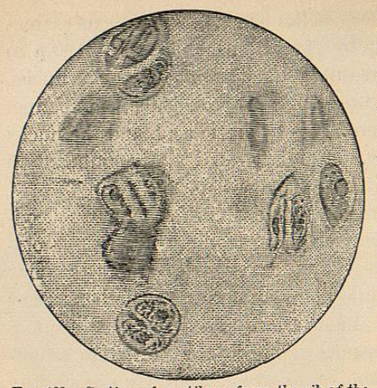


FIG. 163.—*Section of cartilage from the rib of the ox, showing the homogeneous fundamental substance, cartilage-cavities and cartilage-cells; magnified 370 diameters* (from a photograph taken at the United States Army Medical Museum).

regenerated. The importance of the periosteum has been still farther illustrated by the experiments of Ollier and others, upon transplantation of this membrane in the different tissues of living animals, which has been followed by the formation of bone in these situations.

Physiological Anatomy of Cartilage.—In this connection the structure of the articular cartilages presents the chief physiological interest. The articular surfaces of all the bones are encrusted with a layer of cartilage, varying in thickness between $\frac{1}{50}$ and $\frac{1}{25}$ of an inch (0·5 and 1 mm.). The cartilaginous substance is white, opaline, and semi-transparent when examined in thin sections. It is not covered with a membrane, but in the non-articular cartilages it has an investment analogous to the periosteum.

Examined in thin sections, cartilage is found to consist of a homogeneous fundamental substance, marked with excavations, called cartilage-cavities or chondroplasts. The intervening substance has a peculiar organic constituent, called chondrine. The organic matter is united with a certain proportion of inorganic salts. This fundamental substance is elastic and resisting. The cartilages are closely united to the subjacent bony tissue. The free articular surface has already been described in connection with the synovial membranes.

Cartilage-Cavities.—These cavities are rounded or ovoid, measuring $\frac{1}{1250}$ to $\frac{1}{300}$ of an inch (20 to 80 μ) in diameter. They are generally smaller in the articular cartilages than in other situations, as in the costal cartilages. They are simple excavations in the fundamental substance, have no lining membrane, and they contain a small

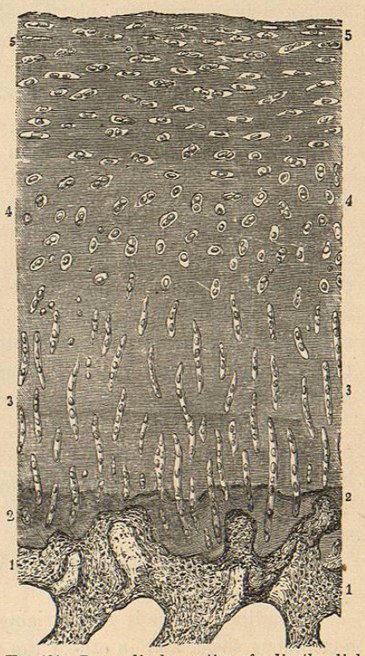


FIG. 164.—*Perpendicular section of a diarthrodial cartilage* (Sappey).

1, 1, osseous tissue; 2, 2, superficial layer of osseous tissue treated with hydrochloric acid; 3, 3, cavities and cells of the deep layer of cartilage; 4, 4, cavities and cells of the middle layer; 5, 5, cavities and cells of the superficial layer.

quantity of a viscid liquid with one or more cells. They are analogous to the lacunæ of the bones.

Cartilage-Cells.—Near the surface of the articular cartilages the cavities contain each a single cell; but in the deeper portions the cavities are long and contain two to twenty cells arranged longitudinally. The cells are of about the size of the smallest cavities. They are ovoid, with a large, granular nucleus. They often contain a few small globules of oil. In the costal cartilages the cavities are not abundant but are rounded and quite large. The cells contain generally a certain quantity of fatty matter. The appearance of the ordinary articular cartilage is represented in Fig. 164.

The ordinary cartilages have neither blood-vessels, lymphatics nor nerves, and are nourished by imbibition from the surrounding parts. In the development of the body, the anatomy of the cartilaginous tissue possesses peculiar importance, from the fact that the deposition of cartilage, with a few exceptions, precedes the formation of bone.

Fibro-Cartilage.—This variety of cartilage presents certain important peculiarities in the structure of its fundamental substance. It exists in the synchondroses, the cartilages of the ear and of the Eustachian tubes, the interarticular disks, the intervertebral cartilages, the cartilages of Santorini and of Wrisberg, and the epiglottis.

Fibro-cartilage is composed of true fibrous tissue with a great predominance of elastic fibres, fusiform, nucleated fibres, a certain number of adipose

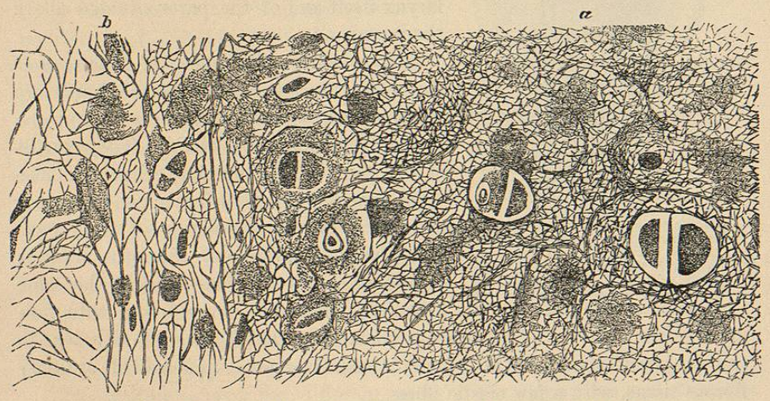


FIG. 165.—*Section of the cartilage of the ear of the human subject* (Rollett).
a, fibro-cartilage; *b*, connective tissue. In this preparation, the cartilage had been boiled and dried.

vesicles, cartilage-cells, blood-vessels and nerves (Sappey). The fibrous elements above mentioned take the place of the homogeneous fundamental substance of the true cartilage. The most important peculiarity in the structure of this tissue is that it is abundantly supplied with blood-vessels and nerves.

The reader is referred to works upon anatomy for a history of the action of the muscles. In some works upon physiology, will be found descriptions

of the acts of walking, running, leaping, swimming etc.; but it has been thought better to omit these subjects, rather than to enter so minutely as would be necessary into anatomical details and to give elaborate descriptions of movements that are simple and familiar.

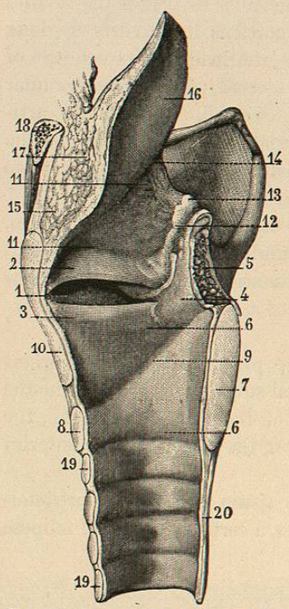


FIG. 166.—*Longitudinal section of the human larynx, showing the vocal chords* (Sappey).

1, ventricle of the larynx; 2, superior vocal chord; 3, inferior vocal chord; 4, arytenoid cartilage; 5, section of the arytenoid muscle; 6, 6, inferior portion of the cavity of the larynx; 7, section of the posterior portion of the cricoid cartilage; 8, section of the anterior portion of the cricoid cartilage; 9, superior border of the cricoid cartilage; 10, section of the thyroid cartilage; 11, 11, superior portion of the cavity of the larynx; 12, 13, arytenoid gland; 14, 16, epiglottis; 15, 17, adipose tissue; 18, section of the hyoid bone; 19, 19, 20, trachea.

VOICE AND SPEECH.

The principal organ concerned in the production of the voice is the larynx. The accessory organs are the lungs, trachea, expiratory muscles, the mouth and the resonant cavities about the face. The lungs furnish the air by which the vocal chords are thrown into vibration, and the mechanism of this action is merely a modification of expiration. By the action of the expiratory muscles the intensity of vocal sounds is regulated. The trachea not only conducts the air to the larynx, but it may assist, by resonance, in modifying the quality of the voice. Most of the variations in the tone and quality, however, are effected by the action of the larynx itself and of the parts situated above the larynx.

Sketch of the Physiological Anatomy of the Vocal Organs.—The vocal chords are stretched across the superior opening of the larynx from before backward. They consist of two pairs. The superior, called the false vocal chords or the ventricular bands, are not concerned in the production of the voice. They are less prominent than the inferior chords, although they have nearly the same direction. They are covered by a thin mucous membrane, which is closely adherent to the subjacent tissue. The chords themselves are composed of ordinary fibrous tissue, with a few elastic fibres.

The true vocal chords, or vocal bands, are situated just below the superior chords. Their anterior attachments are near together, at the middle of the thyroid cartilage, and are immovable. Posteriorly they are attached to the movable arytenoid cartilages; and by the action of certain muscles, their tension may be modified and the chink of the glottis may be opened or closed. These are much larger than the false vocal chords, and they contain a great number of elastic fibres. Like the superior vocal chords, they are covered with a very thin and closely adherent mucous membrane. The mucous membrane over the borders of the chords is covered with flattened epithelium

without cilia. There are no mucous glands in the membrane covering either the superior or the inferior chords. The inferior vocal chords alone are concerned in the production of the voice.

Muscles of the Larynx.—The muscles of the larynx are classified as extrinsic and intrinsic. The extrinsic muscles are attached to the outer surface of the larynx and to adjacent organs, such as the hyoid bone and the sternum. They are concerned chiefly in the movements of elevation and depression of the larynx. The intrinsic muscles are attached to the different parts of the larynx itself, and by their action upon the articulating cartilages, are capable of modifying the condition of the vocal chords.

The vocal chords can be rendered tense or loose by muscular action. Their fixed point is in front, where their extremities, attached to the thyroid cartilage, are nearly or quite in contact with each other. The arytenoid cartilages, to which they are attached posteriorly, present a movable articulation with the cricoid cartilage; and the cricoid, which is narrow in front, and is wide behind, where the arytenoid cartilages are attached, presents a movable articulation with the thyroid cartilage. It is evident, therefore, that muscles acting upon the cricoid cartilage can cause it to swing upon its two points of articulation with the inferior cornua of the thyroid, raising the anterior portion and approximating it to the lower edge of the thyroid; and as a consequence, the posterior portion, which carries the arytenoid cartilages and the posterior attachments of the vocal chords, is depressed. This action would, of course, increase the distance between the arytenoid cartilages and the anterior portion of the thyroid, elongate the vocal chords, and subject them to a certain degree of tension. Experiments have shown that such an effect is produced by the contraction of the crico-thyroid muscles.

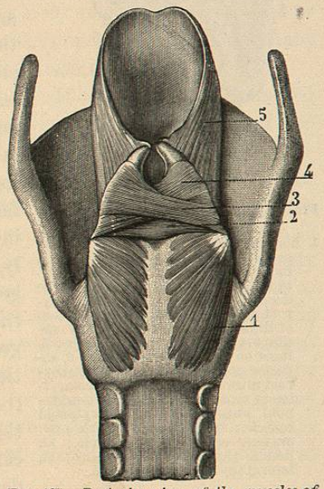


FIG. 167.—*Posterior view of the muscles of the larynx* (Sappey).

1, posterior crico-arytenoid muscle; 2, 3, 4, different fasciculi of the arytenoid muscle; 5, aryteno-epiglottidean muscle.

The articulations of the different parts of the larynx are such that the arytenoid cartilages may be approximated to each other posteriorly, thus diminishing the interval between the posterior attachments of the vocal chords. This action can be effected by contraction of the single muscle of the larynx (the arytenoid) and also by the lateral crico-arytenoid muscles. The thyro-arytenoid muscles, the most complicated of all the intrinsic muscles in their attachments and the direction of their fibres, are important in regulating the tension and capacity of vibration of the vocal chords.

The posterior crico-arytenoid muscles, arising from each lateral half of the posterior surface of the cricoid cartilage and passing upward and outward

to be inserted into the outer angle of the inferior portion of the arytenoid cartilages, rotate these cartilages outward, separate them, and act as dilators of the chink of the glottis. These muscles are chiefly concerned in the respiratory movements during inspiration.

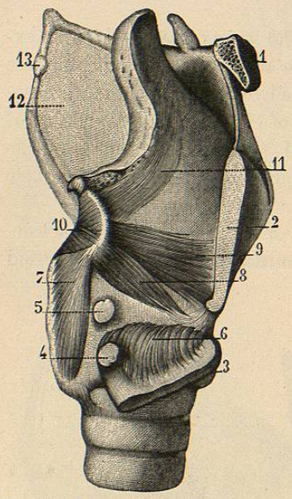


FIG. 168.—*Lateral view of the muscles of the larynx* (Sappey).

1, body of the hyoid bone; 2, vertical section of the thyroid cartilage; 3, horizontal section of the thyroid cartilage, turned downward to show the deep attachment of the crico-thyroid muscle; 4, facet of articulation of the small cornu of the thyroid cartilage with the cricoid cartilage; 5, facet on the cricoid cartilage; 6, superior attachment of the crico-thyroid muscle; 7, posterior crico-arytenoid muscle; 8, lateral crico-arytenoid muscle; 9, thyro-arytenoid muscle; 10, arytenoid muscle; 11, aryteno-epiglottidean muscle; 12, middle thyro-hyoid ligament; 13, lateral thyro-hyoid ligament.

The muscles mainly concerned in the modifications of the voice by their action upon the vocal chords, are the crico-thyroids, the arytenoid, the lateral crico-arytenoids and the thyro-arytenoids. The following is a sketch of their attachments and mode of action:

Crico-thyroid Muscles.—These muscles are situated on the outside of the larynx, at the anterior and lateral portions of the cricoid cartilage. Each muscle is of a triangular form, the base of the triangle presenting posteriorly. It arises from the anterior and lateral portions of the cricoid cartilage, and its fibres diverge to be inserted into the inferior border of the thyroid cartilage, extending from the middle of this border posteriorly, as far back as the inferior cornua. Longet, after dividing the nervous filaments distributed to these muscles, noted a certain degree of hoarseness of the voice due to relaxation of the vocal chords; and by imitating their action mechanically, he approximated the cricoid and thyroid cartilages in front, carried back the arytenoid cartilages and rendered the chords tense.

Arytenoid Muscle.—This single muscle fills up the space between the two arytenoid cartilages and is attached to their posterior surface and borders. Its action evidently is to approximate the posterior extremities of the chords and to constrict the glottis, as far as the articulations of the arytenoid cartilage with the cricoid will permit. In any event, this muscle is important in phonation, as it serves to fix the posterior attachments of the vocal chords and to increase the efficiency of certain of the other intrinsic muscles.

Lateral Crico-arytenoid Muscles.—These muscles are situated in the interior of the larynx. They arise from the sides and superior borders of the cricoid cartilage, pass upward and backward, and are attached to the base of the arytenoid cartilages. By dividing all the filaments of the recurrent laryngeal nerves, except those distributed to these muscles, and then stimulating the nerves, Longet has shown that they act to approximate the vocal chords, and that they constrict the glottis, particularly in its interligamentous portion. These muscles, with the arytenoid, act as constrictors of the larynx.

Thyro-arytenoid Muscles.—These muscles are situated within the larynx. They are broad and flat, and they arise in front from the upper part of the crico-thyroid membrane and the lower half of the thyroid cartilage. From this line of origin, each muscle passes backward in two fasciculi, both of which are attached to the anterior surface and the outer borders of the arytenoid cartilages. Stimulation of the nervous filaments distributed to these muscles renders the vocal chords tense. The great variations that may be produced in the pitch and quality of the voice by the action of muscles operating directly or indirectly upon the vocal chords render the problem of determining the precise mode of action of the intrinsic muscles of the larynx complicated and difficult. It is certain, however, that in these muscular acts, the thyro-arytenoids play an important part. Their contraction regulates the thickness of the vocal chords, while at the same time it modifies their tension. The swelling of the chords, which may be rendered regular and progressive under the influence of the will, is one of the most important elements in the formation of the timbre of the voice.

Mechanism of the Production of the Voice.—If the glottis be examined with the laryngoscope during ordinary respiration, the wide opening of the chink during forced inspiration, due to the action of the posterior crico-arytenoid muscles, can be observed without difficulty. This action is effected by a separation of the posterior points of attachment of the vocal chords to the arytenoid cartilages. During ordinary expiration, none of the intrinsic muscles seem to act and the larynx is entirely passive, while the air is gently forced out by the elasticity of the lungs and of the thoracic walls; but so soon as an effort is made to produce a vocal sound, the appearance of the glottis undergoes a change, and it becomes modified in the most varied manner with the different changes in pitch and intensity that the voice can be made to assume. Although sounds may be produced, and even words may be articulated, with the act of inspiration, true and normal phonation takes place during expiration only. It is evident, also, that the inferior vocal chords alone are concerned in this act.

Movements of the Glottis during Phonation.—It is somewhat difficult to observe with the laryngoscope all of the vocal phenomena, on account of the epiglottis, which hides a considerable portion of the vocal chords anteriorly, especially during the production of certain notes; but the patience and skill of Manuel Garcia, a celebrated teacher of singing, enabled him to overcome most of these difficulties, and to settle, by autolaryngoscopy, certain important questions with regard to the action of the larynx in singing. It is fortunate that these observations were made by one versed theoretically and practically in music and possessed of great control over the vocal organs.

Garcia, after having observed the respiratory movements of the larynx, as they have just been briefly described, noted that as soon as any vocal effort was made, the arytenoid cartilages were approximated, so that the glottis appeared as a narrow slit formed by two chords of equal length, firmly attached posteriorly as well as anteriorly. The glottis thus undergoes a marked change. A nearly passive organ, opening for the passage of air

into the lungs but entirely inactive in expiration, has now become a musical instrument, presenting a slit with borders capable of accurate vibrations.

The approximation of the posterior extremities of the vocal chords and their tension by the action of certain of the intrinsic muscles are accomplished just before the vocal effort is actually made. The glottis being thus prepared for the emission of a particular sound, the expiratory muscles force air through the larynx with the required power. The power of the voice is due simply to the force of the expiratory act, which is regulated chiefly by the antagonistic relations of the diaphragm and the abdominal muscles. From the fact that the diaphragm, as an inspiratory muscle, is exactly opposed to the muscles which have a tendency to push the abdominal organs, with the diaphragm over them, into the thoracic cavity and thus to diminish the pulmonary capacity, the expiratory and inspiratory acts may be balanced so nicely that the most delicate vocal vibrations can be produced. The glottis, thus closed as a preparation to a vocal act, presents a certain resistance to the egress of air. This is overcome by the action of the expiratory muscles, and with the passage of air through the chink, the edges of the opening, which are formed by the true vocal chords, are thrown into vibration. Many of the different qualities that are recognized in the human voice are due to differences in the length, breadth and thickness of the vibrating bands; but aside from what is technically known as quality, the pitch is dependent upon the length of the opening through which the air is made to pass and the degree of tension of the chords. The mechanism of these changes in the pitch of vocal sounds is illustrated by Garcia in the following, which relates to what is known as the chest-voice:

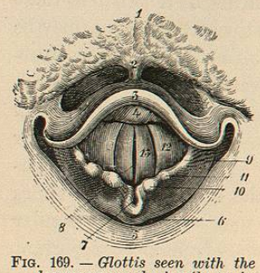
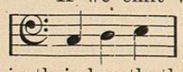
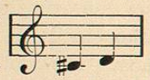


FIG. 169. — *Glottis seen with the laryngoscope during the emission of high-pitched sounds* (Le Bon).

1, 2, base of the tongue; 3, 4, epiglottis; 5, 6, pharynx; 7, aryteno-epiglottidean folds; 8, opening between the true vocal chords; 9, aryteno-epiglottidean folds; 10, cartilage of Santorini; 11, cuneiform cartilage; 12, superior vocal chords; 13, inferior vocal chords.

"If we emit veiled and feeble sounds, the larynx opens at the notes  and we see the glottis agitated by large and loose vibrations throughout its entire extent. Its lips comprehended in their length the anterior apophyses of the arytenoid cartilages and the vocal chords; but, I repeat it, there remains no triangular space.

"As the sounds ascend, the apophyses, which are slightly rounded on their internal side, by a gradual apposition commencing at the back, encroach on the length of the glottis; and as soon as we reach the sounds  they finish by touching each other throughout their whole extent; but their summits are only solidly fixed one against the other at the notes  In some organs these summits are a little vacillating when they form the posterior end of the glottis, and two or three half-tones which are formed show a certain want of purity and strength, which is very well known to singers. From

 the vibrations, having become rounder and purer, are accomplished by the vocal ligaments alone, up to the end of the register.

"The glottis at this moment presents the aspect of a line swelled toward its middle, the length of which diminishes still more as the voice ascends. We shall also see that the cavity of the larynx has become very small, and that the superior ligaments have contracted the extent of the ellipse to less than one-half."

These observations have been in the main confirmed by Battaille, Emma Seiler and others who have applied the laryngoscope to the study of the voice in singing.

In childhood the general characters of the voice are essentially the same in both sexes. The larynx is smaller than in the adult, and the vocal muscles are more feeble; but the quality of the vocal sounds at this period of life is peculiarly penetrating. While there are certain characters that distinguish the voices of boys before the age of puberty, they present, as in the female, the different qualities of the soprano and contralto. After the age of puberty, the female voice does not commonly undergo any very marked change, except in the development of additional strength and increased compass, the quality remaining the same; but in the male there is a rapid change at this time in the development of the larynx, and the voice assumes an entirely different quality. This change does not usually take place if castration be performed in early life; and this operation was frequently resorted to in the seventeenth century, for the purpose of preserving the qualities of the male soprano and contralto, particularly for church-music. It is only of late years, indeed, that this practice has fallen into disuse in Italy.

The ordinary range of all varieties of the human voice is equal to nearly four octaves; but it is rare that any single voice has a compass of more than two and a half octaves. There are examples, however, in which singers have acquired a compass of three octaves. In music the notes are written the same for the male as for the female voice, but the actual value of the female notes, as reckoned by the number of vibrations in a second, is always an octave higher than the male.

In both sexes there are differences, both in the range and the quality of the voice, which it is impossible for a cultivated musical ear to mistake. The different voices in the male are the bass, the tenor, and an intermediate voice called the barytone. The female voices are the contralto, the soprano, and the intermediate, or mezzo-soprano. In the bass and barytone, the lower and middle notes are the most natural and perfect; and while the higher notes may be acquired by cultivation, they do not possess the same quality as the corresponding notes of the tenor. The same remarks apply to the contralto and soprano.

The following scale (Landois) gives the ordinary ranges of the different kinds of voice; but it must be remembered that there are individual instances in which these limits are exceeded: