now, the larger the lungs, so much the less will be the extra force demanded of the right heart in order to bring about the necessary increase of pressure in the pulmonary veins, and the longer will the right heart be able to hold out. Given two individuals suffering from mitral disease, and identical in all respects save that the one has well-developed and the other ill-developed lungs, the prognosis will be very much better in the former case than in the latter.

It follows that in all cases of failing heart every care should be taken to keep the lungs in as perfect a state of efficiency as possible. I have seen many deaths from heart disease which could have been averted had this cardinal fact been acted upon. It is a point which we should always impress upon the patient. As a rule it is upon the lungs rather than upon the heart that his attention should be concentrated.

Not only do respiratory exercises do good in heart disease by promoting pulmonary efficiency, but also by aiding the circulation of the blood; for, as we have seen, it is possible so to modify the respirations as materially to facilitate the transference of blood from the veins to the arteries. By their means the lymphatic circulation may also be aided, lymph being pumped from the peritoneal cavity into the pleuræ, from the latter and from the pericardium into their respective lymphatics, and from the two thoracic ducts into the great veins. Such aids to the lymph flow are very helpful in heart disease, especially when there is a tendency to œdema and ascites. Forced abdominal breathing should be employed for removing the latter.

I would emphasize the fact that it is not merely in mitral disease that breathing exercises are useful; they should be resorted to both in aortic valve disease and in weakness of the heart-muscle, seeing that the evil effects in both cases tend to work backwards beyond the mitral ring, and no sooner does this occur than the right heart feels the strain.

It is largely through their influence on the respiratory movements that such exercises as walking (especially hill-climbing), running, swimming, rowing, riding, not to mention talking and singing, are useful in heart disease. Even the so-called Nauheim treatment benefits in large measure by causing an increase in the mean size of the chest, and thus favouring the pulmonary circulation.*

How profoundly the breathing is affected in hill-climbing is well shown in the following passage from Oertel:

> 'If the locomotion be extended till the patient ascends elevations or mountains, not only is there a great increase of sweating, but the patient soon breathes only by summoning all the means at his command. He is obliged to stop every ten or twelve steps. The frequent and loudly audible respirations begin with *long-drawn and deep inspirations*, with spasmodic contraction of the diaphragm, and the patient supports himself against some fixed object, his alpenstock, *e.g.*, the pectoral muscles labouring hard, and the ribs being raised by the intercostals. The expiration, on the other hand, is but short, and is quickly followed by the long-drawn inspiration. The same thing occurs every fifteen or twenty steps, without any diminution in the intensity of the respiratory movements, and the exertion can go on for hours with but slight interruption. But by exercise the respiratory muscles, like any other muscles, undergo a great increase of their functional capacity.' †

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* For the author's views on the *rationale* of the Nauheim treatment, see *Brit. Med. Jour.*, vol. ii., p. 712, 1896, and *Lancet*, 1896, vol. I., p. 951.

† Von Ziemssen's 'Handbook of General Therapeutics,' vol. vii., p. 32.

Oertel here refers to the great shortness of expiration as compared with inspiration. He might have added that the expirations are not only short but incomplete, and that the mean size of the chest is therefore increased. I have already pointed out that this is the mode of breathing best calculated to facilitate the pulmonary flow, and thus to relieve an overburdened right heart.

The following passage shows that Oertel himself recognised that some good end was served by this altered mode of breathing:

'Through the powerful and involuntary respiration caused by hill-climbing the thorax enlarges in all its dimensions, the *lungs* attain their *utmost possible respiratory distension*, and from the *enlargement of their vessels* are able to receive far greater quantities of blood. The intensity of the respiratory movements, which are conducted with all the strength possible, causes the aspiration of more blood into the thorax . . . the exit of the blood from the right heart is thus facilitated. . . .

'By these processes in the lungs, part of the hindrances exciting and keeping up the circulatory derangement are removed, and the circulation becomes freer. Inasmuch as for a long time after each ascent the thorax has a greater mobility and expands more easily, so the alteration in the pulmonary circulation also outlasts the period of the ascent; and by repetition of these muscular exertions we are enabled to bring about a permanent increase in the capacity of the pulmonary vessels by increase of thoracic mobility, enlargement of the thoracic space, and increase of pulmonary capacity.'*

I will not say anything further on the treatment of heart disease in this place, as I propose to deal with the subject at length in a separate work.

* Von Ziemssen's 'Handbook of General Therapeutics,' vol. vii., pp. 165, 166.

CHAPTER XXIV.

RESPIRATORY EXERCISES IN THE TREATMENT OF NERVOUS DISEASES.

Great benefit can be derived from respiratory exercises in functional diseases of the nervous system. This is not surprising when we reflect upon their influence on the circulation of blood and lymph. That they exert a profound influence upon the brain is shown by the increased power of sustained voluntary effort which they confer (see p. 141), as also by the giddiness which they not infrequently induce, especially when first undertaken. By accelerating the flow of blood and lymph in the nervous system, they not only increase the supply of oxygen and food-stuffs, but they also promote the withdrawal of waste-products, and all this, be it noted, while the nervous system remains in a state of comparative rest. Nor must we in this connection neglect the beneficial influence of respiratory exercises on the digestive viscera, notably on the liver. There can be little doubt that auto-intoxication plays a prominent part in the causation of functional nervous disorders, and that such auto-intoxication largely results from faulty action of these viscera; and I cannot but think that much of the benefit derived from respiratory exercises in nervous disease is wrought through the digestive system. Finally, the influence of suggestion, which plays so prominent a part in therapeutics, must not be forgotten.

But whatever be the mode in which respiratory exercises benefit, in functional nervous disorder their good effect is unmistakable. One rarely fails to get benefit from them in neurasthenia; and in inordinate blushing this mode of treatment has yielded surprising results. Those who have had no experience of this disease—for such, in truth, it is—can have no conception of the misery it may cause. I have known it to prompt to suicide. In all such extreme cases the sufferer is morbidly self-conscious, and is of nervous temperament, although I have frequently been told by patients of this kind that if only the tendency to blush were removed all would be well with them, this being, as they thought, the beginning and end of their sufferings. I have, however, met with a number of cases in which morbid self-consciousness and other evidences of the nervous diathesis have persisted after the morbid tendency to blush has been cured.

The following is an instance of morbid blushing cured by respiratory exercises:

M., æt. 28. Until æt. 14 he was devoid of morbid self-consciousness. At this time he one day suddenly and unexpectedly blushed in class. This was made the subject of chaff by his schoolfellows; thenceforward he became recognised as a blusher, and he was so plagued and tormented that school became unbearable, and he begged his parents to take him away, which they did. Hereafter his entire life was dominated by the dread of blushing, and of being the object of remarks by others. He spent two years with a family in Germany, in order to avoid association with other boys, and after being under a tutor in England entered the University. Here he was so fearful of being chaffed by the men that he kept entirely to himself, making no friends, and eventually finding himself compelled to leave college without graduating. After this his time was mainly spent in travel, so as to avoid close association with others, and in the vain endeavour to flee from his trouble. The fear that he might at any moment blush and be an object of derision was never absent all these years. It formed the background to all his thoughts. He went to sleep with it, it troubled his dreams, he awaked with it. He felt himself debarred from marriage, and, indeed, from all social intercourse; and, in spite of youth, position, and sound physical health, his life was so utterly miserable that he had serious thoughts of suicide. It was then that I first saw him.

It would need more space than I can afford to describe the method of treatment which was adopted with entire success in this case. It was, of course, in large degree psychical, but the result was achieved mainly, I believe, by respiratory exercises. The patient threw himself enthusiastically into the treatment, and for many months spent an hour every morning and evening in exercises. This gradually lessened the vaso-motor instability. The dread that the tendency to blush would return persisted for some time, but eventually yielded to mental treatment.

The subjoined is a case of severe hypochondria in which respiratory exercises did great good:

M., æt. 30. Has for some years thrown great energy into his business. Lives in constant fear of having some deadly malady. If he feels a pain, or unpleasant sensation anywhere, at once fancies it is the precursor of some terrible illness, and even after he has been assured, and apparently convinced of the contrary, will again and again recur to the matter. Thus on one occasion he experienced numbness in the feet, and it was with the greatest difficulty he could be persuaded that it was not locomotor ataxy; and, on another occasion, an urticarial rash made him fancy he was going to get typhoid.

This patient rapidly improved under a course of respiratory exercises, and though he is still inclined to exaggerate the importance of trivial symptoms, he is practically cured.

NOTE.—As showing how profoundly breathing exercises affect the nervous system, I may mention that a patient now under treatment informs me that his susceptibility to alcohol is very decidedly diminished by taking a series of deep breaths.

CHAPTER XXV.

RESPIRATORY EXERCISES IN THE TREATMENT OF DIGESTIVE DISORDERS.

Disorders of digestion may often be greatly benefited by breathing exercises, which are capable of profoundly influencing the circulation of lymph and blood in the digestive viscera. It must be remembered that general muscle-exercises, such as walking, running, cycling, are incapable of producing such a localized effect, for in their case the effect upon the circulation is widespread, the splanchnic circulation being often depressed, rather than stimulated, owing to the determination of a large mass of blood to the musculo-cutaneous system. Hence it is that active muscle-exercise after a meal tends to retard, rather than to promote, digestion. But by suitable and specially-adapted breathing exercises we are able to determine a large flow of blood to the splanchnic area, and at the same time to quicken the flow through it, and we are also able to accelerate the flow of chyle. As a result, the nutrition of the liver and alimentary tube is stimulated. The latter acquires increased tone, and is thus enabled to contract more effectively upon its contents, while the secretion of the digestive juices and the absorption of the food-stuffs are promoted.

Most forms of dyspepsia, gastric and intestinal, benefit by suitable breathing exercises, but perhaps the atonic forms chiefly. Intestinal dyspepsia has not yet received the attention it merits. Many a one who does not suffer from any of the obtrusive symptoms of gastric dyspepsia, such as pain, flatulence, weight, and acidity, and who would stoutly deny the charge of being dyspeptic, is a martyr to intestinal dyspepsia and to the many forms of blood-poisoning which it entails. In cases of this kind we shall often find breathing exercises a most valuable adjunct to other treatment.

'As regards the movements of the stomach proper,' writes Allchin,* 'there is reason to believe that they are capable of being aided in their effect upon the gastric contents by the movements of the diaphragm and even of the heart, which may together be sufficiently effective to compensate for the complete absence of the stomach peristalsis when that organ, by adhesions or other causes, is incapable of acting.' If such is the case, how much more likely are we to act mechanically upon the stomach (and intestines) by special exercises of the diaphragm and anterior abdominal muscles! How potently these act is well shown by their power to dislodge flatus. This in itself is no small gain, seeing how distressing are the symptoms resulting from its mere mechanical presence.

These exercises will be found of great benefit in treating constipation. Quite recently a patient to whom I had recommended them for quite another cause wrote, saying that he intended to persevere in them if only because they enabled him to have a daily evacuation.

In selecting the exercises for dyspepsia, we should choose those which have the most effect upon the abdominal circulation. One of the most valuable is alternate contraction of the diaphragm (while firm pressure is made on the abdomen) and retraction of the belly. The exercises for strengthening the abdominal muscles (especially when the latter are flabby) will also be found of the greatest service.

* *Lancet*, 1897, vol. ii., p. 1031.

CHAPTER XXVI.

RESPIRATORY EXERCISES IN OTHER DISEASES.

Respiratory exercises may be employed with benefit in many other diseases than those already mentioned. To refer to some of these briefly.

Gall-stones.—William Hunter has shown that catarrh of the gall-bladder and bile-ducts plays an important part in the causation of gall-stones, this catarrh in the case of the gall-bladder and large ducts being for the most part due to infection from the bowel, and in the case of the smaller ducts to the elimination by them of poisonous substances from the blood. The second great factor is sluggishness of the bile-flow, which favours the formation of gall-stones not only directly, but also indirectly, by inducing catarrh.*

This second factor we can do a great deal to remove. There are several mechanical interferences with the active flow of bile. Such are: a lax state of the abdominal walls, which allows 'the liver to fall down, so that the fundus of the gall-bladder is considerably below the level of the junction of the cystic duct with the hepatic duct' (Hunter); a

* *Brit. Med. Jour.*, 1897, vol. ii., pp. 1235-1240. Hunter insists that 'stagnation alone is not sufficient to cause the condition.' That it is not a necessary factor is shown by the fact that gall-stones may occur in those leading active lives. I have recently had under observation a man of fine physique and a champion runner who was suffering from complete biliary obstruction owing to the impaction of a gall-stone in the common duct.

sedentary life, in which the liver is no longer shaken and compressed as it is by active exercise; and interference with the proper abdominal breathing, during which the liver is rhythmically compressed between the diaphragm and anterior abdominal wall. It is probably in this way that pregnancy and tight-lacing favour the production of gall-stones. One half of the women whose livers show evidence post-mortem of tight-lacing are found to have them.

From these considerations it is manifest that anything which favours the flow of bile tends to check their formation, and there is no more efficient way of doing this than by exercises of the diaphragm and abdominal muscles. We should also seek to prevent catarrh of the bile-ducts by keeping the alimentary tract in a healthy state. Finally, we should advise the drinking of large quantities of water; for, as Lauder Brunton observes, sufferers from gall-stones are frequently very small drinkers.

Obesity.—It is a well-recognised fact that obesity is predisposed to by defective oxygenation of the tissues. It is for this reason that the chlorotic have a tendency to plumpness. It is not therefore surprising that respiratory exercises, by increasing blood oxygenation, should tend to promote fat absorption. It should be remembered in this connection that great obesity favours the further deposit of fat by interfering with the respiratory movements, and thus with the proper aeration of the blood.

Prolonged treatment by means of the compressed-air chamber reduces obesity.

Anæmia.—Breathing exercises will be found of great service in the treatment of anæmia, but especially of chlorosis. It is evident that whatever increases the amount of oxygen in the blood when this fluid is defective in it, must be of benefit.

Epistaxis.—For this a writer in the *Medical Annual* (1896, p. 290) recommends 'very rapid breathing with open mouth, the vowel A being enunciated with each expiration.'

Stammering.—It is now known that many cases of stammering are due to faulty breathing, and in consequence they yield to breathing exercises systematically carried out. The diaphragm is often the muscle chiefly at fault.

Hiccough.—An old-fashioned remedy for hiccough is to hold the breath for a time. The best plan is to take a series of rapid diaphragmatic breaths, holding the breath at intervals for as long as possible, with the object of breaking the convulsive habit of the diaphragm.

Sleeplessness.—Deep breaths are very helpful in inducing sleep.

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THE END.

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