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Functional Anatomy and Physiology of Airway

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Abstract

In this chapter, we scope the importance of functional anatomy and physiology of the upper airway. The upper airway has an important role in transporting air to the lungs. Both the anatomical structure of the airways and the functional properties of the mucosa, cartilages, and neural and lymphatic tissues influence the characteristics of the air that is inhaled. The airway changes in size, shape, and position throughout its development from the neonate to the adults. Knowledge of the functional anatomy of the airway in these forms the basis of understanding the pathological conditions that may occur. The upper airway extends from the mouth to the trachea. It includes the mouth, the nose, the palate, the uvula, the pharynx, and the larynx. This section also describes the functional physiology of this airway. Managing the airway of a patient with craniofacial disorders poses many challenges to the anesthesiologist. Anatomical abnormalities may affect only intubation, only airway management, or both. This section also focuses on the abnormal airways in obesity, pregnancy, children and neonate, and patients with abnormal facial defects.

Keywords: anatomy, airway, function, physiology, upper airway

1. Introduction

The upper airway has an important role in conducting air to the lungs. Both the anatomical structure of the airways and the functional properties of the mucosa, cartilages, and neural and lymphatic tissues influence the characteristics of the air that is inhaled [1]. The upper airways begin with the nasal cavity and continue over nasopharynx and oropharynx to the larynx and the extrathoracic part of the trachea. The structure and function of this system have a major influence upon the conduction of the air to the lower airways [1]. Functions of the airway include phonation, olfaction, digestion, humidification, and warming of inspired

air [2]. Clinical application of anatomical and physiological knowledge of respiratory system improves patient's safety during anesthesia [3]. This chapter focuses on airway anatomy and physiology, which form the basis for airway management and endotracheal intubation, and also for anesthesiologists.

2. Functional anatomy and physiology of airway

The knowledge of normal anatomy and anatomic variation is important in guiding anesthesiologists in airway management planning. The airway can be divided into upper airway, which includes the nasal cavity, the oral cavity, the pharynx, and the larynx, and the lower airway, which consists of tracheobronchial tree (**Figure 1**) [4].

2.1. The upper airway

2.1.1. Nasal cavity

The nose originates in the cranial ectoderm and is composed of the external nose and the nasal cavity [2]. The nose is divided into the external nose and the nasal cavity [5]. The external nose is a pyramidal structure, situated in the midface, with its base on the facial skeleton and its apex projecting anteriorly [6]. The external nose is formed by an upper framework of bone, a series of cartilages in the lower part, and a small zone of fibro fatty tissue that forms the lateral margin of the nostril (the ala). The upper framework of bone is made up of the nasal bones, the nasal part of the frontal bones, and the frontal processes of the maxillae [5]. The paired nasal bones form the external nose superiorly and two sets of paired cartilage inferiorly. The upper lateral cartilages provide the shape of the middle third of the nose and support for the underlying nasal valve. The paired nasal bone form consists of two parts, the upper nose and the lower cartilage. The upper lateral cartilage

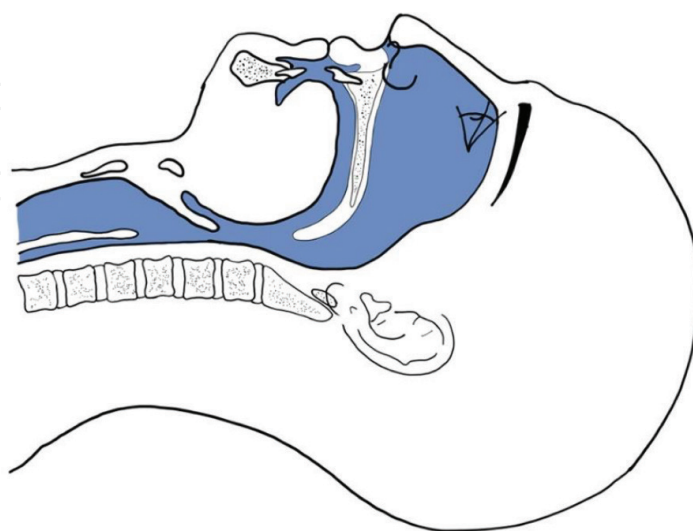


Figure 1. Functional upper airway.

provides protection which is of the shape of the middle third part of the nose and supports the nasal valve. The lower lateral cartilage segments are butterfly shaped and consist of medial and lateral crura. The medial crus forms the columellar, while the lateral crus forms the nasal area. These crura together form the nasal vestibule deficit. Cartilage is supported by nasal septum [6]. The nasal cavity is divided into two compartments by the nasal septum. One of them opens out into the nostrils. The other compartment is the nasopharynx, which opens to the concha or the posterior nasal opening. The vestibule, which includes the nostrils between the small flat nose hairs, is a small aperture [5]. **The nasal septum** divides the nasal cavity into two separate compartments. It consists of an anterior cartilaginous portion, which provides support for the nasal tip, and a posterior bony portion formed by the perpendicular plate of the ethmoid and the vomer (**Figure 2**) [6].

Deviations of the septum are very common; in fact, they are present to some degree in about 75% of the adult population. When the rapid growth in this region, septal cartilage, occurs from an unspecified minor dislocation, the deformity as often as the appearance of the second tooth structure often does not manifest itself. A distribution that supports this traumatic theory is that men are more often affected than women [5]. Due to the possibility of septum deviation, before passing instrumentation, through the nasal passages, the more open side should be determined [4]. The lateral wall of the nasal passages includes **the turbinates (the concha)**. These are three, rarely four, scroll-like projections from the lateral nasal wall. The lower two, referred to as the inferior and middle turbinates, are functionally the most significant. Each turbinate consists of a bony frame with the overlying respiratory epithelium (**Figure 3**) [6].

The **inferior meatus**, between the inferior turbinate and the floor of the nasal cavity, is the preferred pathway for the passage of nasal airway devices [4]. The cribriform plate, part of

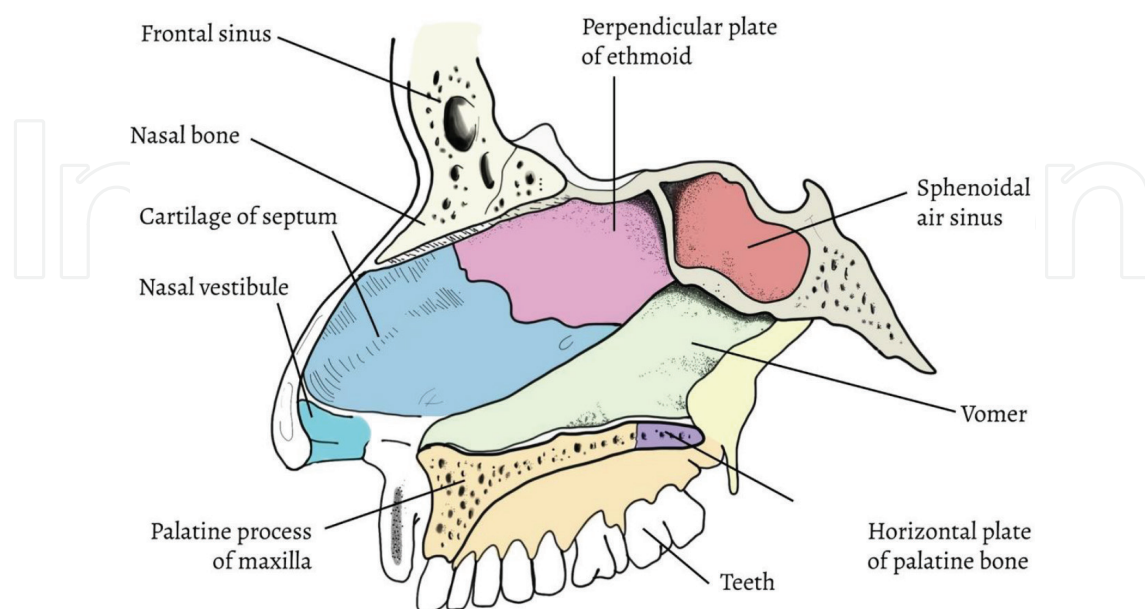


Figure 2. Nasal Sinuses.

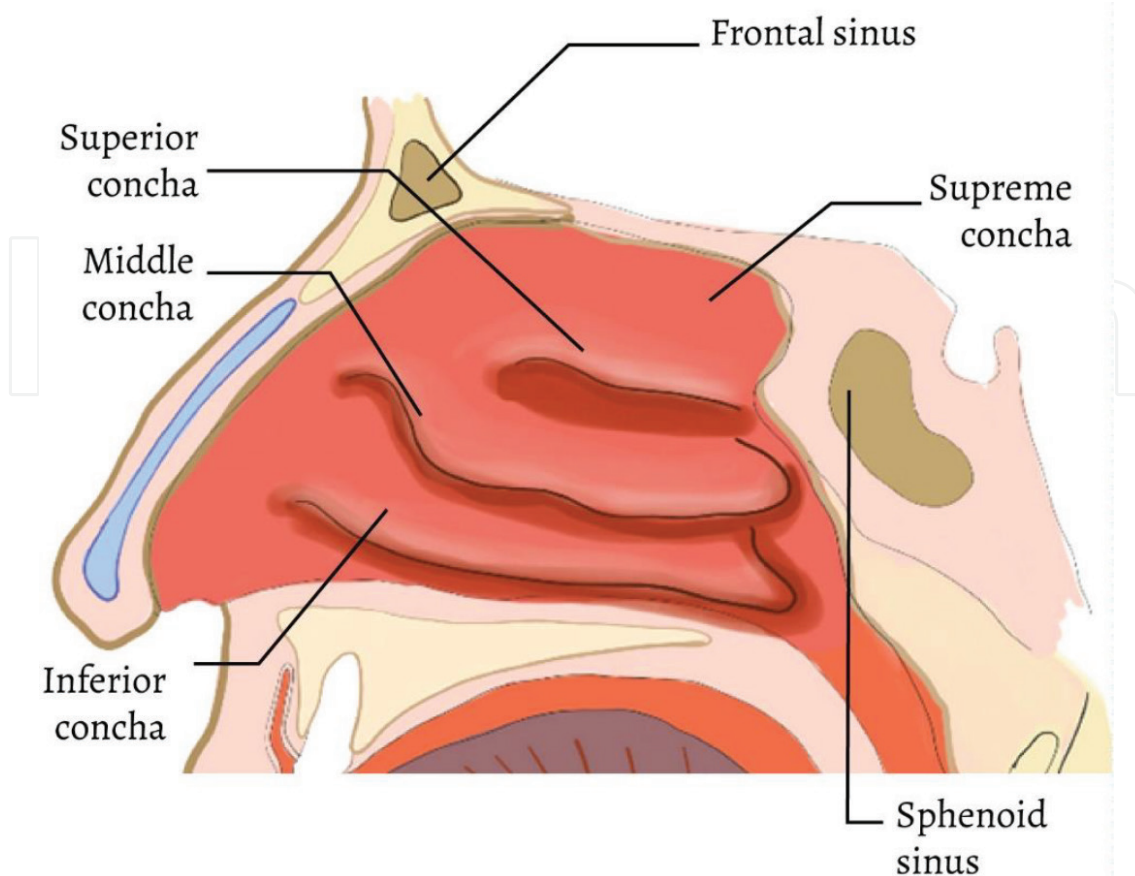


Figure 3. Lateral wall of the nasal cavity.

the ethmoid bone, is a fragile structure of the nasal cavity. This structure is in communication between the nasal and the intracranial cavity. Cerebrospinal fluid may leak when this part fractured [4]. The **paranasal sinuses** consist of the maxillary, sphenoid, frontal, and ethmoidal sinuses. They are outgoing from the lateral wall of the nasal cavity into which they drain. They are rarely symmetrical. There are traces of sinuses and sphenoid sinuses in the newborn; the remainder being between the ages of 7 and 8 depending on the development of the second teeth and the extension of the face. They only develop completely in adolescence [6].

The olfactory nerve (I) innervates the region designated as the nose-specific olfactory area, which covers an area of 2 cm² in the uppermost part of the nose and the lateral wall of the nasal cavity. The nerves of common sensation are derived from the nasociliary branch of the first division of the trigeminal nerve (V1) and also from the second, or maxillary division (V2) [4].

Blood supply: the upper part of the nasal cavity provides arterial blood flow from the anterior and posterior ethmoidal branches of the ophthalmic artery and a branch of the internal carotid artery. The sphenopalatine of the maxillary artery feeds the lower part of the cavity. The lower part of the septum is also infused by the septal part of the upper labial branch of the facial artery. This area, also known as the little area, is a region where 90% of the epistaxis develops [6].

The nose is the main portal of air exchange between the inner and the outer environment. The nose creates favorable conditions for approximately 37.8° and 100% relative humidity

of respiratory air required for vital functions, and it plays a role in conjunction with local defense and filtering of particulate matter and gases introduced. There is also a role for the individual in defending and delighting smells. In a healthy adult, the total nasal airway resistance is relatively stable, but the airflow of each nasal cavity changes in a reciprocal manner (as the flow increases in one space, the flow decreases on the other). This change in airflow, known as the nasal cycle, reflects changes in the vascular involvement of the canals and septal tuberculosities. The normal individual is unaware of this return, because the total airway resistance remains constant. During the cycle, the water vapor saturation level of the breathing air is not affected. The warning center for the nasal cycle is located in the hypothalamus [5].

2.1.2. Oral cavity

Oral cavity consists of mouth, palate, teeth, and tongue. The mouth cavity is bounded by the alveolar arch of the maxilla and the mandibula, and teeth in front, the hard and soft palate above, the anterior two-thirds of the tongue and the reflection of its mucosa forwards onto the mandible below, and the oropharyngeal isthmus behind [6]. For a secure intubation, it is important that the anesthesiologist should evaluate the condition of **the teeth** on preoperative evaluation. For a protective strategy, it is important that anesthesiologists have a thorough knowledge of the anatomy of the teeth, supporting structures, dental pathology, and techniques used in dental restoration so that they can properly identify the under-exposed teeth. Adult dentition includes 32 teeth supported by two opposing bones: mandibula and maxilla. The dentitions are divided into four sections each with eight teeth (one central front tooth, one lateral tooth, one dog, two small teeth, and three small teeth). However, the number of teeth of the infant consists of no more than 20 teeth, and each quarter has five teeth (a center cutter, a lateral cutter, a canine, and two molar teeth). The tooth is divided into two parts: the root and the crown. Healthy teeth are very strong and designed to withstand the pressures created during mastication. However, the insertion, manipulation, or removal of any airway device can cause lesions in the oral cavity. Although there is a risk of dental injury during extubation, the risk during intubation is more important. The upper maxillary teeth, especially the upper left central cutter, are the most risky of injury, but the lower and back teeth may also be injured. Patients with difficulty in intubation are 20 times more at risk for dental lesions. During laryngoscopy, the support on the upper jaw and consequently on maxillary incisors improves the line of sight and facilitates the insertion of the endotracheal tube, which explains the high incidence of dental injury during difficult intubation [7]. **The hard palate** is made up of the palatine processes of the maxillae and the horizontal plates of the palatine bones [6]. **The soft palate** hangs the back edge of the hard palate. Its free border bears the **uvula** centrally and blends on either side with the pharyngeal wall (**Figure 3**) [6]. **The tongue** is interwoven with various structures with different muscle structures [4]. Genioglossus muscle is the most clinically relevant to the anesthesiologist, which connects the tongue to the mandible (**Figure 4**) [4].

The epiglottis functionally separates oropharynx and laryngopharynx at the root of tongue. In addition, it prevents aspiration by closing the glottis during swallowing [8]. The jaw-thrust maneuver uses the sliding component of the temporomandibular junction (TMJ) to move the mandible and the attached tongue anteriorly, thereby relieving airway obstruction caused by the posterior displacement of the tongue into the oropharynx [4]. Oral cavity is more

preferred for airway instrumentation due to the narrow nasal passages and the high possibility of bleeding after trauma. Many airway procedures require adequate mouth opening. This is possible with rotation and subluxation of the temporomandibular joint [4]. The hinge movement of the mandible controls mouth opening. A horizontal gliding movement allows for subluxation of the mandible, which allows additional anterior displacement of the tongue during direct laryngoscopy (**Figure 5**) [9].

Mouth opening is an important parameter for intubation, and its definition is the distance between the mandibular and the maxillary central incisor teeth. Temporomandibular joint dysfunction, congenital fusion of the joints, trauma, tissue contracture around the mouth, and trismus may limit mouth opening [9]. The Mallampati score is a scoring scale for estimating the size of the tongue according to the oral cavity, and it can be useful in predicting whether or not the laryngoscope will be easy to move with the laryngoscope blade. In addition, it also assists in whether or not the opening of the mouth to allow intubation [10]. Protrusions of the anterior teeth are among the factors affecting intubation. During laryngoscopy and placement of the intubation tube, the anterior teeth and tongue will affect the imaging on the oral cavity [9]. A small mandibular space may fail to adequately accommodate tongue displacement, thus interfering with visualization of the larynx [9].

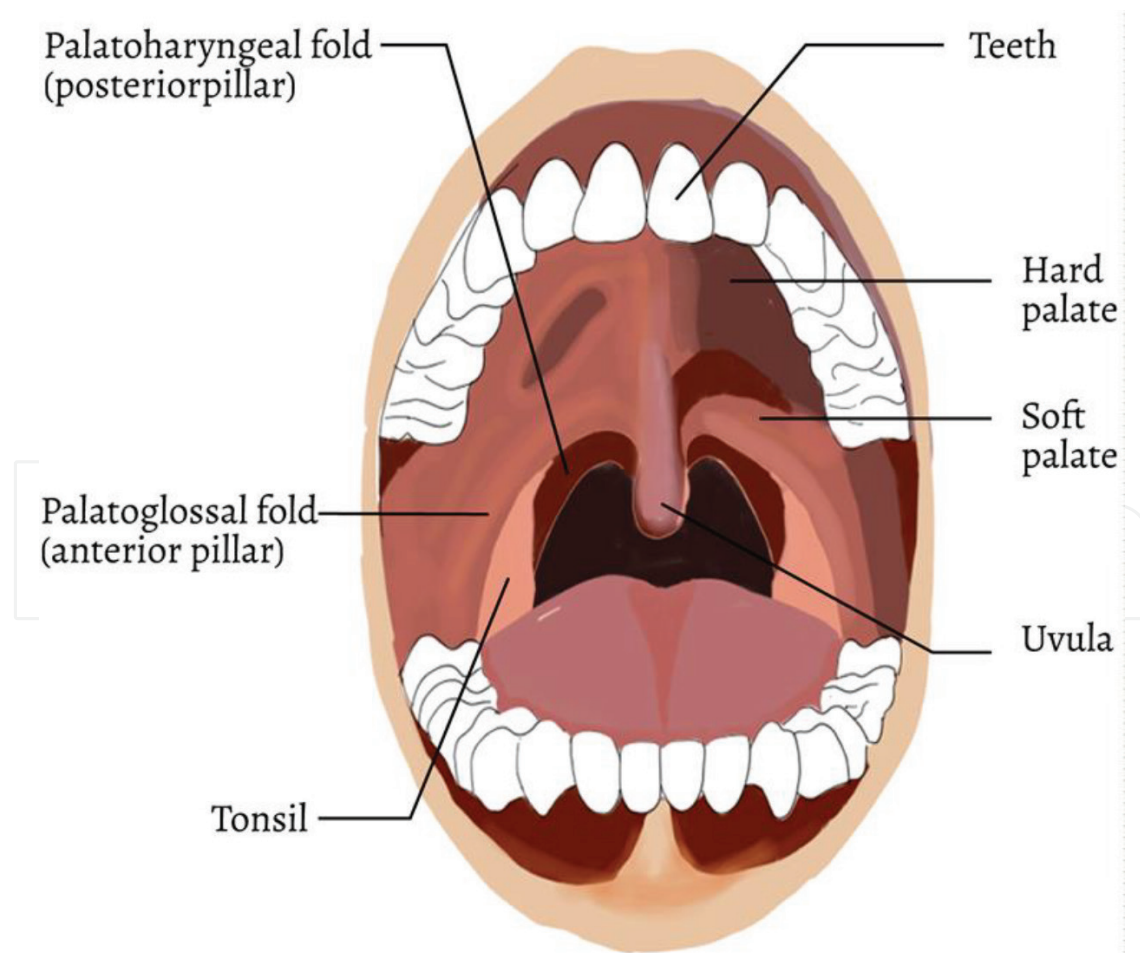


Figure 4. Oral cavity and oropharynx.

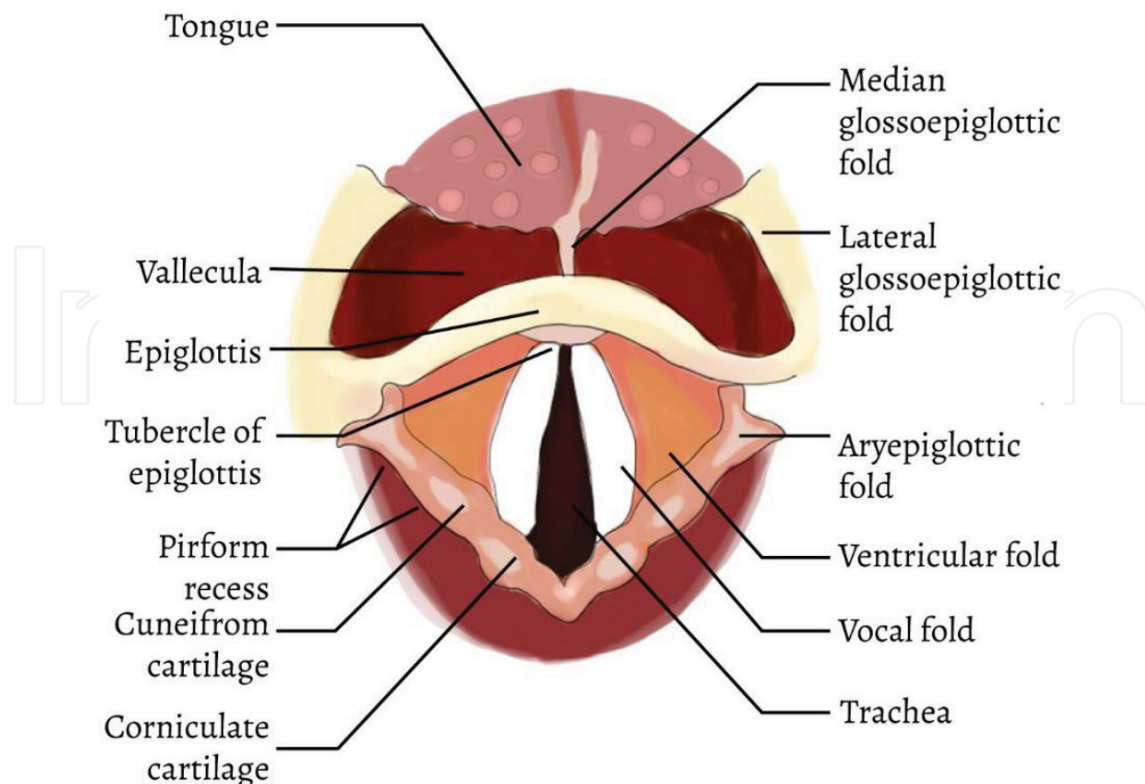


Figure 5. Larynx as visualized from the hypopharynx.

The pharynx is a tube-like passage that connects the posterior nasal and oral cavities to the larynx and esophagus. It is divided into nasopharynx, oropharynx, and laryngopharynx [3]. The pharynx is a muscular tube extending from the base of the skull down to the level of the cricoid cartilage and connecting the nasal and oral cavities to the larynx and esophagus [4]. In order to facilitate the understanding of its functions, the pharynx can be divided into three or four parts (**Figure 6**).

Nasopharynx → between the nares and the hard palate;

Velopharynx or retropalatal oropharynx → between the hard palate and the soft palate;

Oropharynx → from the soft palate to the epiglottis;

Hypopharynx → from the base of the tongue to the larynx (**Figure 7**).

Pharynx is a tube-like passage that connects the posterior nasal and oral cavities to the larynx and the esophagus. It is separated into nasopharynx, oropharynx, and laryngopharynx [3]. The pharynx is a muscle tube extending from the base of the skull to the level of the cricoid cartilage and connecting the nasal and oral cavities to the larynx and the esophagus [4]. To facilitate understanding of its functions, the pharynx can be divided into three or four parts. These four structures form the appropriate route for air passage from the nose to the lung. It also has other physiological functions such as phonation and swallowing. There are 20 or more airway upper muscles surrounding the airway and actively constricting and expanding the upper respiratory tract lumen. These muscles can be divided into four groups: muscles that

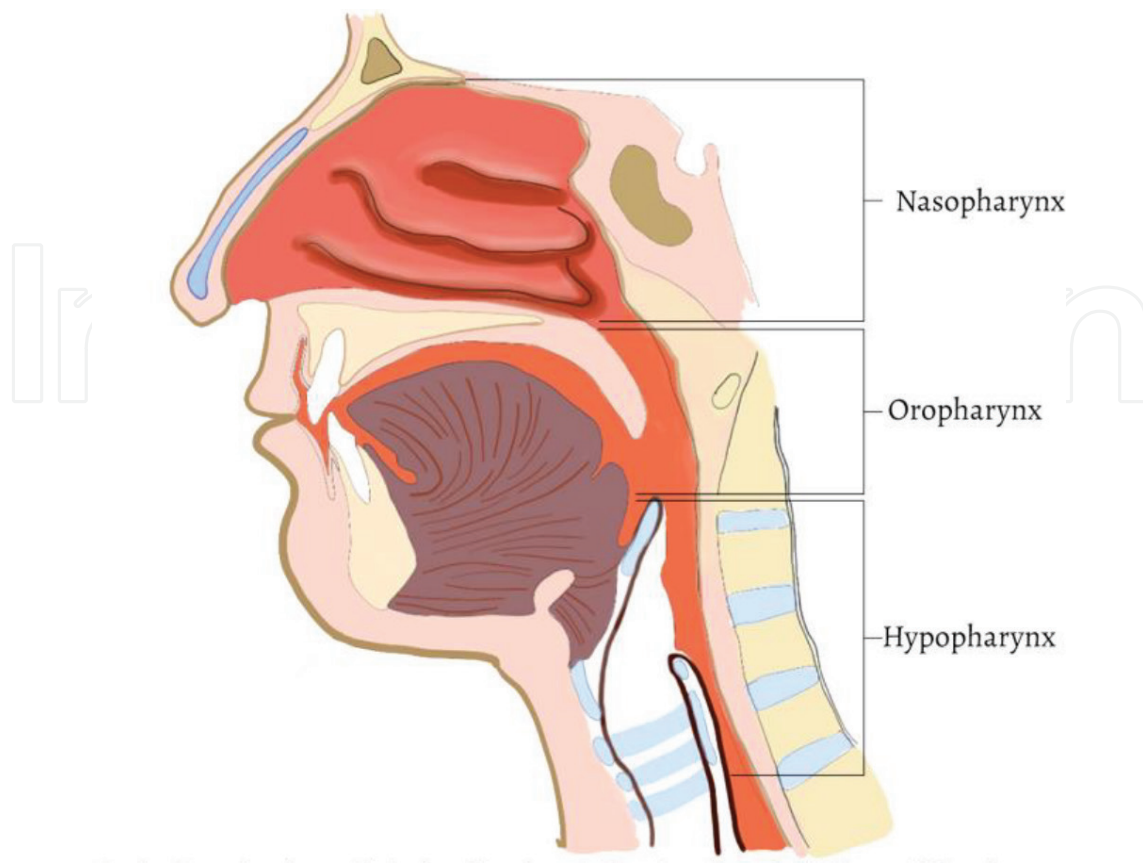


Figure 6. Sagittal section through the head and neck showing the subdivisions of the pharynx.

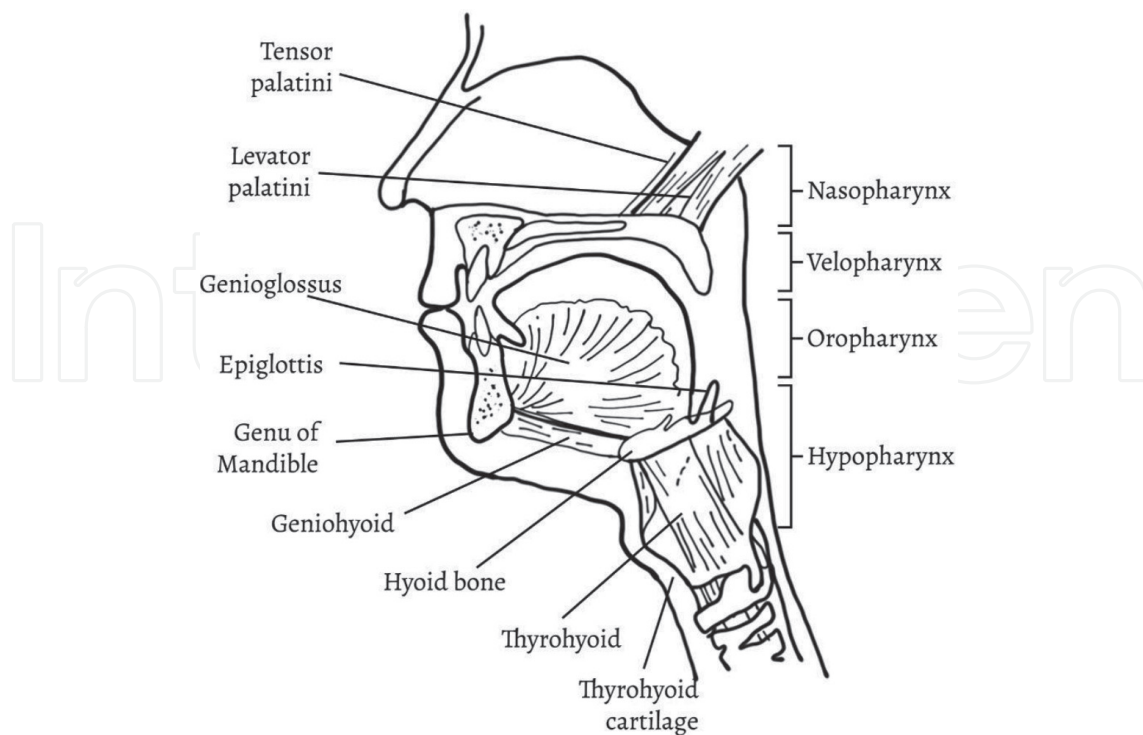


Figure 7. Upper airway lateral view.

regulate the soft palate position (ala nasi, tensor palatini, levator palatini), tongue (genioglossus, geniohyoid, hyoglossus, styloglossus), hyoid device (hyoglossus, genioglossus, digastric, geniohyoid, sternohyoid), and posterolateral pharyngeal walls (palatoglossus) pharyngeal constructors). These muscle groups interact in a complex way to keep the airway open and close. Soft tissue structures form the walls of the upper airway and tonsils including soft palate, uvula, tongue, and lateral pharyngeal walls (**Figure 4**) [11]. The pharyngeal muscle structure seen in the patient who is awake helps to maintain airway patency. However, during anesthesia, the loss of pharyngeal muscle tone is one of the major causes of upper airway obstruction [4]. **The nasopharynx** lies behind the nasal cavity and above the soft palate and communicates with the oropharynx through the pharyngeal isthmus, which becomes closed off during the act of swallowing [6]. Between the superior and the posterior walls of the nasopharynx are adenoid tonsils, which can lead to chronic nasal obstruction and which airway facilities may have difficulty passing. In the soft palate of the nasopharynx, after the end of the ear, it is called velopharynx and is a common area of airway obstruction in patients who are awake or anesthetized [4]. The pharyngeal opening of the pharyngeal tympanic (Eustachian) tube is located in the lateral wall of the nasopharynx, 1 cm behind and just below the inferior nasal convolutions. The posterosuperior side of the nasopharynx is the sphenoid sinus that separates the phalanges from the sella turcica containing the pituitary gland. This sinus is fundamental to the transnasal approach to pituitary surgery [6].

The oral cavity enters the oropharynx via oropharyngeal isthmus, which is limited by palatoglossal arches, soft palate, and lingual dorsum [6]. The oropharynx begins with a soft palate and extends to the epiglottic level. The lateral walls contain, respectively, palatoglossal folds and palatopharyngeal folds, referred to as front- and back-faceted (tonsillar) columns. These layers include palatine tonsils and cause hypertrophy of the tonsils, leading to airway obstruction [4]. The anterior wall of the oropharynx is mainly limited with the soft palate, the tongue, and the lingual tonsils, and the posterior wall is delimited by a muscular wall of the upper, middle, and inferior contraction muscles lying in front of the cervical vertebrae. The minimum diameter of the upper airway during waking, retropalatal oropharynx as a primer, is of interest as a potential localization of collapse during sleep [11].

The laryngopharynx is the last part of the pharynx extending from the edge of the epiglottis to the lower border of the cricoid at the level of C6. Its front faces are the laryngeal entrance first confined to the aryepiglottic folds, then the rear portions of the arytenoids, and finally the cricoid cartilage [6]. The larynx extends toward the center of the laryngeal pharynx and tends to swallow sharp foreign bodies such as chicken-bone bones, leaving a recess on both sides called the piriform fossa [4, 6]. The inner lobe of the superior laryngeal nerve passes into the submucous part of the piriform fossa. Local anesthetic solutions applied to the piriform fossa surface may provide anesthesia for the voice strands. During laryngoscopy procedures, this fossa may be useful as a nerve block supporting oral anesthesia [6].

The larynx is a dynamic, flexible structure composed of a cartilaginous core with interconnecting membranes and associated musculature. The larynx is a midline structure positioned at the interface between the digestive and the respiratory tracts [12]. Larynx is a complex structure of cartilage, muscles, and ligaments that serves as the entrance to the trachea and performs various functions, including phonation and airway protection [4].

The anatomical position, composition, associated musculature, and innervation of the larynx all contribute to this structure's capabilities [12]. The cartilaginous frame of the larynx is made up of different nine cartilages [4]. The arytenoid, corniculate, and cuneiform cartilages are paired, whereas the thyroid, cricoid, and epiglottis are unpaired (**Figure 8**) [13].

They are associated by ligaments, membranes, and synovial joints that are lined by the hyoid bone via the thyrohyoid ligaments and the membrane [4]. The epiglottic, thyroid, and cricoid cartilages make up the three unpaired cartilages and are arranged superior to inferior, respectively. The thyroid cartilage, with the epiglottic cartilage superior, predominates anteriorly and forms the laryngeal prominence (i.e., Adam's apple), while the predominate cartilage dorsally is the cricoid cartilage which sits inferior to the thyroid cartilage [12]. This laryngeal prominence is appreciable from the anterior neck and serves as important landmarks for percutaneous airway techniques and laryngeal nerve blocks [4]. The thyroid cartilage is the largest one and forms a protective shield-like shape in front of the vocal cords [13]. The cricoid cartilage, which lies below the thyroid cartilage and above the entrance to the trachea, is the only complete ring of the laryngeal skeleton. The cricoid cartilage encloses the subglottic region of the larynx. Stenosis may form if the mucosa in this region is injured, as can occur with a prolonged endotracheal tube intubation [13]. The paired arytenoid cartilages are found on the dorsal aspect of the larynx, attached superiorly to the cricoid cartilage. Both arytenoid cartilages give off a lateral extension (muscular process) and anterior extension (vocal process) which aid in supporting the vocal ligaments [12]. The arytenoids are pyramidal-shaped

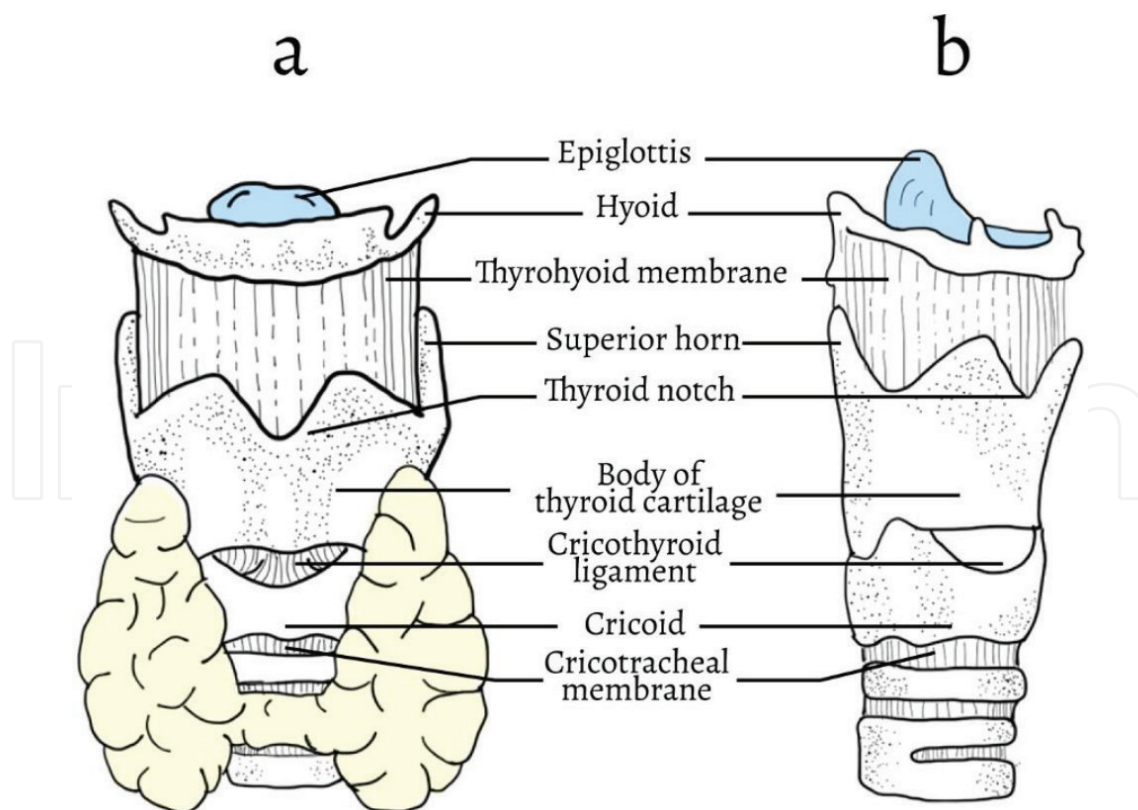


Figure 8. External views of the larynx: (a) anterior aspect; (b) anterolateral aspect with the thyroid gland and cricothyroid ligament removed.

(**Figure 9**) cartilages positioned on the upper border of the posterior cricoid cartilage; these attach at the synovial cricoarytenoid joints. The arytenoids serve as attachment sites for some of the intrinsic muscles of the larynx and allow complex movement and fine adjustment of the vocal cords [13]. In addition, each arytenoid cartilage has an associated corniculate and cuneiform. These two small, paired cartilages border the opening into the laryngeal vestibule both dorsally and laterally cartilage.

The corniculate cartilage can be found at the apex of both arytenoid cartilages. The cuneiform cartilage can be found seated anterior and lateral to both arytenoids. These cartilages form connections via numerous membranes, ligaments, and synovial joints [12].

There are two essential **synovial joints** associated with the larynx. One pair of synovial joints exists between the thyroid and the cricoid cartilages. This joint allows the thyroid cartilage to rotate about the cricoid cartilage and allows the cricoid cartilage to separate from or approximate to the thyroid cartilage anteriorly. The second set of synovial joints exists between the cricoid and the arytenoids (**cricoarytenoid synovial joint**). The cricoarytenoid synovial joint allows the arytenoid cartilages to translate on both an anterior–posterior axis and a lateral-medial axis, as well as rotate about a cranial-caudal axis [12]. Fibrosis or fixation

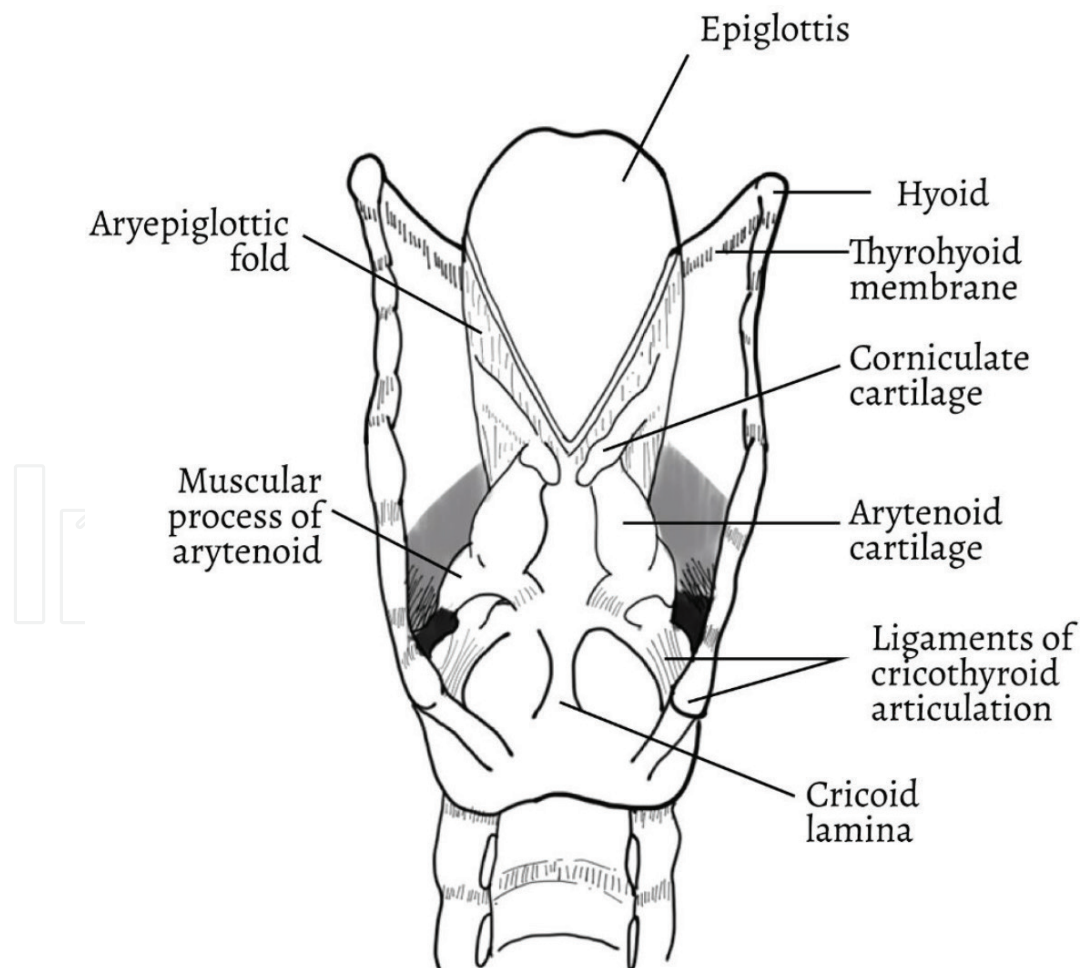


Figure 9. The cartilages and ligaments of the larynx seen posteriorly.

of the cricoarytenoid joint, as can be seen with rheumatoid arthritis or following trauma, can result in vocal fold immobility and respiratory or phonatory impairment [13].

The vocal cords are medial projections of the walls of the larynx that can approximate to each other in the midline to completely obstruct the lumen of the larynx. These vocal folds delineate the plane referred to as the glottis within the vocal cords and there is a muscle known as the vocalis muscle outside the vocal ligament. In addition to the absence of blood vessels on the surface of the folds, the presence of ligaments in this region results in a characteristic white appearance of the vocal cords. This provides visual distinction compared to the pink-appearing vestibular folds. The space found between the vocal folds is termed **the rima glottidis** [12]. **The true vocal cords** are bands of tissue composed of muscle, fibrous ligament, and mucosa extending from the arytenoids posteriorly to the midline thyroid cartilage anteriorly. **The false (or “ventricular”) vocal folds** are situated superior to the true vocal cords and are separated from them by a lateral recess termed the laryngeal ventricle. The ventricle contains mucus-producing glands that provide lubrication for the true vocal cords, which are themselves devoid of glandular elements. The false vocal folds are adducted only during effortful closure, as with Valsalva and reflex laryngeal closure due to noxious stimuli. They do not normally approximate during phonation; however, this may be observed in pathologic conditions, such as in patients with incompetent true vocal fold closure due to vocal fold paralysis, mass lesion, or presbyphonia (vocal fold changes due to aging of the larynx) [13].

The larynx is subdivided into three regions: the supraglottis, glottis, and subglottis. The space between the vocal cords is termed the glottis; the portion of the laryngeal cavity above the glottis is known as the supraglottis, and the portion inferior to the vocal cords is known as the subglottis [4]. **The supraglottis** encompasses the area above the true vocal folds and includes the epiglottis, false vocal folds, aryepiglottic folds, and arytenoids. **The glottis** consists of the true vocal folds and the immediate subjacent area extending 1 cm inferiorly. **The subglottis** refers to the region beginning at the inferior edge of the glottis and extending down to the inferior border of the cricoid cartilage [13]. The larynx **during direct laryngoscopy** begins with epiglottis, which is a cartilaginous flap that serves as the anterior border of the laryngeal entrance. Epiglottis functions to divert food away from the larynx during the act of swallowing. This role is not essential to prevent tracheal aspiration [4]. **Laryngeal position:** the anatomical position of the larynx is also dynamic in nature and varies from birth to maturity. Initially, at birth and for the first couple of years of life, the larynx is further superior in the neck than in adults. In infants, this high position results in direct contact between the soft palate and the epiglottis. This allows inspired air to move from the nose to the trachea directly. It is because of this anatomical relationship, an infant is able to swallow liquids and breathe almost simultaneously [12]. By adulthood, the larynx descends inferiorly to its final position. The larynx is the superior portion of the respiratory tract and aligned on its long axis, is vertically adjacent to the trachea, which lies directly inferior to the larynx, and is connected via the cricotracheal ligament [12]. **The muscles of the larynx** are divided into extrinsic and intrinsic muscles. The extrinsic group, including the anterior strap muscles and digastrics, affects the position of the entire larynx in the neck. This is important for laryngeal elevation during swallowing and fixation of the larynx during Valsalva maneuver. The intrinsic muscles are more

delicate and are responsible for the movement of the vocal cords within the larynx as well as subtle tension adjustments related to phonation. The main intrinsic muscles are posterior cricoarytenoid, lateral cricoarytenoid, interarytenoid, thyroarytenoid, and cricothyroid. The thyroarytenoid muscle makes up the bulk of the vocal cord. Movement at the cricoarytenoid joint allows the vocal cords to be adducted during phonation or abducted during inspiration [13]. **Vascular supply for the larynx** is derived from the superior and inferior thyroid arteries. The external carotid artery gives rise to the superior thyroid artery. The thyrocervical artery, which arises from the anterosuperior surface of the subclavian artery, gives rise to the inferior thyroid artery and two other branches. **The venous drainage of the larynx** is via the inferior, middle, and superior thyroid veins. The inferior thyroid veins continue via the subclavian or left brachiocephalic vein. The middle and superior thyroid veins drain into the internal jugular vein. **Lymphatic drainage** of the larynx is accomplished via the deep cervical and paratracheal nodes medially and via the pretracheal and pre-laryngeal nodes medially [12]. **The vagus nerve** innervates the laryngopharynx. The recurrent laryngeal nerves branch from the vagus in the upper chest and reenter the neck in the thoracic inlet. The recurrent laryngeal nerve branches from the vagus in the thorax and loops around the arch of the aorta on the left and the subclavian artery on the right before traveling back up between the esophagus and the trachea [14]. The recurrent laryngeal nerve innervates all intrinsic muscles except for the cricothyroid muscle, which is innervated by the external branch of the superior laryngeal nerve. Motor function of the lower pharynx and the upper esophagus is supplied by direct pharyngeal branches of the vagus and recurrent laryngeal nerve. A mass lesion along the course of these nerves can result in **vocal cord paralysis**. Sensory function above the level of the vocal cords is mediated by the internal branch of the superior laryngeal nerve [12]. Sensory function below the level of the vocal cords is transmitted through the recurrent laryngeal nerve. The vagus nerve receives sensory information from the external auditory canal as well as the hypopharynx. Thus, a reflex cough can be provoked by instrumenting the ear for cleaning, and cancer in the hypopharynx results in ear pain [13].

2.1.3. Lower airway

The tracheobronchial tree: the tracheobronchial airways form a complex series of branching tubes that culminate in the gas exchange area, with the average number of branches approximately (**Figure 10**) [15].

The trachea is a cartilage tissue that can stretch during breathing [14]. The trachea begins at the level of the cricoid cartilage and extends to the carina at the level of the fifth thoracic vertebra (the lower end of the trachea can be seen in oblique radiographs of the chest to extend to the level of the fifth, or in full inspiration the sixth, thoracic vertebra); this length is 10–15 cm in the adult. It consists of 16–20 C-shaped cartilaginous rings that open posteriorly and are joined by fibroelastic tissue; the trachealis muscle forms the posterior wall of the trachea [4, 6, 14]. The cartilage at the tracheal bifurcation is the keel-shaped carina, which is seen as a very obvious sagittal protrusion when the trachea is inspected bronchoscopically [6]. The trachea bifurcates into the right and left main bronchi at the carina. In the adult, the right main bronchus branches out at a more vertical angle than the left main bronchus, as it results in a greater

likelihood of foreign bodies and endotracheal tubes entering the right bronchial lumen [4]. The trachea extends from the neck to the thorax to the midline, but slightly diverges to the right by the aortic arch in the thorax. At the lower part of the neck, the edges of the sternohyoid and sternothyroid muscles are adjacent to the trachea. This region is covered by the inferior thyroid venules with cross-communication between the anterior jugular venules and the lateral side of the thyroid gland which is branched from the aortic arch or brachiocephalic artery. Because of this close association with the brachiocephalic artery, erosion by the tracheal wall of the tracheostomy tube can lead to sudden abdominal bleeding [6]. Laterally, the lateral lobes of the thyroid gland, which are located between the trachea and the carotid sheath [14], the esophagus, and the recurrent laryngeal nerve, lie in the posterior side [6, 14].

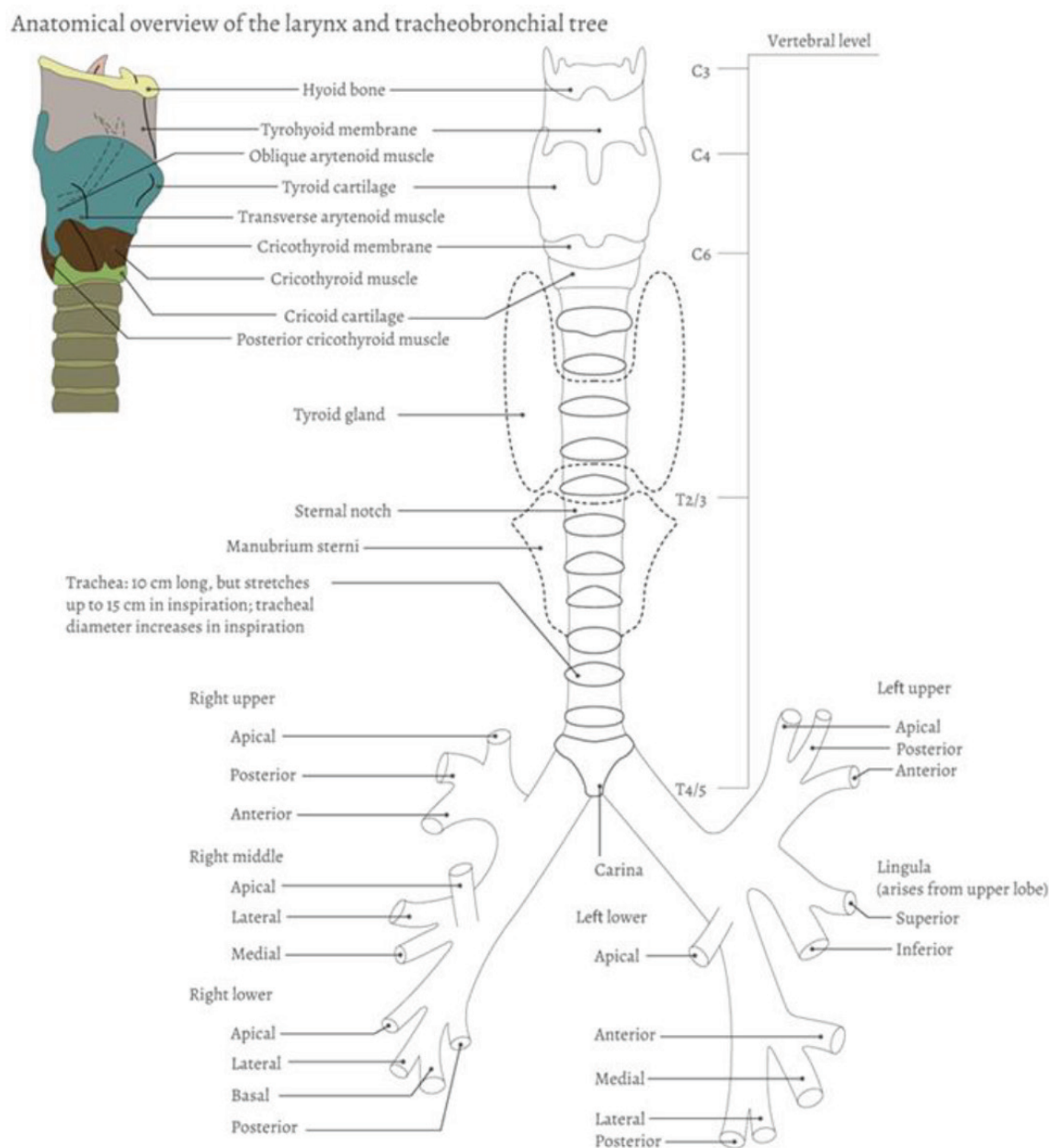


Figure 10. Anatomical overview of the larynx and tracheobronchial tree.

Vascular, lymphatic, and nerve supply: the arterial supply to the trachea is derived from the inferior thyroid arteries, and the venous drainage is via the inferior thyroid veins. Lymphatics pass to the deep cervical, pretracheal, and paratracheal nodes [6]. Nerve supply is from vagus and recurrent laryngeal nerves for pain and secretomotor functions [14] and sympathetic supply from the middle cervical ganglion [6].

2.1.4. *The main bronchi*

In full inspiration, the bifurcation level is at T6. The right main bronchus is shorter, wider, and more perpendicular than the left bronchus. This situation can be explained by the transformation into a shorter and wider structure because the embryologically will feed larger lungs. In addition, the aortic arc is the reason for the placement to be more perpendicular due to the position (at 25° perpendicular to the 45° left) [6]. This is the result of a greater possibility of foreign bodies and endotracheal tubes entering the right bronchial lumen [4]. The bronchi are supplied by the bronchial arteries from the aorta and drained by the azygos vein on the right and the hemiazygos vein on the left, and also, some drainage by pulmonary veins and the bronchial veins [14].

3. Evaluation of the complex airway

3.1. Pediatric airway differences

The pediatric airway changes significantly from birth to adulthood. These changes affect the development of the skull, oral cavity, throat, and trachea. The head is larger than the body in infants and young children. Due to the absence of paranasal sinuses, the facial skeleton is smaller in neonates compared with neurocranium. Oral cavity is small at birth. It grows in the first year of life due to the significant growth of the mandibles and teeth in the following period. In neonates, the tongue has a flat surface and limited lateral mobility and appears relatively large in the small mouth space. Neonatal laryngeal and tracheal structures are especially important for anesthesiologist. The larynx appears more prominently during direct laryngoscopy, but when compared with adults, the surrounding structure is loosely embedded. External manipulation allows direct laryngoscopic intubation to be easily carried to a position where it is possible. If the epiglottis is not removed by the bladder of the laryngoscope, the glottic appearance on the laryngoscopy is prevented long, narrow, and often U- or V-shaped (“flopping”) [16]. Glottis is higher in the newborn (C2/C3) than in the vertebrae, and after 2 years, it falls to the normal position in C5 [17]. In newborn, vocal cords are shorter, and anterior glottis, which normally corresponds to two-thirds in a larger child, constitutes about 50% of the newborn. The newborn larynx is conical, but in a larger child, it is approximately cylindrical. Though the larynx is thought to be widest in the supraglottic region and narrowest in the subglottic region, this suggests that the narrowest portion of the magnetic resonance imaging (MRI) studies may be in glottic. Also, the cricoid ring is the narrowest part of the neonatal airway and is an ellipsoid-shaped mucosa layer which is highly sensitive to trauma. Bypassing the air leak at this level from the untrained tracheal

tube does not guarantee avoidance from the pressure points and the next payment [18]. Intubation tubes with small tracheal internal diameter cause a significant increase in airway resistance and this can lead to an exaggerated mucosal injury. The tracheal length depends on the child's age and height but is not dependent on body weight. During the operation, changes in the head position may lead to a displacement of the tracheal tube and reevaluate the position of the tube with the head's new position. Verification of the position of the tracheal tube clinically (chest movement, auscultation) or by other means (chest radiography, fluoroscopy, ultrasonography, or bronchoscopy) is recommended.

Physiological conditions: in human, the downward movement of the laryngeal structures according to age is the main factor in transaction from nasal breathing to oral breathing. Direct result is the dissociation of the epiglottis and the soft palate. The pediatric airway cannot be assessed in young children without considering very low functional residual capacity. This situation, a high oxygen demand, an increased carbon dioxide production, and an increased closure capacity, is together. And the situation which is in very low tolerance to apnea appears with this result. This rapidly leads to significant hypoxemia and respiratory acidosis. Even the optimal time preoxygenation cannot result in a "safety time" that is long enough to prevent desaturation following short periods of apnea. The smaller the child, the more limited the time is [19, 20]. In human, one of the most strongest reflexes is laryngeal reflexes and it can be thought to prevent pulmonary aspiration. These functional reflexes are undernapped by the inner and outer branches of the larynx, recurrent laryngeal nerve, and superior laryngeal nerves. The afferent innervation of the subglottic part of the larynx and all muscles is also provided by the recurrent laryngeal nerve, except for the cricothyroid scar. The larynx is relatively insensitive to irritant gases that are inhaled but is very sensitive to mechanical or chemical stimuli caused by fluid or solutes.

3.2. Congenital disease

It may produce abnormalities of the head, neck, or upper airway [9]. Cardiovascular, nervous, musculoskeletal, or excretory system disease is more often tabulated with these abnormalities. Crouzon, Goldenhar, Pierre Robin, and Treacher Collins syndromes are known for their abnormal head and neck. The patients with micrognathia, retrognathia, and macroglossia must be remembered for the congenital diseases in childhood [9]. The most significant vascular malformations are vascular rings, usually of aortic arch origin, encircling the trachea. Tracheomalacia, congenital tracheal stenosis, shortened trachea, and bronchogenic cysts can contribute to difficult airway management [21]. Infants with congenital malformation syndromes associated with cardiovascular anomalies and skeletal dysplasia have a shortened trachea significant percentage [21]. Soft tissue changes that cause airway management difficulties are usually divided into two categories as those that disturb the motion of the airway and limit the movements that disturb the airway by mass effects. Soft tissue changes that limit airway motion usually affect mouth opening. Microstomy, a feature of Freeman-Sheldon syndrome, is a condition in which the movement of oral tissues that do not respond to stomach relaxation is limited. Other rare diseases that limit the movement of airway tissue include fibrofacial myositis ossificans and dermatomyositis. The mass effects on the airway due to soft tissue abnormalities may be the result of congenital, end-of-life, or subsequent disease outcomes of surgical interventions [22]. Macroglossia is one of the most common problems appearing with birth, and the tongue expands and fills the oral cavity, making it difficult to

see the larynx. Macroglossia occurs in Beckwith-Wiedemann syndrome, Down syndrome, Sturge-Weber syndrome, and in a variety of dystrophically related syndromes [22].

3.3. Obese patients

Perioperative management in obese patient, including airway management, is an increasing and a worldwide concern for the anesthesiologist. Since obese patients have an increased fatty tissue distributed in a truncal fashion, obesity may have an important and negative impact on the airway patency and respiratory function. Respiratory function and airway patency can be significantly altered by this change in position [23]. Airway assessment of the obese patient should be performed with the patient in both the sitting and supine positions. Respiratory function and airway patency can be significantly altered by this change in position [24]. Body weight may not be as critical as the location of excess weight. Massive weight in the lower abdomen and hip area may be less important than when the weight is in the upper body area. A short, thick, immobile neck caused by cervical spine fat pads will interfere with rigid laryngoscopy. Furthermore, the redundancy of soft tissue structures inside the oropharyngeal and supralaryngeal area may also make visualization of the laryngeal structures difficult. Mask ventilation should be difficult in the obese patient. When a high positive pressure is required to ventilate the patient, the chance of inflating the stomach is increased. Rapidly oxygen desaturation during apnea, secondary to a reduced functional residual capacity, limits intubation time. In the case of a cannot-intubate-cannot-ventilate situation, access to the neck for transtracheal jet ventilation or establishing a surgical airway (emergency tracheostomy or cricothyroidotomy) will also be more complex [9].

3.4. Pregnancy

Maternal, fetal, surgical, and personal factors in pregnancy cause an increase in the incidence of unsuccessful intubation. The mucosa of the upper respiratory tract becomes more vascular and edematous, which increases the risk of bleeding and swelling in the airway [25]. These changes cause the Mallampati score to increase as the pregnancy progresses and during labor. Airway edema may be exacerbated by preeclampsia, oxytocin infusion, intravenous fluids, and Valsalva maneuvers during labor and delivery. A decreased functional residual capacity and increased oxygen requirements accelerate the onset of desaturation during apnea and are further exacerbated in obese patients. Progesterone reduces the lower esophageal sphincter tonus, which results in gastric reflux. Risk of reflux is further increased because of delayed gastric emptying after prolonged painful delivery and opioid administration. Enlarged breasts can make laryngoscopy difficult [26]. Airway anatomy may become distorted during prolonged labor or toxemia, leading to an edematous soft tissue encroachment of the upper airway [27]. At last, in cases of fetal distress or maternal hemorrhage, the emergency nature of the circumstances compounds airway management problems [9].

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