Rhinitis

Mechanisms and Management

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Chapter 2

Anatomy, Physiology and Ultrastructure of the Nose

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Structure and function in the nose as elsewhere, are both closely related and interdependent. They are, in fact, the two differing sides of the same coin and are best considered together. This chapter will concentrate on those points which are of clinical and practical importance.

The Anatomy of the Nose

The nose is divided by its septum into right and left nasal cavities. Anteriorly the nasal cavities open on to the face through the nostrils or anterior nares, whilst posteriorly they communicate via the posterior nares or choanae with the nasopharynx. The roof of the nose is formed by the cribriform plate which separates it from the anterior cranial fossa, whilst the floor of the nose is formed by the hard palate separating it from the cavity of the mouth.

Nasal cavities

Each nasal cavity is divided into three parts which include the nasal vestibule, the olfactory region and the respiratory region.

The nasal vestibule is the most anterior and extends from the nostril margin or external nares antero-inferiorly, to the internal nares or nasal valve, postero-superiorly. It is supported by the alar cartilage which normally maintains its patency during the negative intranasal pressure occurring during inspiration. When due to various possible structural defects it is unable to perform this task, inspiratory alar collapse will occur with resulting nasal obstruction. The nasal vestibule is lined by skin from which grow hairs and these constitute the first line of protective filtration which occurs in the nose during inspiration.

The olfactory area is confined to the upper part of the nasal cavity and includes the cribriform plate or roof, the adjacent part of the nasal septum and the superior turbinates. It is only about 10 sq cm in area, compared with the 120 sq cm area of the respiratory region. In many other species the sense of smell is of greater importance and here the olfactory area is correspondingly much larger.

The rest of the nasal cavity constitutes the respiratory region. As we have seen, this is bounded anteriorly by the internal nares or nasal valve area, which is a structure of very great importance because it is here that the nasal cavity is most narrow and therefore most vulnerable to obstruction. It is a waisted constriction separating the nasal vestibule from the respiratory region and it is triangular in shape with an area of only 0.3 sq cm on each side. The medial wall is formed by the nasal septum and the outer wall by the lower border of the upper lateral cartilage. There is an angle of about 15° between the two walls and the valve area can be opened by exerting traction on the soft tissues of the cheek in an upper and outer direction. This is the so-called Cottle test which is useful when differentiating between obstruction due to a structural abnormality in the valve area and a more posteriorly sited lesion.

The thin, narrow, irregular lumen of the nasal cavity, together with such constrictions as the internal nares, does make the delivery of topical medication to extensive areas of the nasal mucosa far from easy. As a consequence, failure of response to topical medication is more often due to this factor rather than to the basic inadequacies of the actual drug.

The nasal septum

The skeletal framework of the nasal septum consists of the quadrilateral cartilage anteriorly, the perpendicular plate of the ethmoid bone postero-superiorly and the vomer postero-inferiorly.

The nasal septum is not always positioned exactly in the midline, but is often deviated to one, or sometimes in cases of multiple displacement, to both sides. Morrell McKenzie stated that of the 2152 skulls which he examined, only 23% had a straight septum. The incidence of these anatomical variations differ greatly ethnically, and the largest numbers are found in Caucasians, with the fewest in the black races, and the mongoloids occupying an intermediate position. Many are due to direct nasal trauma, but a history of past injury is absent in the majority of cases. Here, the cause is probably due to moulding pressures which occur during pregnancy or to birth trauma, as has been postulated by Lindsay Gray. The neonatal septum is displaced from the mid-line in these patients and the deviations are then accentuated during the subsequent growth period. In the vast majority of cases, the degree of septal deviation is not severe enough to cause any obstruction and minor degrees can, therefore, be considered to be the norm rather than the exception. Cottle has classified septal deviations as:

1. *A simple deviation*

Here there is a mild deflection of the septum which does not cause obstruction. The majority of Caucasians have this type of septum and it certainly does not require any surgical treatment.

2. *Obstruction*

This is a more severe deviation of the nasal septum which may touch the lateral wall of the nose, but on vasoconstriction, however, the turbinates shrink away from the septum.

3. *Impaction*

This is a very marked angulation of the septum with a spur which lies in contact with the lateral nasal wall, even after the application of a vasoconstrictor. This is an absolute indication for surgical treatment.

The effects of the septal deviation depend on its position, and when the lesion occurs in a very narrow part of the nasal cavity such as the internal nares or valve area, even relatively minor deviations can easily cause obstructive symptoms and require surgical straightening.

Lateral nasal wall

The lateral nasal wall of the nasal cavity is dominated by three horizontal projections which are described in the clinical literature as turbinates and in the anatomical literature as nasal conchae. The inferior turbinate is much the largest and is a separate bone, whereas the medium-sized middle turbinate and the small superior turbinate are merely medial projections from the ethmoid bones. The turbinates greatly increase the surface area of the nasal cavity and this allows much greater contact between the unfiltered, unconditioned, inspired air, and the functional nasal mucosa.

Below and lateral to each of the respective turbinates are found the inferior, middle and superior nasal meati. The naso-lacrimal duct enters the nasal cavity through the inferior nasal meatus and consequent nasal disease in this area can block the duct and lead to epiphora. The frontal, maxillary and anterior ethmoidal sinuses drain into the middle nasal meatus, whereas the posterior ethmoidal sinuses drain into the superior meatus and the sphenoid sinus into the sphenoid-ethmoidal recess. These area are, therefore, of critical importance to the ventilation and drainage of the nasal sinuses. The draining ostium of each sinus is usually 3-4 mm in diameter, but it has been found that an ostium size of less than 2.5 mm predisposes to infection. Allergic diseases cause mucosal oedema, which can easily narrow the ostium, and the recent development of nasal endoscopy has shown that quite small anatomical anomalies and/or pathological lesions in this area which are not visible on routine rhinoscopy, can often interfere with the drainage of the sinuses and lead to the development of sinus infection. These infections often respond inadequately to antibiotic therapy and usually require surgical treatment which is often of a very minor type to effect a complete cure. Typical anatomical anomalies of this type include the so-called paradoxical middle turbinate which has a reverse curve, and the gross widening of the middle turbinate occurring when it contains an air cell (concha bullosa). These lesions produce gross narrowing of the middle nasal meatus.

Most cases of sinusitis result from infection spreading from the cavity of the nose. However, in the case of the maxillary sinuses, probably up to 5% are dental in origin. The roots of the upper teeth are often in very close contact with the floor of this sinus, and as a consequence an apical dental abscess can easily be spread upwards to involve the sinus. Likewise, there is always a risk that dental extractions in this area can lead to the development of an oro-antral fistula.

Blood supply to the nose

The blood supply of the nose is very profuse and is of considerable importance when considering both normal nasal physiology and the various disease processes which occur in the nose. The two main feeding arteries are the spheno-palatine posteriorly, which is a branch of the external carotid system; and the anterior ethmoidal artery anter-superiorly, which comes via the internal carotid system through its ophthalmic branch. These arteries converge on the antero-inferior part of the septum where they anastomose with the nasal branches of both the superior labial artery and the greater palatine artery. This area is usually known on the continent of Europe as Kiesselbach's area, and in the English-speaking countries more often as Little's area; 70% of nose bleeds come from this area.

The Ultrastructure of the nose

The working tissue of the nose is its lining mucous membrane and a fairly detailed histological study of this vitally important structure is necessary before a clear understanding of nasal function and immunology can be obtained. The nasal mucosa is capable of enormous physiological and pathological variations in thickness due to its vascularity and to the looseness of its submucosa. The potential for distension and swelling is maximal on the lateral wall of the nose. It is therefore at the lateral wall of the nose that one finds the greatest evidence of mucosal disease such as allergy, infection and nasal polyposis. The more generalised oedema found in allergy and infection causes a considerable and obvious enlargement of the turbinates. Polypi are evidence of a more localised oedematous process which more commonly affects the mucosal lining of the middle and superior nasal meati.

The olfactory area is confined to the upper part of the nasal cavity, the rest of which is divided into the nasal vestibule and the respiratory region. The vestibule is lined by skin, whereas the posterior 80% of the respiratory region is lined by a columnar, ciliated mucous membrane. A transitional and sparsely ciliated columnar epithelium is found in the intermediate area. It is, however, with the ciliated columnar mucosa that we are primarily concerned.

Columnar ciliated epithelium

Superficially this consists of a pseudo-stratified columnar epithelium resting on a basement membrane which separates it from the underlying submucosa or lamina propria.

The epithelium consists of ciliated columnar cells, non-ciliated columnar cells, goblet cells and basal cells. The basal cells are the primitive cells from which the columnar and goblet cells develop. They lie on the basement mucous membrane, but do not reach the surface of the epithelium.

Goblet cells constitute the glandular element of the epithelial layer. These are unicellular mucous glands with a basal nucleus. Numerous droplets of mucus are produced in the more superficial part of the cell before being expelled into the nasal cavity where a protective layer of mucus is found over the surface of the nasal mucosa. This layer of mucus is important in relation to the filtration function of the nose and its immunological protective mechanisms. Below this layer of mucus, the surface epithelial cells are all bound together by terminal bars which form another protective seal.

All the columnar cells are covered by short finger-like projections from their superficial surfaces called microvilli. Three to four hundred are found on each cell and the size is about one-third that of the average cilium. These microvilli are incapable of active movement and are not precursors of cilia. They do, however, greatly increase the surface area of the epithelium and prevent drying of its surface. Mygind has used the analogy of the garden lawn which keeps the morning dew much better than a surfaced road.

Most, but not all, of the columnar epithelial cells are ciliated. Probably 50-100 of these vitally important structures project for 4-6 microm from the surface of each cell. They are long, thin and mobile and have a diameter of 0.33 microm. The structural framework of each cilium consists of a ring of nine doublet microtubules surrounding two single central microtubules. The breakdown of adenosine tri-phosphate (ATP) by the enzyme dynein provides the energy for ciliary movement. Dynein arms or projections are found associated with the nine outer doublet microtubules. Rarely these dynein arms are absent, and this is found in cases of Kartagener's syndrome (sinusitis, bronchiectasis and situs inversus).

Satir has postulated a sliding-microtubule hypothesis for ciliary motion in which the energy is provided by the dynein arms and this results in movement of the peripheral microtubules which slide past one another. The shear resistance in the cilium causes the sliding to be extended into a bending movement. The cilia project into the layer of mucus which has an outer viscous gel phase. The mucous blanket is propelled backwards by ciliary activity. Each beat of the cilium consists of a rapid propulsive stroke followed by a slower recovery phase. The ciliary beat frequency is 10-15 beats per second and the mucus flows from the front to the back of the nose in about 5-20 minutes, as shown by the saccharin test. Mucus from each of the sinuses passes through its draining ostium on to the lateral wall of the nose, where it joins the main nasal mucus screen passing backwards into the nasopharynx around the orifice of the eustachian tube before being swallowed.

Ciliary activity is depressed by drying and also by the damage produced by nasal infections. Messerklinger has also shown that it is absent in structural abnormalities of the nose where two opposing mucosal surfaces come into direct contact. Local applications to the mucosa can affect ciliary activity. Extremes of pH and some drugs such as adrenaline and cocaine, both of which are widely used in rhinological practice, do produce a paralysis of ciliary activity.

The submucosa

The main components of this layer include the various glands, the blood vessels and the numerous extravascular cells, which have important protective and immunological functions.

The submucosa is a fairly loose connective tissue with some collagen and very few elastic fibrils. The ground substance is a gel composed mainly of mucopolysaccharides, with water, electrolytes and serum proteins forming the tissue fluids. The tissue fluid content can be abnormally high in some pathological conditions of the nasal mucosa such as polyposis.

Connective tissue cells such as fibroblasts, fibrocytes and histiocytes are found in the submucosa in addition to many other cells which play an important role in the immunological mechanism of the nose such as mast cells, plasma cells, eosinophils, lymphocytes, neutrophils, leucocytes and macrophages. The full details of nasal immunology and immunopathology are given in a later chapter, but in this account of the ultrastructure of the mucosa, a brief description of the mast cells and the plasma cells will now be given.

Mast cells are found in all layers of the submucosa but are only very rarely in the epithelium or nasal secretions. They are large cells averaging 15-20 microm in diameter and have an oval centrally placed nucleus. Their chief feature, however, is the presence of about 200 granules which are scattered throughout the cytoplasm. These granules stain Toluidine blue and are characterised by whorls and scrolls. They contain histamines and other powerful mediators of the allergic reaction. The function of these cells in the normal non-allergic individual is unknown, but they play a very important role in the immunopathology of allergy.

The plasma cells are also quite large, are egg shaped and have an eccentrically placed nucleus. The cytoplasm contains an abundance of RNA-containing ribosomes from which antibodies are synthesised.

The submucosal glands consist of the anterior serous glands and the more widespread small seromucinous glands. There are about 100-150 glands in the anterior serous group which open into the upper part of the internal nares. They appear to secrete a watery fluid with a high protein content.

The seromucinous glands are widely distributed throughout the entire respiratory region. They include distal serous tubules with more central mucous tubules which drain into a collecting, and finally a ciliated duct, before discharging their secretions into the nasal cavity. The serous solution has a high protein content and the collecting duct has the capacity to modify and control the iron and water content of the glandular secretions. The protein content of the serous tubule secretions contain the bacteriolytic enzyme, lysozyme, in addition to lactoferrin, which has the capacity to remove heavy metal ions and prevent the growth of certain bacteria such as staphylococci and pseudomonas. The plasma cells around the seromucinous glands produce the immunoglobulin IgA, which is discharged into the duct system of the glands, and as a result, IgA is the principal immunoglobulin to be found in nasal secretions. A layer of protective IgA then covers the outer surface of the nasal mucosa and constitutes a first line of defence against microorganisms. IgA deficiency is usually found in atopic individuals and, according to Southill, this leads to a secondary over-activity of the IgE system. IgE is only found in extremely minute amounts in normal individuals, but its levels are very greatly raised in atopic subjects.

The main constituent of nasal fluid is, of course water (95-97%), but it also contains mucin (2.5-3%) and electrolytes (1-2%). Normal nasal secretions are clear and slightly viscous and it used to be taught that any colouration of the nasal discharge usually indicates active infection. However, a yellow colouration of the discharge can indicate a raised protein content and this is sometimes found in allergic disorders which are not complicated by secondary infection. A green colouration is due to the enzyme verdoperoxidase released from dead leucocytes which are found in active nasal infections. The secretomotor nerve supply to the nose is parasympathetc. These fibres are derived from the facial nerve and reach the nasal mucosa via the vidian nerve.

Blood vessels

The nasal mucosa is a very vascular membrane and its total blood flow per cubic centimetre of tissue is greater than in muscle, brain and liver. Some degree of pathological behaviour of the blood vessels is found in all cases of rhinitis, although the term in "vasomotor" rhinitis is usually reserved for patients suffering from symptoms indistinguishable from allergic rhinitis, in whom no immunological evidence of an allergic cause can be found.

A distinctive characteristic of the nasal blood vessels is their extreme porosity. This is produced by defects or fenestra in the lining endothelial basement membrane. This facilitates a very rapid passage of fluid through the vascular wall and also makes the absorption of drugs such as sympathomimetic agents, histamine and corticosteroids, both easy and rapid.

Blood, in addition to flowing from arteries, through the capillary network and into the venules, can also be directed straight from the arteries through the arteriovenous anastomoses into the venous system. Angaard has shown in the cat that 60% of the blood flow is normally shunted through arteriovenous anastomoses.

Erectile tissue in the form of cavernous sinusoids are found between the capillaries and the venules. These potentially cavernous structures are usually in an empty contracted state. The walls of these vessels contain smooth muscle cells whose activities are usually controlled by the autonomic nervous system. These sinusoids are normally constricted by a continuous sympathetic stimulation, but they can dilate when this tone is lost and also parasympathetic stimulation produces some vascular dilatation. The concentration of sinusoids is most marked in the mucosa covering the inferior and middle turbinates and, when gorged with blood, they produce an enormous increase in thickness of the nasal mucosa with a resulting obstruction of the airway.

Function of the Nose

Airway

Normal breathing occurs through the nose, which has the task of filtering, warming and humidifying the inspired air, which is later delivered to the lungs in an optimal state. The nose also helps to protect the lower respiratory tract and all these valuable functions are lost when breathing occurs through the mouth. Nasal breathing is obligatory in the neonate, due to the somewhat different anatomy at this age and as a consequence bilateral choanal atresia causes an alarming and life-threatening degree of respiratory obstruction in the newborn.

Usually about 10% of the inspired air reaches the olfactory area of the nose during normal breathing, although this can be increased to 20% with sniffing. A selective obstruction in the upper nasal cavities could, therefore, rob the patient of his sense of smell, without obstructing the main nasal airway. Nasal breathing makes heavy commitments on the lining mucous membrane of the nose which, if excessive, can change to the squamous epithelial type. It may be for this reason that a nasal cycle can be detected in 80% of the population. Here, there is a cyclic and alternate obstruction occurring every four or twelve hours. One side of the nose will block off due to the engorgement of the erectile sinusoids in the turbinates and there will be shrinkage of the mucosa on the opposite side through which all breathing takes place. Nasal secretions are cyclic, being greatest from the unobstructed side. This cycle is controlled by the autonomic nervous system and passes unnoticed by most people. It could, however, give rise to the phenomenon of "paradoxical nasal obstruction". This was described by Arbour and Kern in which these patients have a longstanding, fixed, unilateral nasal obstruction, to which they have become accustomed and of which they are no longer aware. The mucosal swelling associated with the nasal cycle does result in an additional intermittent nasal obstruction on the normal side of the nose, and this becomes the dominant symptom to be appreciated by the patient.

Heating and humidification

The glandular and vascular elements of the nose evidently warm and humidify the inspired air. When the air reaches the nasopharynx it is normally 31°C and 95% saturated. This performance is maintained despite gross changes in environmental conditions.

Filtration

The alveoli are extremely delicate and may be damaged by particles in the inspired air. An important function of the nose is to filter off these contaminants. The shape of the nasal cavities favour this process because they ensure the maximum contact between line mucosa and inspired air with a slit-like lumen, with a major constriction at the internal nares. This produces turbulence with deposition of particles on the mucus blanket which covers the nasal mucosa. Here the particles adhere to the viscid mucus, which is transported like a conveyor belt by ciliary action in a backwards direction into the nasopharynx and is then swallowed. In addition to this mechanical process there are also protective immunological mechanisms.

The nose is extremely effective in filtering off particles down to a size of microm. Particles below this size pass through the nose and into the lungs and this has an important bearing on whether an atopic patient develops asthma or allergic rhinitis. Sensitivity to smaller allergens, such as fungal spores (3-5 microm) usually causes an asthmatic condition, whereas the larger allergens, such as grass pollens (30 microm) are filtered off in the nose and this results in the development of an allergic rhinitis.

Sense of smell

This subject will be covered in detail in Chapter 5.

The nose and voice

Phonation arises in the larynx but the primary laryngeal sounds are modified by the resonance which occurs in the nose, pharynx, oral cavity and lips. The nasal cavities are closed off by the soft palate during the production of most sounds, but nasal resonance is necessary for such consonants as 'm' and 'n'. A reduction of nasal resonance occurs when the nose is obstructed and this results in rhinolalia clausa. Excessive nasal resonance causes rhinolalia aperta, which occurs when there are defects in the nasopharyngeal sphincter, such as are present in cases of cleft palate.

Nasal reflexes

The nose is both the afferent and efferent component of several reflexes which are often of clinical importance, because many patients with nasal symptoms often have an abnormally labile mucosa which reacts in an exaggerated fashion to these stimuli. The main reflexes in the nose are:

1. Intense chemical, thermal or physical stimulation of the nose produces sneezing and in extreme cases this can progress to closure of the laryngeal sphincter with intense vasoconstriction of skin, muscles and viscera.

2. Exertion causes intense vasoconstriction of the nasal mucosa, and it is for this reason that exercise is used prior to making nasal resistance tests on the nose in order to differentiate between blockage due to structural defects and those due to mucosal swelling.

3. Heating the general skin surface causes nasal vasodilation and this, together with the dryness of the air, can lead to nasal symptoms which are often found in those who are working in such environments as a hot, air-conditioned office without humidification.

4. Cooling of the general skin surface produces a vasoconstriction with clearing of the nasal passage.

5. Increasing the airflow through one side of the nose results in increased ventilation of the homolateral lung.

6. Burrows and Eccles have shown that when an individual lies on his side this produces vasodilation in the lower nasal cavity with often a sensation of blockage and vasoconstriction in the upper nasal cavity.

Endocrine and psychological factors

Some hormones have quite dramatic effects on the nasal mucosa. The action may be more on disease states, such as is accomplished by the corticosteroids which have a dramatic effect on the inflammatory process which is present in many types of rhinitis. In other examples, the effects are on the normal mucosa. Hypothyroidism may cause nasal obstruction due to the deposition of mucopolysaccharides in the extracellular spaces of the submucosa.

The sex hormones can have profound effects on the nasal mucosa. Oestrogens produce nasal congestion and for this reason have been used in the treatment of atrophic rhinitis. Certainly, changes in the mucosa can occur during menstruation and pregnancy. Some of the higher dose oestrogen contraceptives can produce an iatrogenic rhinitis. Also, the syndrome of "honeymoon" rhinitis has been described by Watson Williams, where severe nasal symptoms occur during moments of sexual excitement. The nasal mucosa also reacts to certain psychological states. Anger produces a sympathomimetic reaction with vasoconstriction and reduced secretory activity, whereas such emotions as resentment and possibly depression, have the opposite effect, inducing obstruction with excessive nasal discharge and sneezing.