short, to the veins, which are capacious, distensible and but slightly contractile. This begins immediately after death while the contractility of the muscular coat of the arteries remains, and is seconded by the subsequent cadaveric rigidity, which affects all the involuntary as well as the voluntary muscular fibres. Once in the venous system, the blood can not return on account of the valves. Thus, after death, the blood is found in the veins and capillaries of dependent parts of the body.

CHAPTER IV.

RESPIRATION—RESPIRATORY MOVEMENTS.

General considerations—Physiological anatomy of the respiratory organs—Movements of respiration—Inspiration—Muscles of inspiration—Expiration—Muscles of expiration—Types of respiration—Frequency of the respiratory movements—Relations of inspiration and expiration to each other—Respiratory sounds—Capacity of the lungs and the quantity of air changed in the respiratory acts—Residual air—Reserve air—Tidal, or breathing air—Complemental air—Extreme breathing capacity—Relations in volume of the expired to the inspired air—Diffusion of air in the lungs.

THE characters of the blood are by no means identical in the three great divisions of the vascular system; but physiologists have thus far been able to investigate only the differences which exist between arterial and venous blood, for the capillaries are so short, communicating directly with the arteries on the one side and the veins on the other, that it is impossible to obtain a specimen of true capillary blood. In the capillaries, however, the nutritive fluid, which is identical in all parts of the arterial system, undergoes changes which render it unfit for nutrition. Thus modified it is known as venous blood; and the only office of the veins is to carry it back to the right side of the heart, to be sent to the lungs, where it loses the vitiating substances it has collected in the tissues, takes in a fresh supply of oxygen and goes to the left, or systemic heart, again prepared for nutrition. As the processes of nutrition vary in different parts of the organism, there are of necessity corresponding variations in the composition of the blood in different veins.

The important substances that are given off by the lungs are exhaled from the blood; and the gas which disappears from the air is absorbed by the blood, mainly by the red corpuscles.

A proper supply of oxygen is indispensable to nutrition and even to the comparatively mechanical process of circulation; but it is no less necessary to the nutritive processes that carbon dioxide, which the blood acquires in the tissues, should be removed.

Respiration may be defined strictly as the process by which the various tissues and organs receive and appropriate oxygen.

As it is almost exclusively through the blood that the tissues and organs are supplied with oxygen, and as the blood receives and exhales most of the carbon dioxide, the respiratory process in the lungs may be said to consist

chiefly in the change of venous into arterial blood; but experiments have demonstrated that the tissues themselves, detached from the body and placed in an atmosphere of oxygen, will absorb this gas and exhale carbon dioxide. Under these conditions they certainly respire; and it is evident, therefore, that in this process, the intervention of the blood is not an absolute necessity.

The tide of air in the lungs does not strictly constitute respiration. These organs merely serve to facilitate the introduction of oxygen into the blood and the exhalation of carbon dioxide. If the system be drained of blood or if the blood be rendered incapable of interchanging its gases with the air, respiration ceases, and all the phenomena of asphyxia are presented, although air be introduced into the lungs with perfect regularity. It must be remembered that the essential processes of respiration take place in all the tissues and organs of the system and not in the lungs. Respiration is a process similar to what are known as the processes of nutrition; and although it is much more active and uniform than are the ordinary nutritive changes, it is inseparably connected with and strictly a part of the general process. As in the nutrition of the tissues the nitrogenized constituents of the blood, united with inorganic substances, are transformed into the tissue itself, finally changed into excrementitious products, such as the urinary matters, and discharged from the body, so the oxygen of the blood is appropriated, and carbon dioxide, which is an excrementitious substance, is produced, whenever tissues are worn out and regenerated. There is a necessary and inseparable connection between all these processes; and they must be considered, not as distinct in themselves, but as different parts of the general function of nutrition.

As physiologists are unable to follow out all the intermediate changes which take place between the appropriation of nutritive materials from the blood and the production of effete, or excrementitious substances, it is impossible to say precisely how oxygen is used by the tissues and how carbon dioxide is produced. It is known only that more or less oxygen is necessary to the nutrition of all tissues, in all animals, high or low in the scale, and that the tissues produce a certain quantity of carbon dioxide. The fact that oxygen is consumed with much greater rapidity than any other nutritive substance and that the production of carbon dioxide is correspondingly active, as compared with other effete products, points to a connection between the absorption of the one and the production of the other.

The essential conditions for respiration in animals which have a circulating nutritive fluid are air and blood separated by a membrane which will allow the passage of gases. The effete products of respiration contained in the blood, the most important of which is carbon dioxide, pass out and vitiate the air. The air is deprived of a certain portion of its oxygen, which passes into the blood, to be conveyed to the tissues. Thus the air must be changed to supply fresh oxygen and get rid of the carbon dioxide. The rapidity of this change is in proportion to the nutritive activity of the animal and the rapidity of the circulation of the blood.

Physiological Anatomy of the Respiratory Organs.

Passing backward from the mouth to the pharynx, two openings are observed; a posterior opening, which leads to the œsophagus, and an anterior opening, the opening of the larynx, which is the beginning of the passages concerned exclusively in respiration.

Beginning with the larynx, it is seen that the cartilages of which it is composed are sufficiently rigid and unyielding to resist the pressure produced by any inspiratory effort. Across its superior opening are the vocal chords, which are four in number and have a direction from before backward. The two superior are called the false vocal chords, because they are not concerned in the production of the voice. The two inferior are the true vocal chords. They are ligamentous bands covered by folds of mucous membrane, which is

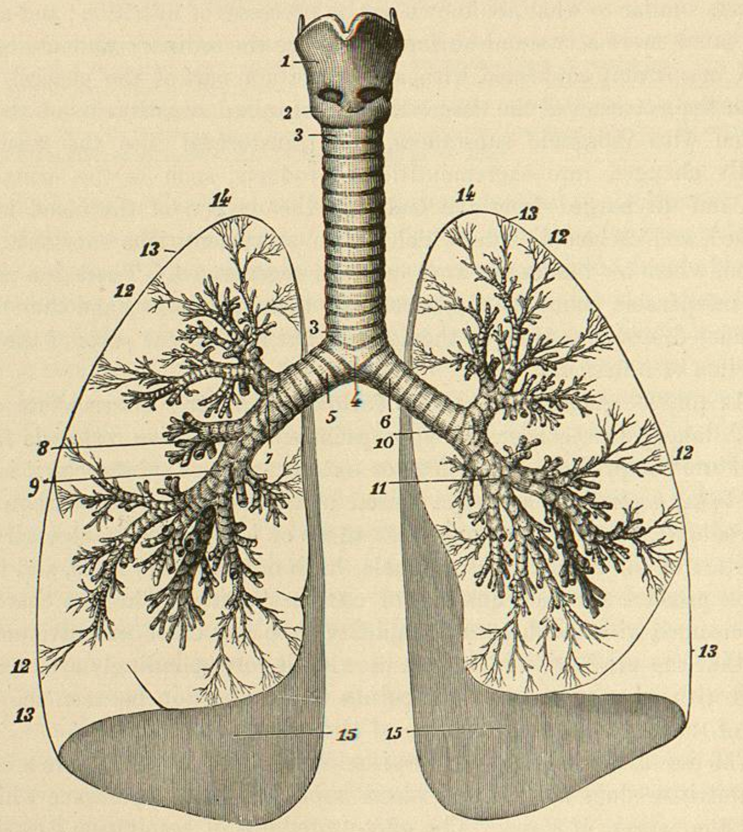

Fig. 39.—*Trachea and bronchial tubes* (Sappey).

1, 2, larynx; 3, 3, trachea; 4, bifurcation of the trachea; 5, right bronchus; 6, left bronchus; 7, bronchial division to the upper lobe of the right lung; 8, division to the middle lobe; 9, division to the lower lobe; 10, division to the upper lobe of the left lung; 11, division to the lower lobe; 12, 12, 12, 12, ultimate ramifications of the bronchia; 13, 13, 13, 13, lungs, represented in contour; 14, 14, summit of the lungs; 15, 15, base of the lungs.

quite thick on the superior chords and very thin and delicate on the true vocal chords. These bands are attached anteriorly to a fixed point between

the thyroid cartilages, and posteriorly, to the movable arytenoid cartilages. Air is admitted to the trachea through an opening between the chords, which is called the rima glottidis. Little muscles, arising from the thyroid and cricoid and attached to the arytenoid cartilages, are capable of separating and approximating the points to which the vocal chords are attached posteriorly, so as to open and close the rima glottidis.

If the glottis be exposed in a living animal, certain regular movements are presented, which are synchronous with the acts of respiration. The larynx is slightly opened at each inspiration, by the action of the muscles referred to above, so that the air has a free entrance to the trachea. At the termination of the inspiratory act these muscles are relaxed, the vocal chords fall together by their own elasticity, and in expiration, the chink of the glottis returns to the condition of a narrow slit. The expulsion of air from the lungs in tranquil respiration is a passive process and tends in itself to separate the vocal chords; but inspiration, which is active, were it not for the movements of the glottis, would have a tendency to draw the vocal chords together. The muscles which are concerned in producing these movements are animated by the inferior laryngeal branches of the pneumogastric nerves. The respiratory movements of the larynx are entirely distinct from those concerned in the production of the voice.

Attached to the anterior portion of the larynx, is the epiglottis, a little, leaf-shaped lamella of fibro-cartilage, which, during ordinary respiration, projects upward and lies against the posterior portion of the tongue. During the act of deglutition, respiration is momentarily interrupted, and the air-passages are protected by the tongue, which presses backward, carrying the epiglottis before it and completely closing the opening of the larynx. Physiologists have questioned whether the epiglottis be necessary to the complete protection of the air-passages; and it has frequently been removed from the lower animals without apparently interfering with the proper deglutition of solids or liquids (Magendie). It is a question, however, whether the results of this experiment can be absolutely applied to the human subject. In a case of loss of the entire epiglottis, which was observed in the Bellevue Hospital, the patient experienced slight difficulty in swallowing, from the passage of little particles into the larynx, which produced cough. This case, and others of a similar character which are on record, show that the presence of the epiglottis, in the human subject at least, is necessary to the complete protection of the air-passages in deglutition.

Passing down the neck from the larynx toward the lungs, is the trachea, which is four to four and a half inches (10·16 to 11·43 centimetres) in length and about three-quarters of an inch (19·1 mm.) in diameter. It is provided with cartilaginous rings, sixteen to twenty in number, which partially surround the tube, leaving about one-third of its posterior portion occupied by fibrous tissue mixed with a certain number of non-striated muscular fibres. Passing into the chest, the trachea divides into the two primitive bronchia, the right being shorter, larger and more horizontal than the left. These tubes, provided, like the trachea, with imperfect cartilaginous rings, enter the lungs, divide and subdivide, until the minute ramifications of the bronchial tree open directly into the air-cells. After penetrating the lungs, the carti-

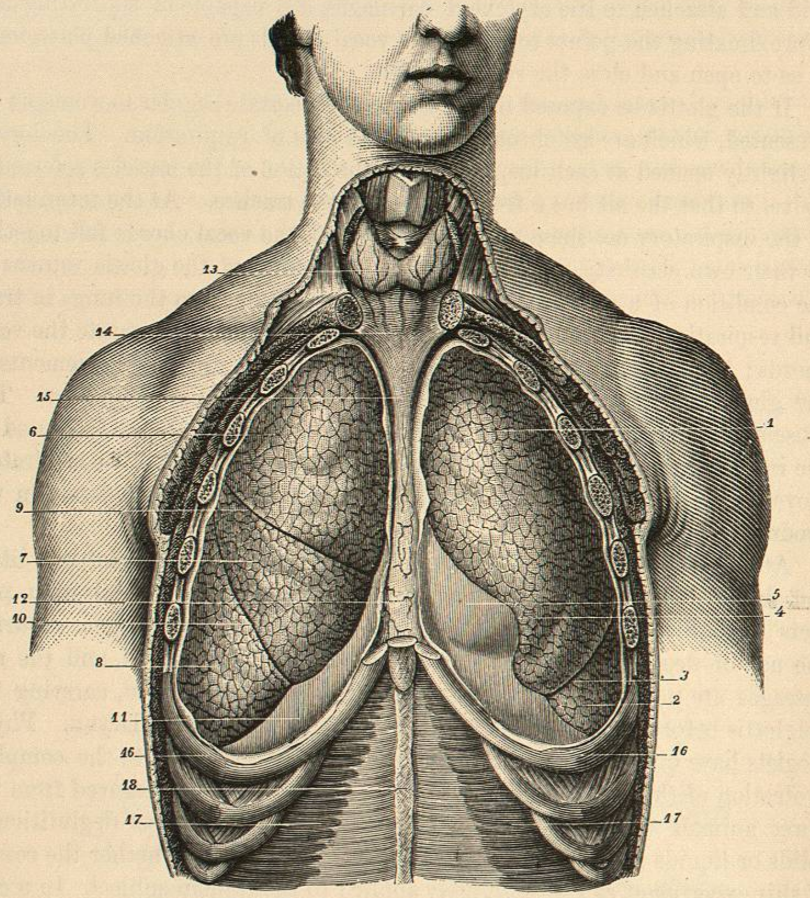

FIG. 40.—*Lungs, anterior view* (Sappey).

1, *upper lobe of the left lung*; 2, *lower lobe*; 3, *fissure*; 4, *notch corresponding to the apex of the heart*; 5, pericardium: 6, *upper lobe of the right lung*; 7, *middle lobe*; 8, *lower lobe*; 9, *fissure*; 10, *fissure*; 11, diaphragm; 12, anterior mediastinum; 13, thyroid gland; 14, middle cervical aponeurosis; 15, process of attachment of the mediastinum to the pericardium; 16, 16, seventh ribs; 17, 17, transversales muscles; 18, linea alba.

lages become irregular and are in the form of oblong, angular plates, which are so disposed as to completely encircle the tubes. In tubes of very small size, these plates are fewer than in the larger bronchia, until, in tubes of a less diameter than $\frac{1}{50}$ of an inch (0·5 mm.), they disappear.

The walls of the trachea and bronchial tubes are composed of two distinct membranes; an external membrane, between the layers of which the cartilages are situated, and a lining, mucous membrane. The external membrane is composed of inelastic and elastic fibrous tissue. Posteriorly, in the space not covered by cartilaginous rings, these fibres are mixed with a certain number of non-striated muscular fibres, which exist in two layers; a thick, internal layer, in which the fibres are transverse, and a thinner, longitudinal layer,

which is external. The collection of muscular fibres in the posterior part of the trachea is sometimes called the trachealis muscle. Throughout the bronchial tubes, there are circular fasciculi of non-striated muscular fibres lying just beneath the mucous membrane, with a number of longitudinal elastic fibres. The character of the bronchia abruptly changes in tubes less than $\frac{1}{50}$ of an inch (0·5 mm.) in diameter. They then lose the cartilaginous rings, and the external and the mucous membranes become so closely united that they can no longer be separated by dissection. The circular muscular fibres continue as far as the air-cells. The mucous membrane is smooth, covered by ciliated epithelium, the movements of the cilia being always from within outward, and it is provided with mucous glands. These glands are of the racemose variety and in the larynx they are of considerable size. In the trachea and bronchia, racemose glands exist in the membrane on the posterior surface of the tubes; but anteriorly are small follicles, terminating in a single, and sometimes a double, blind extremity. These follicles are lost in tubes measuring less than $\frac{1}{50}$ of an inch (0·5 mm.) in diameter.

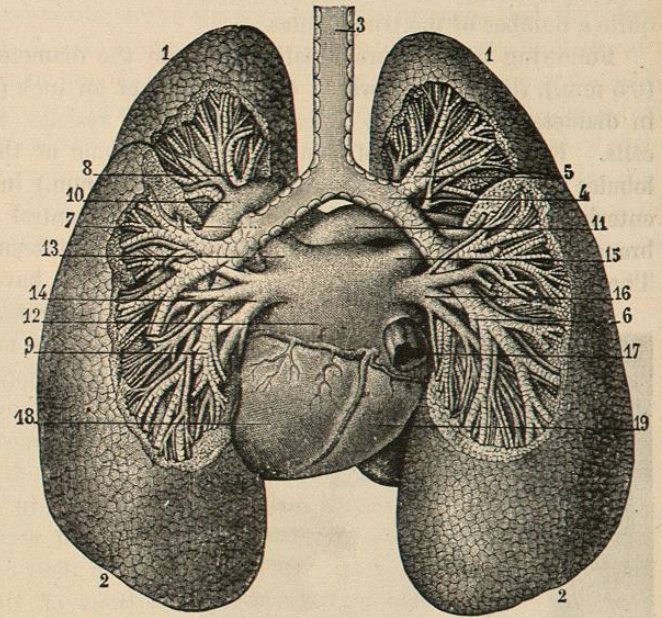

FIG. 41.—*Bronchia and lungs, posterior view* (Sappey).

1, 1, *summit of the lungs*; 2, 2, *base of the lungs*; 3, *trachea*; 4, *right bronchus*; 5, *division to the upper lobe of the lung*; 6, *division to the lower lobe*; 7, *left bronchus*; 8, *division to the upper lobe*; 9, *division to the lower lobe*; 10, left branch of the pulmonary artery; 11, right branch; 12, left auricle of the heart; 13, left superior pulmonary vein; 14, left inferior pulmonary vein; 15, right superior pulmonary vein; 16, right inferior pulmonary vein; 17, inferior vena cava; 18, left ventricle of the heart; 19, right ventricle.

When moderately inflated, the lungs have the appearance of irregular cones, with rounded apices, and concave bases resting upon the diaphragm. They fill that part of the cavity of the thorax which is not occupied by the heart and great vessels, and are completely separated from each other by the mediastinum. The lungs are in contact with the thoracic walls, each lung being covered by a reflection of the serous membrane which lines the cavity of the corresponding side. Thus they necessarily follow the movements of expansion and contraction of the thorax. Deep fissures divide the right lung into three lobes and the left lung into two. The surface of the lungs is divided into irregularly polygonal spaces, $\frac{1}{4}$ of an inch to an inch (6·4 to 25·4 mm.) in diameter, which mark what are sometimes called the pulmonary lobules; although this term is incorrect, as each of these divisions includes quite a number of the true lobules.

Following out the bronchial tubes from the diameter of $\frac{1}{50}$ of an inch (0·5 mm.), the smallest, which are $\frac{1}{120}$ to $\frac{1}{75}$ of an inch (0·21 to 0·33 mm.) in diameter, open into a collection of oblong vesicles, which are the air-cells. Each collection of vesicles constitutes one of the true pulmonary lobules and is $\frac{1}{50}$ to $\frac{1}{12}$ of an inch (0·5 to 2·1 mm.) in diameter. After entering the lobule, the tube forms a tortuous central canal, sending off branches which terminate in groups of eight to fifteen pulmonary cells. The cells are a little deeper than they are wide and have each a rounded, blind extremity. Some are smooth, but many are marked by little circular constrictions, or rugæ. In the healthy lung of the adult, after death, they measure $\frac{1}{200}$ to $\frac{1}{120}$ or $\frac{1}{70}$ of an inch (0·125 to 0·21 or 0·36 mm.) in diameter, but are capable of very great distention. The smallest cells are in the deep portions of the lungs, and the largest are situated near the surface. There are considerable variations in the size of the cells at different periods of life. The smallest cells are found in young children, and they progressively increase in size with age. The walls of the air-cells contain very abundant small, elastic fibres, which do not form distinct bundles for each air-cell, but anastomose freely with each other, so that the same fibres belong to two or more cells. This structure is peculiar to the parenchyma of the lungs and gives to these organs their great distensibility and elasticity, properties which play an important part in expelling the air from the chest, as a consequence simply of cessation of the action of the inspiratory muscles. Interwoven with these elastic fibres, is the richest plexus of capillary blood-vessels found in the economy. The vessels are larger than the capillaries in other situations, and the plexus is so close that the spaces between them are narrower than the vessels themselves. When distended, the blood-vessels form the greatest part of the walls of the cells.

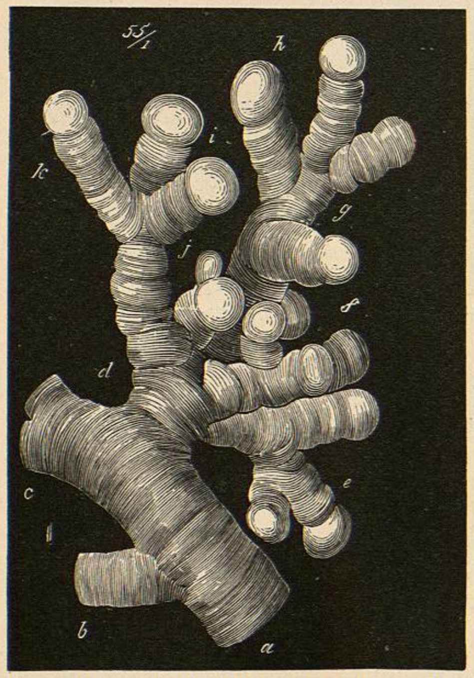

FIG. 42.—*Mould of a terminal bronchus and a group of air-cells moderately distended by injection, from the human subject* (Robin).

Lining the air-cells, are very thin cells of flattened epithelium, $\frac{1}{2500}$ to

$\frac{1}{2000}$ of an inch (10 to 12·5 μ), in diameter, which are applied directly to the walls of the blood-vessels. The epithelium here does not seem to be regularly desquamated as in other situations. Examination of injected specimens shows that the blood-vessels are so situated between the cells, that the blood in the greater part of their circumference is exposed to the action of the air.

The entire mass of venous blood is distributed in the lungs by the pulmonary artery. Arterial blood is conveyed to these organs by the bronchial arteries, which ramify and subdivide on the bronchial tubes and follow their course into the lungs, for the nourishment of these parts. It is possible that the tissue of the lungs may receive some nourishment from the blood of the pulmonary artery; but as this vessel does not send any branches to the bronchial tubes, the bronchial arteries supply the matters for their nutrition and for the secretion of the mucous glands.

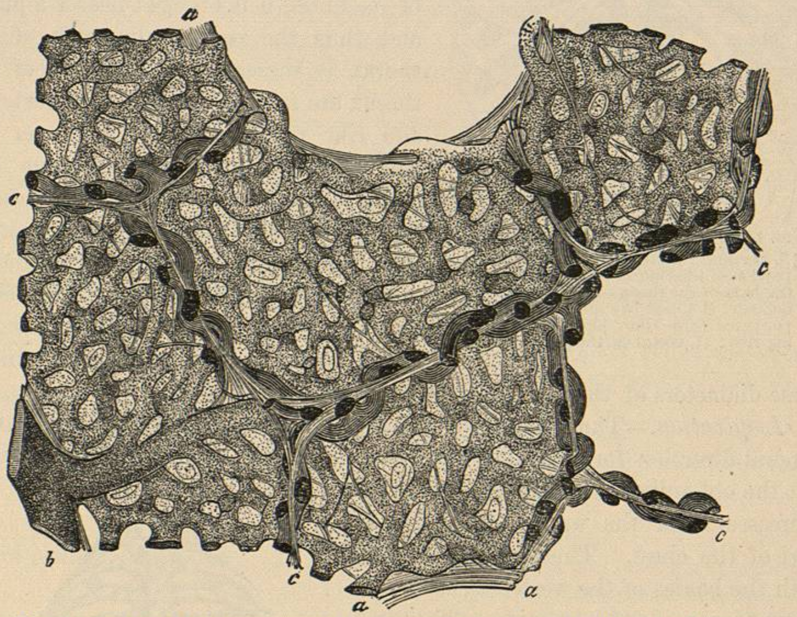

FIG. 43.—*Section of the parenchyma of the human lung, injected through the pulmonary artery* (Schulze).
a, *a*, *c*, *c*, walls of the air-cells; *b*, small arterial branch.

The foregoing anatomical sketch shows the adaptation of the trachea and bronchial tubes to the passage of the air by inspiration to the deep portions of the lungs, and the favorable conditions which it there meets with for an interchange of gases. It is also evident, from the great number of air-cells, that the respiratory surface must be very large, although it is impossible to form an accurate estimate of its extent.

MOVEMENTS OF RESPIRATION.

In man and in the warm-blooded animals generally, inspiration takes place as a consequence of enlargement of the thoracic cavity and the entrance of a quantity of air through the respiratory passages, corresponding to the increased capacity of the lungs. In the mammalia, the chest is enlarged by the action of muscles; and in ordinary respiration, inspiration is an active process, while ordinary expiration is passive.

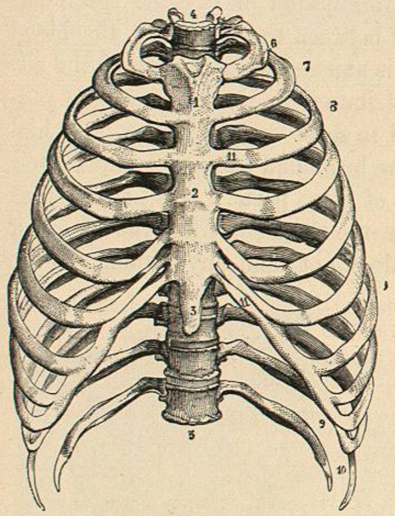

FIG. 44.—*Thorax, anterior view* (Sappey).
1, 2, 3, sternum; 4, circumference of the upper portion of the thorax; 5, circumference of the base of the thorax; 6, first rib; 7, second rib; 8, 8, last five sternal ribs; 9, upper three false ribs; 10, last two, or floating ribs; 11, costal cartilages.

A glance at the physiological anatomy of the thorax in the human subject makes it evident that the action of certain muscles will considerably increase its capacity. In the first place, the diaphragm mounts up into its cavity in the form of a vaulted arch. By contraction of its fibres, it is brought nearer a plane, and thus the vertical diameter of the thorax is increased. The walls of the thorax are formed by the dorsal vertebræ and ribs posteriorly, by the upper ten ribs laterally, and by the sternum and costal cartilages anteriorly. The direction of the ribs, their mode of connection with the sternum by the costal cartilages, and their articulation with the vertebral column, are such that by their movements, the antero-posterior and transverse diameters of the chest may be considerably modified.

Inspiration.—The ribs are somewhat twisted upon themselves and have a general direction forward and downward. The first rib is nearly horizontal, but the obliquity of the ribs progressively increases from the upper to the lower part of the chest. They are articulated with the bodies of the vertebræ, so as to allow of considerable motion. The upper seven ribs are attached by the costal cartilages to the sternum, these cartilages running upward and inward. The cartilages of the eighth, ninth and tenth ribs are joined to the cartilage of the seventh. The eleventh and twelfth are floating ribs and are attached only to the vertebræ.

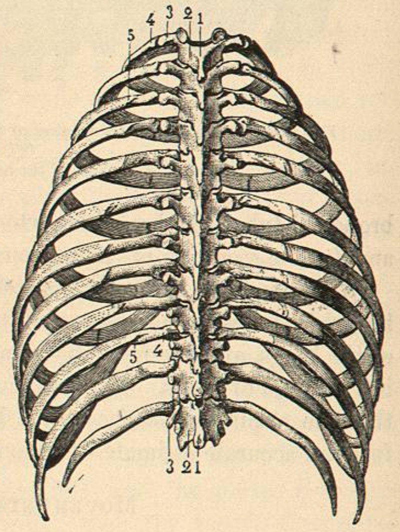

FIG. 45.—*Thorax, posterior view* (Sappey).
1, 1, spinous processes of the dorsal vertebræ; 2, 2, laminæ of the vertebræ; 3, 3, transverse processes; 4, 4, dorsal portions of the ribs; 5, 5, angles of the ribs.

It may be stated in general terms that inspiration is effected by descent of the diaphragm and elevation of the ribs; and expiration, by elevation of the diaphragm and descent of the ribs.

Arising severally from the lower border of each rib and attached to the up-

per border of the rib below, are the eleven external intercostal muscles, the fibres of which have an oblique direction from above downward and forward. Attached to the inner borders of the ribs, are the internal intercostals, which have a direction from above downward and backward, nearly at right angles to the fibres of the external intercostals. There are also certain muscles attached to the thorax and spine, thorax and head, upper part of humerus, etc., which are capable of elevating either the entire chest or the ribs. These must act as muscles of inspiration when the attachments to the thorax become the movable points. Some of them are called into action during ordinary respiration; others act as auxiliaries when respiration is a little exaggerated, as after exercise, and are called ordinary auxiliaries; while others, which ordinarily have different uses, act only when respiration is difficult, and are called extraordinary auxiliaries.

The following are the principal muscles concerned in inspiration:

MUSCLES OF INSPIRATION.

MUSCLE.	ATTACHMENTS.
Ordinary Respiration.	
Diaphragm	Circumference of lower border of thorax.
Scalenus anticus	Transverse processes of third, fourth, fifth and sixth cervical vertebræ——tubercle of first rib.
Scalenus medius	Transverse processes of lower six cervical vertebræ——upper surface of first rib.
Scalenus posticus	Transverse processes of lower two or three cervical vertebræ——outer surface of second rib.
External intercostals	Outer borders of the ribs.
Sternal portion of internal intercostals	Borders of the costal cartilages.
Twelve levatores costarum	Transverse processes of dorsal vertebræ——ribs, between the tubercles and angles.
Ordinary Auxiliaries.	
Serratus posticus superior	Ligamentum nuchæ, spinous processes of last cervical and upper two or three dorsal vertebræ——upper borders of second, third, fourth and fifth ribs, just beyond the angles.
Sterno-mastoideus	Upper part of sternum——mastoid process of temporal bone.
Extraordinary Auxiliaries.	
Levator anguli scapulæ	Transverse processes of upper three or four cervical vertebræ——posterior border of superior angle of scapula.
Trapezius (superior portion)	Ligamentum nuchæ and seventh cervical vertebra——upper border of spine of scapula.
Pectoralis minor	Coracoid process of scapula——anterior surface and upper margins of third, fourth and fifth ribs, near the cartilages.
Pectoralis major (inferior portion)	Bicipital groove of humerus——costal cartilages and lower part of sternum.
Serratus magnus	Inner margin of posterior border of scapula——external surface and upper border of upper eight ribs.