Physiological functions of the nose and paranasal sinuses

The nasal cavity and paranasal sinuses are involved in breathing, smell, speech, and taste. Smell has been dealt with already. Taste will be covered in the next chapter.

The nose and paranasal sinuses are responsible for:

1. Warming and humidifying inhaled air.
2. Mucus production
3. Airway protection: removing and trapping pathogens, particulate matter, and allergens from inhaled air.
4. Draining and clearing the paranasal sinuses and lacrimal ducts.
5. Vocal resonance
6. Brain protection: they protect the brain from injury by acting as a crumple zone to vital structures in the event of facial trauma.
7. Lighten the skull: the paranasal sinuses reduce the weight of the skull while maintaining its strength and shape.

<u>Warming and humidification</u>

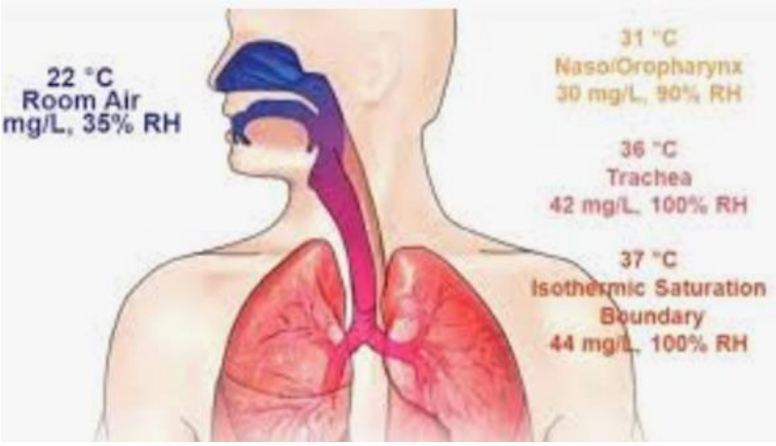

Fig. 1. Temperature and humidification in airway structures

Inspiratory heating and humidification of the gas mixture

- Inspired gas has a water content of around 10g/kg (50% humidity, 22°C)
- The upper airway structures alter the temperature and humidity of air during inspiration and expiration.
- The convoluted air passages of the nasopharynx and pharynx generate turbulent flow of inspired air.
- The turbulence increases evaporative heat exchange between the air and the mucosa; so that the relative humidity of the posterior nasal cavity is 85%.
- In the lower pharynx, the temperature is about 33°C and relative humidity approaches 100%
- The inspired air achieves body temperature at the isothermic saturation boundary, which is about 5cm beyond the carina.

- Alveolar gas has a water content of around 47g/kg (100% humidity, 37°C).

Expiratory reclamation of heat and moisture

- Expired gas passes over the cooler upper airway mucosa and returns some of its heat to it.
- Expired air at the nares is usually 32°C and close to 100% humidified.
- Some of the water is also reclaimed by the process of condensation.
- This process is highly dependent on the temperature of the ambient air; the cooler the ambient air the more moisture is reclaimed.
- In hot environments, humidity cannot be reclaimed and the net water loss increases.

The reclaimed fraction of water can be decreased by:

1. Increased ambient pressure
2. Decreased inspired gas humidity (wall oxygen)
3. Bypassing the upper airway structures (endotracheal intubation or tracheostomy)

The total exhaled water content can increase in the following situations:

- Tachypnoea (moisture loss is proportional to minute volume)
- Tachycardia (moisture loss is proportional to cardiac output)

Mucus production and clearance

Mucus secretion occurs from goblet cells throughout the respiratory tract under the control of *non-cholinergic* parasympathetic nerves. Vasoactive intestinal peptide (VIP) is a non-cholinergic neurotransmitter that is released by parasympathetic nerves. VIP is a transmitter in non-adrenergic, non-cholinergic (NANC) nerves that control blood flow, secretion, smooth muscle tone, and motility. VIP contributes to vasodilation and mucus secretion.

Airway mucus is considered to form a liquid bilayer where an upper gel layer floats above a lower, more watery solution, or periciliary liquid, layer. The gel layer traps particles and is moved on the tips of the cilia.

Respiratory tract mucus requires the correct combination of viscosity and elasticity for optimal ciliary interaction. Viscoelasticity is conferred on the mucus by high molecular weight mucous glycoproteins (mucins), which make up 2% of the weight of the mucus.

Mucins are produced by goblet cells in the epithelium and seromucous glands in the submucosa. Mucins are thread-like molecules made up of a linear peptide sequence (apomucin), often with tandemly repeated regions, that are highly glycosylated, predominantly via O-linkages. Apomucins are encoded by specific mucin (MUC) genes, with 19 human MUC genes currently recognized. Of these, however, only the MUC5AC and MUC5B gene products comprise the major gel-forming mucins in respiratory secretions.

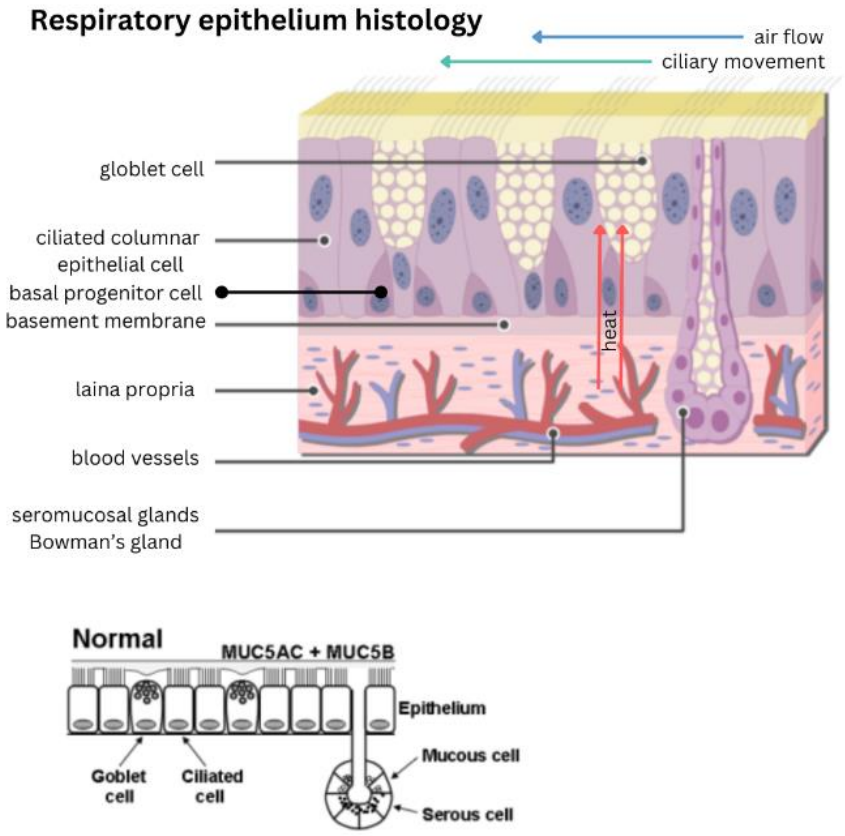

Fig 2. Respiratory epithelium histology

Airway luminal mucus is a complex dilute aqueous solution of lipids, glycoconjugates and proteins. It comprises salts, enzymes and anti-enzymes, oxidants and antioxidants, exogenous bacterial products, endogenous antibacterial agents, cell-derived mediators and proteins, plasma-derived mediators and proteins, and cell debris such as DNA.

Water and electrolyte transport

- Respiratory epithelial cells are joined together by tight junctions and gap junctions.
- Absorption of nutrients and oxygen, and removal of waste products occurs on the basolateral surface.
- Water and ion transport occurs through the transcellular or paracellular pathways.

- Absorption is mainly driven by active Na^+ absorption through epithelial sodium channels (ENaC) in the apical membrane and the Na^+/K^+-ATPase in the basolateral membrane creating an electrochemical driving force for paracellular passive Cl^- transport.
- Water follows either through aquaporins or the paracellular pathway.
- Secretion is mainly driven by Cl^- secretion through the cystic fibrosis transmembrane conductance regulator (CFTR) and other Cl^- channels in the apical membrane. This is a passive transport system.
- The sodium-potassium ATPase pump is an enzyme found in the membrane of all animal cells. It is an active process. For every ATP molecule that the pump hydrolyses, $3Na^+$ are exported and $2K^+$ are imported into the cell. There is a net export of a single positive ion per cycle, which is why the concentrations of intracellular versus extracellular sodium and potassium are:
    - Extracellular $[Na^+]$ = 5 X intracellular $[Na^+]$
    - Intracellular $[K^+]$ = 30 X extracellular $[K^+]$

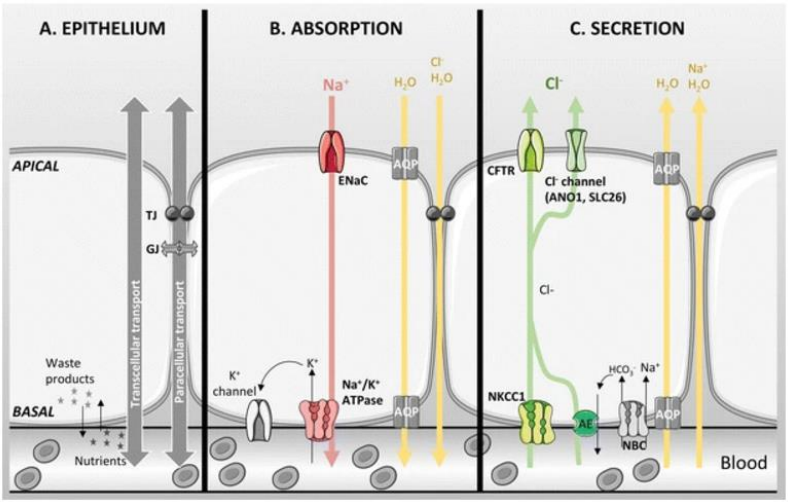

Fig 3. Electrolyte and water transport through the respiratory epithelium.
Red and *green arrows* show active transport, and *yellow arrows* show passive transport

- The sodium potassium chloride cotransporter 1 (NKCC1) is a secondary active transporter it moves solutes across biological membranes using potential energy stored in the gradient of another solute. It is activated by a decrease in intracellular sodium, which mediates transport of sodium, potassium and chloride ions into the cell.
- The coupled action of an anion exchanger and the sodium-bicarbonate cotransporter (NBC) in the basolateral membrane accumulate Cl^- in the cell. Active Cl^- secretion creates the driving

force for Na^+ movement across the epithelium through the paracellular pathway and water transport occurs paracellularly and/or transcellularly.

Airway mucus functions to trap and remove airway debris by means of the mucociliary apparatus. Triggers of inflammation/irritation can lead to over-secretion of mucus via *cholinergic* stimulation leading to airway obstruction. This occurs in asthma/COPD and is exacerbated by ciliary dysfunction. Leukotrienes increase mucus secretion, vascular permeability and chemotaxis of neutrophils.

Videos available on the site:

A visual representation of mucociliary clearance

The mechanism of mucociliary clearance

Vocal resonance

The nasal cavity and paranasal sinuses assist with vocal resonance.

Videos available on the site:

Hyponasal speech produced by nasal obstruction from various causes.

Hypernasal speech occurs when there is velopharyngeal insufficiency. The commonest cause of this is cleft palate, and it may persist after surgical repair.

Hyposmia/anosmia

Anything that disrupts the pathway of olfaction will result in hyposmia or anosmia. Systematically, this includes:

Obstruction of odorants moving through the nasal passages due to

- Mucosal hypertrophy as a result of oedema caused by acute or chronic rhinosinusitis
- Bilateral nasal polyps associated with chronic rhinosinusitis
- Benign or malignant neoplasms of sinonasal origin like, inverting papilloma; sinonasal neuroendocrine tumours, sinonasal undifferentiated carcinomas, squamous cell carcinomas, adenocarcinomas, midline destructive lesions, and juvenile nasapharyngeal angiofibromas.

    This list is purposely not comprehensive and includes the most common sinonasal neoplasms. It is beyond the scope of basic sciences but awareness is necessary for contextual understanding of the pathology.

Midline destructive lesions is an all-encompassing term that includes non-Hodgkin's T-cell lymphoma, granulomatosis with polyangiitis (previously referred to as Wegener's granulomatosis), Immunoglubulin-4 related, and cocaine-induced midline destructive lesions.

Juvenile nasopharyngeal angiofibromas are a rare, benign, but locally destructive neoplasm that exclusively occurs in pre-pubertal males. Beware of a male patient who presents with nasal obstruction and recurrent epistaxis (especially when it is unilateral).

Olfactory epithelial damage or sinonasal mucosal dryness

An excessively dry sinonasal mucosa prevents odorants from dissolving and so prevents odorant-receptor binding.

There are a variety of systemic diseases that may cause epithelial damage or mucosal dryness. These may be categorised into six major groups: connective tissue diseases (granulomatous, vasculitis, autoimmune), infectious, respiratory, haematological, gastrointestinal, and endocrine system conditions.

Viral infections damage the olfactory epithelium and disrupt olfactory signal transduction. There is some evidence for Olfactory training and intranasal corticosteroids.[4,5]

Patients who receive radiotherapy for head and neck cancer develop a mucositis of the upper aerodigestive tract. For many of these patients, excessive dryness of the oral (xerostomia) and sinonasal mucosa is a very uncomfortable side effect. It may be irreversible, and it affects both taste and smell.

Severe and persistent olfactory dysfunction is a common outcome following surgical removal of pathological sinus mucosa in chronic sinusitis cases.

Persistent

Head injuries

Patients with significant head injuries may have hyposmia/anomia as a result of a shearing or traction injury to the olfactory nerve. This may or may not occur in conjunction with a base of skull fracture. The prognosis of this is patient specific and unpredictable.

Olfactory nerve deficits

Congenital hyposmia/anosmia may occur as a result of olfactory nerve agenesis or hypoplasia.