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CONTENTS 18.1.1 The upper respiratory tract 3933 Pallav L. Shah, J.R. Stradling, and S.E. Craig 18.1.2 Airways and alveoli 3937 Peter D. Wagner and Pallav L. Shah 18.1.1 The upper respiratory tract Pallav L. Shah, J.R. Stradling, and S.E. Craig ESSENTIALS The upper respiratory tract extends from the anterior nares to the larynx and comprises (1) the nose—with the main function as first-line defence against problems with incoming air, acting as a coarse particle filter and a conditioner (temperature and humidity) of the air, and with the sense of smell helping to detect noxious substances that are best avoided. (2) The pharynx—this has to act as a rigid tube when used for breathing, but during swallowing it has to be a collapsible tube capable of peristalsis, a combination of functions which is achieved by complex innervation and musculature. Subepithelial collections of lymphoid tissue in the pharynx are ideally suited to process inhaled and swallowed antigens. (3) The larynx—this has three important functions: communication, protection of the airway, and dynamic control of lung volume. The nose Anterior nares The anterior nares, which include the nasal valve just inside the nose, are usually the narrowest part of the respiratory tract and account for about 40–50% of the total respiratory resistance. In normal subjects the resistance in the lower airways is small (<25%) compared with the larynx and nose. This anterior nasal resistance is actively controlled by the levator alae nasi and procerus muscles, which flare the nostrils, and the compressor naris muscle, which narrows the nasal valve further. During mild exercise, these muscles (combined with sympathetic nasal mucosal vasoconstriction) can halve the nasal resistance and allow minute ventilations up to 30 litres/min before conversion to oral breathing is necessary. These muscles receive a phasic inspiratory signal, to brace open the nares with each breath, just in advance of diaphragmatic activity. Occasionally, owing to deformity of the anterior nasal cartilages, the anterior nares are very narrow and limit inspiration, particularly during sleep when the dilator muscle activity is reduced. This is one of the rarer causes of snoring that is amenable to treatment. Turbinates The main function of the nose is as first-line defence against prob- lems with the incoming air. In this respect it acts as a coarse particle filter and a conditioner (temperature and humidity) of the air, and helps the sense of smell to detect noxious substances that are best avoided. The turbinates in the nose present a surface on to which large inhaled particles, such as pollen grains and house dust mite faecal particles, will be retained, with the potential for an allergic response producing allergic rhinitis. Debris arriving on the mucosal surfaces is wafted backwards to be swallowed eventually. Without this so-called mucociliary carpet there is decreased resistance to infections (usually a generalized respiratory problem and not just in the nose), with pooling of mucopurulent material and recurrent sinus infections. This mucociliary function can be tested by placing a saccharine tablet on the anterior floor of the nasal cavity and timing the period that elapses before it can be tasted in the oral cavity. The normal interval is about 15–20 min, but with ciliary defects this can extend to an hour or more. Vascular supply The turbinates fill such a large proportion of the nasal cavity that minor swelling produces large changes in nasal airflow resistance (Fig. 18.1.1.1). There are several rich vascular beds at different depths in the nasal mucosa, providing a large surface area to warm and humidify incoming air. These are supplied by the sphenopalatine branch of the maxillary artery, with venous drainage passing back into the cavernous sinus around the carotid artery. The volume of fluid in these vascular beds is controlled via the vidian nerve, which contains sympathetic vasoconstrictor and parasympathetic vaso- dilator fibres acting on both arterioles and venules. The overall blood flow and total volume of blood in the sinusoids determine the degree 18.1 Structure and function

Section 18 Respiratory disorders 3934 of mucosal congestion, which undergoes a cyclical reciprocal change across the two sides of the nose over 2–4 h, hence as the mucosa on one side is congesting that on the other side is shrinking. This cycle, usually only obvious to individuals with already narrowed nasal pas- sages (when blockage can occur intermittently), can be interrupted by a reflex mediated by pressure on the side of the thorax or in the axilla. Thus, in the decubitus position, the upper nostril becomes clearer and the lower more congested, with the two sides swapping within a minute or two of turning on to the other side. The pur- pose of this nasal cycle is not known, but using the upper rather than the lower nostril when lying on one’s side may lessen the chance of inhaling particulate matter. In addition to this effect there is a gen- eral increase in nasal congestion on lying down, due to a hydrostatic rise in capillary pressure. The volume of fluid needed to humidify the incoming air is con- siderable, but is reduced by condensation of some of this moisture back on to the cooler nasal mucosa during exhalation. Of course, this conditioning is lost during oral breathing, which has important im- plications for exercise-induced asthma, which is due to the cooling and drying of intrathoracic airways. Secretory function and sensory innervation Nasal secretions come mainly from submucosal glands that are stimulated by parasympathetic (cholinergic) fibres. There is some evidence that sympathetic activity can also stimulate secretions, but of higher viscosity. The sensory fibres from the nose travel in the maxillary nerve (mainly the ophthalmic branch) and are the afferent limb of some interesting reflexes. Airflow is sensed and can itself influence breathing pattern. Nerves containing substance P in the epithelium seem to be responsible for sensations leading to sneezing. Sneezing is like coughing, in that an explosive expiration is generated in an attempt to expel foreign matter. Coughing involves closure of the larynx until pressure builds up, whereas sneezing involves closure of the pharynx. Unlike coughing, sneezing is never voluntary. Sensory fibres from much of the upper airway, nose, and face are also involved in the diving reflex. This reflex is of great importance to diving mammals, when the combination of facial stimulation by cold water, apnoea, and hypoxaemia produce intense peripheral, splanchnic, renal, and muscular vasoconstriction. This diverts blood to the brain and conserves oxygen (producing a heart–lung–brain circulation that prolongs diving time), with the rise in blood pres- sure limited by a marked vagally induced bradycardia. This vestigial reflex in humans can be utilized in the control of some cardiac ar- rhythmias, when a brisk increase in vagal tone can be produced by applying ice-cold water to the face. Nasal irritation can lead to either bronchoconstriction or bron- chodilation. The bronchoconstriction can be prevented by atropine and is presumably vagally mediated. This reflex may be important in provoking bronchospasm in some asthmatics. Negative pressure in the nasal cavities can also be sensed, producing a reflex increase in upper airway dilator action (see the following section on the pharynx). Olfaction depends on recognition of molecules by mucosal recep- tors at the very top of the nose. These olfactory cells have central axons that pass through multiple tiny holes in the skull (cribriform plate) to the brain. At this point they are very vulnerable to shearing forces during a blow to the head, leading to anosmia (loss of ability to smell). The pharynx Anatomical divisions The pharynx is divided into the nasopharynx, oropharynx, and laryngopharynx or hypopharynx—behind the soft palate, the back of the oral cavity down to the tip of the epiglottis, and the tip of the epiglottis down to the cricoid cartilage, respectively. Thus the top end is level with the base of the skull and the bottom end is about level with the sixth cervical vertebra, giving an overall length of about 12 cm. When being used for breathing, the pharynx has to act as a rigid tube (like the trachea), but during swallowing it has to be a collapsible tube capable of peristalsis (like the oesophagus). This combination of functions is achieved by having a muscular tube that can constrict to propel food, but also has external muscles whose function is to brace open the pharynx when required. Pharyngeal muscles Fig. 18.1.1.2 shows the enormous complexity of the pharyngeal musculature, supplied mainly by the hypoglossal nerve (XII). The pharyngeal constrictors (superior, middle, and lower) are the main peristaltic muscles; the lower part of the inferior constrictor also functions as a sphincter to the top of the oesophagus, preventing air entry during inspiration. Most of the other pharyngeal muscles work in concert to hold open the pharynx. For example, the genioglossus pulls forward the tongue, the geniohyoid together with the strap muscles (sternothyroid, thyrohyoid, and others) pulls forward the hyoid (enlarging the oropharynx), and the stylopharyngeus probably pulls sideways on the lateral pharyngeal walls. The palatopharyngeus will hold open the pharynx if supported by the levator palati, but will also pull forward the palate to open the nasopharynx. The upper pharyngeal muscles (tensor palati and levator palati) also close off the nasal cavity during swallowing to prevent regurgitation of fluids into the nose. To prevent aspiration, closure of the larynx and the false cords above is coordinated with swallowing. Some of these Fig. 18.1.1.1 Coronal sections of human maxillary sinuses and the turbinates in the nose. The view in the panel on the left was taken after ephedrine drops and shows mucosal shrinkage. The consequent small increase in the size of the lumina was attended by a large increase in maximum nasal airflow. Courtesy of Professor F Gleeson.

18.1.1 The upper respiratory tract 3935 actions require sensory information about the exact location and consistency of any food being swallowed, carried via the glosso- pharyngeal and vagus nerves (IX and X). Sensory branches of these nerves also supply the ear, which explains why pharyngeal lesions may present with pain in the ear. Given the complexities of pharyngeal function, it is not surprising that severe swallowing difficulties with aspiration of food and drink are often seen following cerebrovascular accidents in the brainstem involving the control of pharyngeal muscles and sensory pathways. Powerful mechanisms maintain patency of the pharyngeal airway during breathing. As with the alae nasi, the pharyngeal di- lator muscles receive a respiratory input in time with diaphragm activation. The diaphragm receives a gradually increasing level of phrenic activity to overcome elastic recoil as tidal volume increases, whereas the pharyngeal activation follows more of a ‘square wave’. This makes teleological sense, since the collapsing force is dependent on inspiratory flow and this is roughly constant throughout inspir- ation. Dilator activity increases if pharyngeal patency is threat- ened. Fig. 18.1.1.3 shows the reflex increase in genioglossus tone in response to a fall in intrapharyngeal pressure that will pull in the pharyngeal walls, which is thought to be mediated by ‘distortion’ receptors of some kind. Snoring occurs when the pharynx narrows enough to vibrate, and there is some evidence that this vibration itself can also activate pharyngeal dilators, thus warding off full col- lapse. The factors predisposing to pharyngeal collapse during sleep are discussed in Chapter 18.5.2. Lymphoid tissue Waldeyer’s ring of lymphoid tissue, comprising the adenoids, the palatine tonsils, and the lingual tonsils (back of tongue), is situ- ated in the pharynx. These subepithelial collections of lymphoid tissue are ideally suited to process inhaled and swallowed antigens. Unfortunately, if they hypertrophy too much in response to recur- rent infections, they are also positioned such that they obstruct the airway, particularly in small children. This is usually first apparent during sleep, but may become severe enough to provoke inspiratory stridor, even while awake. Adenoidal enlargement, by blocking nasal airflow, will force mouth breathing which, if it occurs early enough (perhaps <18 months of age), retards development of the lower jaw (the so-called adenoidal facies). This probably leads to overcrowding of the teeth and a narrower retroglossal space (further discussed in Chapter 18.5.2). The larynx The larynx (Fig. 18.1.1.4) has three important functions: communi- cation, protection of the airway, and dynamic control of lung volume. Communication and neuromuscular function A few of the intrinsic and extrinsic muscles of the larynx (e.g. crico- thyroid, posterior cricoarytenoid) open (abduct) or brace the vocal cords, whereas most (e.g. thyroarytenoid, transverse, and oblique arytenoids) close (adduct) the cords. The recurrent laryngeal nerve (from the vagus) supplies all the muscles apart from the cricothyroid (supplied from the superior laryngeal nerve, which is also a branch of the vagus; see Fig. 18.1.1.5). The left recurrent laryngeal nerve comes off the vagus and passes under the aortic arch before run- ning up close to the thyroid gland to the larynx. This means it can be damaged by a tumour at the left hilum and surgically during a thyroidectomy. The right recurrent laryngeal nerve passes under the right subclavian artery, where it can be damaged by a right-sided apical lung tumour. Protection of the airway As mentioned earlier, there are reflexes initiated by supralaryngeal sensory fibres (mainly via the internal branch of the superior laryn- geal nerve) to protect the airway. Fluid or food landing on or near Palatopharyngeus Styloglossus Hyoid bone Palatopharyngeus Uvula Hamulus Tensor palati Levator palati Superior constrictor Middle constrictor Middle turbinate Levator veli palati Tensor veli palati Musculus uvulae Stylo- pharyngeus Stylohyoid ligament Nasal septum Fig. 18.1.1.2 Two views of the pharyngeal muscles: from inside the pharynx looking laterally (left panel), and from high up on the posterior pharyngeal wall looking anteriorly (right panel). These muscles act in concert and the physical effect of their contraction depends on which other muscles are simultaneously activated.

Section 18 Respiratory disorders 3936 the vocal cords will provoke coughing and/or laryngeal closure. During sleep, irritation of the cords tends to produce apnoea and laryngeal adduction, and

coughing occurs only when wakefulness supervenes. Dynamic control of lung volume One of the less well-known functions of the larynx is to brake ex- piratory flow and thereby control lung volume. In some species, and in neonates, laryngeal expiratory braking is very important, acting rather like positive end-expiratory pressure to maintain end-expiratory lung volume above the passive functional residual 100 ms –15 cmH2O Rectified and integrated EMG (reset every 10 ms) Raw genioglossus EMG Fig. 18.1.1.3 Response of the genioglossus muscle in a conscious human to a sudden fall in intrapharyngeal pressure. The time delay (about 50 ms) is too short to be due to a cortical response and is presumably a spinal cord reflex. From Horner RL, et al. (1991). Evidence for reflex upper airway dilator muscle activation by sudden negative airway pressure in man. J Physiol, 436, 15–29,
© 1991 The Physiological Society, with permission of Wiley-Blackwell. Fig. 18.1.1.4 Bronchoscopic view of the larynx from above. The top of the picture is the anterior. © Pallav Shah. Right superior laryngeal nerve Right recurrent laryngeal nerve Left recurrent laryngeal nerve Left superior laryngeal nerve Larynx Fig. 18.1.1.5 The paths of the laryngeal nerves.

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