Chapter 5: Anatomy of the nose and paranasal sinuses

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Embryology

The complex anatomy of the midfacial structures, including the nose, the paranasal sinuses, the mouth and the pharynx, can be fully understood only if it is considered in relation to the embryological development of those structures. In the original yolk sac vesicle, the fundamental structural change which initiates a number of other developments is the rotation of the cephalic end of the embryonic disc with the formation of the embryo head.

In the early embryo, the pericardial cavity and heart tube lie cephalic to the notochondral plate, from which they are separated by the buccopharyngeal membrane. The ectodermal and endodermal layers of the embryonic disc are separated by a layer of mesoderm, which later differentiates laterally into the somites, the so-called 'paraxial' structures, which include the pharyngeal arches.

Rotation of the heart tube caudally around the axis of the buccopharyngeal membrane brings the cardiogenic region, the future septum transversum, and the cranial mesoderm from their original position to lie ventral to the foregut. The folding of the original ventral mesodermal layer, which lined the yolk sac cavity, results in the formation of an endodermal-lined diverticulum lying between the cardiogenic complex and the anterior end of the notochord. At the closed anterior end of this 'primitive foregut' is the buccopharyngeal membrane, which consists of an endodermal layer and the adjacent ectoderm.

The differentiation of the paraxial mesoderm on either side of the notochord, which results in the formation of somite ridges, occurs almost synchronously with the foregoing changes. Between the somites and lateral plate mesoderm lie the intermedial cell masses of mesoderm. The lateral plate mesoderm subsequently splits to enclose the intraembryonic coelom, and cranially this extends forwards to fuse in the midline, forming the coelomic ducts. It is the mesoderm at the cephalic end of the embryonic disc which condenses cranially, differentiating into the branchial arch structures surrounding the caudal derivatives of the foregut.

Development

The development of the nose and paranasal sinuses is a continuous process which commences in the third week of gestation, when the primordial structures first appear, and continues until completion in early childhood, when sinus pneumatization and bony growth have ceased. Knowledge of the intrauterine developmental changes is essential for a basic understanding of the anatomical relation of these structures, but it is equally important for the clinician to appreciate the important anatomical changes which continue to take place throughout childhood.
The external nose

The nose develops from the cranial ectoderm above the stomatodeum, where paired thickenings - the olfactory or nasal placodes - become apparent in the fourth intrauterine week when the embryo has a crown-rump length of 5.6 mm (Streeter, 1945). Proliferation of the surrounding mesoderm into the medial and lateral nasal folds results in the gradual depression of the placodes to form olfactory pits, which eventually deepen by the fifth week to form the nasal sacs (Streeter, 1948). Between these pits, the medial nasal folds fuse below the frontonasal process, and eventually develop into the central portion of the upper lip, the premaxilla and the primitive nasal septum.

The nasal cavity

In the 12.5 mm embryo, the maxillary process of the first branchial (mandibular) arch grows anteriorly and medially below the developing eye, across the inferior border of the nasal pits, to fuse anteriorly with the medial nasal folds and the frontonasal process. The nasal pits then become closed inferiorly and form the primitive nasal cavities. The nasolacrimal furrow is also obliterated by fusion of the outer aspect of the maxillary process and the lateral nasal process. At this junction, the adjacent layers of ectoderm fuse to form a solid cellular rod, producing a surface elevation of the nasolacrimal ridge, which later sinks into the mesenchyme. The solid rod later becomes canalized to form the nasolacrimal duct.

The primitive palate is formed at this stage by proliferation of mesoderm in the free lower border of the frontonasal process. The blind ends of the nasal sacs continue to extend posteriorly with progressive thinning of the bucconasal membrane, so that by the thirty-eighth day this membrane is just a thin layer of nasal and oral epithelium. This eventually ruptures in embryos of crown-rump length 12-14 mm, with formation of the choanae, which are the posterior apertures of the nose. The position of the bucconasal membrane (or primitive posterior naris) is more anterior to the eventual position of the definitive posterior naris, which does not become established until the third month because of the continued posterior growth of the palate (Warbrick, 1960). Choanal atresia, caused by failure of rupture of the bucconasal membrane, may therefore lie in a more anterior position in the nasal cavity. Membranous and bony atresia may also occur to a variable degree because of failure of recanalization of the nasal cavity, which temporarily becomes filled with proliferating epithelial cells between the sixth and eighth weeks.

At this stage, the cranial boundary of the oral opening consists of the fused premaxillary and maxillary regions, and only later does the upper lip separate from the deeper tissues which will ultimately form the maxillary alveolus. The eventual contribution made by the frontonasal process and the maxillary processes to the formation of the premaxilla, external nose and upper lip is in some doubt. Frontonasal process derivatives are supplied by the ophthalmic nerve, a branch of which - the anterior ethmoidal nerve - supplies the external nose. The upper lip, including the philtrum, is supplied by the maxillary nerve and is therefore considered to be derived from the maxillary processes. Others believe that the philtrum is derived entirely from premaxillary tissue (Keith, 1948; King, 1954; Warbrick, 1960; Wood, Wragy and Stuteville, 1967), and that the maxillary innervation extends into the frontonasal derivative in the upper lip.
The palate and nasal septum

By the time the embryo is 13.5 mm, the primitive palate is beginning to form by fusion of the maxillary processes with the caudal end of the frontonasal process. Behind this are the openings of the primitive posterior nares, and in the midline the rudiment of the nasal septum. At this stage, therefore, only the ventral (or anterior) part of the palate is formed. As the head increases in size, mesenchymal proliferation occurs between the forebrain and buccal cavity, and the nasal cavities deepen towards the forebrain. A midline ridge develops from the posterior edge of the frontonasal process in the roof of the buccal cavity, extending posteriorly to the opening of Rathke's pouch. This becomes the nasal septum which is continuous anteriorly with the partition between the primitive nasal cavities. On either side of the elongating septum, the nasal cavities continue to deepen and extend dorsally from the primitive choanae to become two deep, narrow grooves in the roof of the oral cavity. At this stage, the tongue is almost in contact with the broad dorsocaudal (inferior) border of the developing septum, and there is free communication between the nasal cavities (behind the primitive palate) and the mouth.

As the nasal cavities enlarge, the palatal processes, derived from the lateral maxillary mesoderm, grow medially towards each other and the developing septum. The free edges are at first directed vertically on either side of the tongue, but with further growth the latter structure and the mandibular region are drawn ventrally. This is followed by a rapid change in direction growth of the palatal processes, occurring at about the eighth week, so that these processes now approach each other horizontally and fuse. The mechanism of this directional change is of particular relevance to maldevelopment of the palate, and is the subject of much controversy (Kraus, Jordan and Pruzansky, 1966). The fusion initially occurs along the posterior margin of the primitive palate, except for a small dehiscence in the midline, where the nasopalatine canal remains patent for a time between the two cavities, later marking the site of the incisive foramen. The palatal processes then fuse progressively with each other and with the caudal border of the septum in an anteroposterior direction. The nasal and oral cavities are thus separated from each other, and the choanae are progressively moved in a posterior direction until they lie adjacent to the free dorsal margin of the nasal septum. The palatal processes continue to fuse posteriorly, forming the soft palate and uvula, thereby separating the nasopharynx from the oral cavity.

At the anterior (ventral) end of the nasal septum, above the primitive palate, are situated the paired vomeronasal organs of Jacobson. The ectoderm becomes invaginated on either side to form a diverticulum, which is directed dorsally adjacent to the developing septal cartilage. The vomeronasal organs become well developed auxiliary olfactory organs in many vertebrates, but they are vestigial in man. In some adults, a residual small slit or pit can be identified on each side of the anterior septum, just above the nasal floor (Johnson, Josephson and Hawke, 1985).

The paired vomeronasal cartilages are narrow longitudinal strips, 7-15 mm in length, which lie alongside the lower border of the septal cartilage. They are attached anteriorly to the maxillary crest and posteriorly to the vomer. In the adult, they may be identified as a cartilaginous bulge along either side of the lower border of the septum, or may remain as separate, discrete strips of cartilage.
The bony and cartilaginous structures of the midface develop from the primitive nasal capsule, which is formed by mesenchymal condensation during the third fetal month. This is the primary skeleton of the upper and midface, just as the Meckel's cartilage is for the lower face. In the sixth month, this capsule differentiates anteriorly into the alar, the upper lateral and septal cartilages, which are the only parts of the capsule to remain cartilaginous into adult life. The greater part of the capsule becomes ossified posteriorly into the ethmoid bones, the turbinates, part of the sphenoid bone and the vomer, and laterally into the maxillae and nasal bones.

The paranasal sinuses

Progressive changes in the lateral nasal walls with formation of the paranasal sinuses occur simultaneously with development of the palate. In the 40-day-old fetus, as the nasal cavity expands, so horizontal grooves appear on the lateral wall, which will later form the inferior and middle meatus. Between them, the maxilloturbinate mesenchyme proliferates, bulging into the lumen, and later becomes the inferior turbinate. The upper turbinates develop from ethmoidturbinate folds which appear later, and by term as many as five may be present. The upper ones regress after birth and remain vestigial (Schaeffer, 1920a). Development of the sinuses occurs once the turbinate folds are established; this is a slow process which continues until cessation of bony growth in early adult life. Of the four named sinuses, only the maxillary and ethmoid sinuses have their origin in early fetal life.

Maxillary sinus

The maxillary sinus is the first to appear as an ectodermal depression just above the uncinate ridge on the inferior turbinate. This pit, which is the site of the eventual maxillary ostium in the central part of the middle meatus, deepens laterally and expands so that by term a cavity measuring 7 x 4 x 4 mm is present (Ritter, 1973). The expansion continues after birth at an estimated growth rate of 2 mm vertically and 3 mm anteroposteriorly each year (Proetz, 1953). By the age of 12 years, the floor of the sinus has descended to the level of the nasal floor and further downgrowth is achieved by expansion of the lumen into spaces vacated by the erupting teeth.

Ethmoid sinus

During the fifth fetal month, small ectodermal evaginations develop on the lateral nasal wall and grow laterally into the ethmoid bone. By term, these diverticula are globular shaped and they continue to grow until late puberty, or until they abut against compact bone or against another sinus (Ritter, 1973).

Frontal sinus

At the anterosuperior part of the middle meatus, a small evagination, the frontal recess, develops during the third month. This gradually deepens and by term a small diverticulum is present. The formation of the frontal sinuses occurs with gradual upwards expansion of the diverticulum into the frontonasal region. At 6 years, this may just be recognizable in the frontal bone on X-ray. The sinus may, on rare occasions, develop as an extramural expansion.
of one of the anterior ethmoidal cells (Schaeffer, 1920b). Medially, the two sinuses come to lie in close proximity, divided by a thin intersinus septum.

**Sphenoid sinus**

The primitive sphenoid sinus develops, during the fourth fetal month, as an ectodermal pit in the posterosuperior aspect of the nasal capsule. At birth, it measures 2 x 2 x 1.5 mm and is still only rudimentary. In the fourth postnatal year, when the nasal capsule resorbs, sphenoid pneumatization begins at a rate of 0.25 mm growth each year in a posterior direction, although progress may well be irregular (Hinck and Hopkins, 1965). It is the first of the paranasal sinuses to reach full development.

The degree of pneumatization of the sphenoid sinus varies considerably, and three main types are recognized:

1. **Sellar type.** In 90% of individuals, pneumatization extends beyond the tuberculum sellae by early adulthood. In 20% of these, it extends underneath the sella turcica, or even beyond it towards the basiocciput.

2. **Presellar type.** In under 10% of adults, pneumatization extends only as far posteriorly as the tuberculum sellae, although in childhood, as pneumatization is progressing, the proportion is much greater.

3. **Conchal type.** In 2-3% of cases, pneumatization does not progress beyond the rudimentary infantile stage (Hammer and Radberg, 1961).

**Anomalies and variations in development**

**The external nose**

The shape of the nose is determined by genetic and racial factors and there is wide individual variation. Cleft-palate and cleft-lip deformities are always associated with nasal abnormality, as their development is intimately related. The nasal dermoid cyst is a common developmental midline abnormality on the dorsum of the nasal bridge, resulting from failure of fusion of the medial nasal folds. Failure of fusion more caudally may result in a bifid nasal tip.

**The upper lip and palate**

The commonest congenital anomaly in this region is the cleft palate, which is often associated with a cleft or hare lip. These deformities are a consequence of failure of fusion of the maxillary processes medially with the frontonasal process and the developing nasal septum. The condition may be unilateral or bilateral.

**The septum and nasal cavities**

Deviation or asymmetry of the nasal septum occurs in approximately 80% of individuals (Gray, 1978), often involving the junction of the ethmoid plate and the vomer.
However, the posterior border of the septum, where it articulates with the rostrum of the sphenoid, is always in the midline, an important landmark in transethmoidal hypophysectomy.

Choanal atresia results from failure of recanalization of the nasal cavities and may be unilateral or bilateral. Simple membranous atresia may occur if the bucconasal membrane fails to rupture.

**The external nose**

**Surface anatomy**

The skin covering the nose is thicker towards the tip, and at this point contains a large number of sebaceous glands. It is also more tightly adherent to the underlying alar cartilages, whereas the skin over the upper part of the nose is more loosely attached to the underlying nasal bones and, to a lesser extent, to the upper lateral cartilages. Muscles also intervene between the skin and upper part of the nasal skeleton.

**Bony and cartilaginous structures**

The supporting framework of the nose is derived from the nasal capsule, most of which becomes ossified. Anteriorly, the capsule remains cartilaginous, forming the paired alar (lower lateral) cartilages, the upper lateral cartilages and the septal cartilage in the midline. Small accessory alar cartilages are present laterally in the alar fold. The lateral crus of the alar cartilage forms the lateral boundary of the nasal vestibule (the external nasal valve), and is moved by the compressor and dilator naris muscles. The medial crus is attached to its counterpart forming the support of the columella. The alar cartilage is thin and consists of elastic cartilage, while the other cartilages, by contrast, are of the hyaline type. The upper lateral cartilage is overlapped by the cephalic edge of the alar cartilage, to which it is attached by dense connective tissue. This creates a ridge across the roof of the nasal vestibule which forms the inner nasal valve. The outer aspect of the upper lateral cartilage is firmly attached to the frontal process of the maxilla, but the alar cartilage is separated by fibroareolar tissue containing the accessory and sesamoid cartilages, thereby allowing mobility.

Along its cephalic border, the upper lateral cartilage is also overlapped by the caudal margin of the nasal bone, to which it is closely adherent.

The medial aspects of the upper lateral cartilages are continuous with the cartilaginous part of the nasal septum. This is a quadrangular-shaped cartilage whose tapering posterior prolongation articulates with the perpendicular plate of the ethmoid and the vomer. Caudally, the septal cartilage articulates with the nasal spine anteriorly, and with the vomer where it normally rests in a groove. On either side, the vomeronasal cartilage may be separate from, or fused with, the lower border of the septal cartilage. The free anterior caudal margin of the septum is separated from the medial crura of the alar cartilages by the membranous portion of the septum, which aids mobility of the tip of the nose. A short length of the dorsal margin of the septum can be identified between the alar and upper lateral cartilages, the so-called 'septal angle'. Above this, the cartilage becomes bifid, forming a shallow median groove, and merges into the upper lateral cartilages on each side.
The bony nasal pyramid, to which the cartilaginous structures are attached, consists of the paired nasal bones above, and the frontal processes of the maxillae laterally. The fusion inferiorly of the bodies of the maxillae complete the pear-shaped opening. Because of the recessed position of the anterior border of the bony septum, which divides the nasal cavity posteriorly, it is a single aperture, and in the centre of its inferior border is the elevated anterior nasal spine.

The nasal bones articulate with each other in the midline and with the medial part of the nasal notch of the frontal bone superiorly. Additional support is also obtained on the deep aspect from the nasal spine of the frontal bone. Laterally, the nasal bone articulates with the medial border of the frontal process of the maxilla. The nasal bones are quadrangular in shape and are flatter and wider at the bottom, but where they articulate with the frontal bone they are narrow and thick.

**Musculature of the nose**

Movements of the tip of the nose, including the alae and the lower part of the septum, are controlled by procerus nasalis, consisting of transverse fibres (compressor naris) and alar fibres (dilator naris), and depressor septi. Other smaller muscles are attached to the alar cartilage: the anterior and posterior dilator naris muscles and the compressor narium minor muscles. The muscle fibres are either attached to the cartilages or, as in the case of the compressor naris, pass across the upper lateral cartilages to be inserted into a median aponeurosis. Their actions are indicated by their names, but they are less well developed in humans than in other primates.

**Nerves and vessels of the nose**

The cutaneous sensation of the external nose is through the infratrochlear nerve above, and the external nasal nerve towards the tip, the latter being a continuation of the anterior ethmoidal nerve. Both are branches of the ophthalmic division of the trigeminal nerve. Laterally, branches of the infraorbital nerve encroach on to the side walls of the nasal skin. The nasal muscles are supplied through the buccal branches of the facial nerve, and paralysis of the nerve will cause collapse of the alae with nasal obstruction on that side.

There is a rich blood supply, partly from the facial artery to the alae and lower part of the septum, but also from the external nasal branch of the ophthalmic artery superiorly, and from branches of the infraorbital artery to the lateral surface and septum laterally. The marginal vein, which continues as the facial vein, is situated at the medial canthus on the side wall of the nose, and here it may be quite prominent.

**Surgical anatomy of the nose**

The nose is the most prominent feature of the face and, as such, is easily subject to traumatic injury. Fractures of the nose usually involve only the thinner, distal portions of the nasal bones. Injuries to the tip of the nose often cause fracture or dislocation of the cartilaginous septum, with the resulting deformity depending on the direction and force of the impact. Disruption of the external nasal artery by bony fractures may often cause severe bleeding, which may need to be controlled by ligation of the anterior ethmoid artery. In
corrective surgery, dissection should be carried out close to the bony and cartilaginous framework to avoid unnecessary injury to the vessels in the soft tissues.

The nasal cavity

Functional anatomy

The anatomical structure of the nasal cavity is intimately related to its important functions of respiration and olfaction. As in other primates, the sense of smell in humans has become less well developed and the olfactory area is confined to a small around the cribriform plate in the roof of the nasal cavity. In man, the main function of the nose is respiratory and, apart from providing an airway, the nasal cavity is also important for humidification and cleaning of the inspired air.

The nasal cavity is closed off from the mouth by the bony hard palate, so that mastication of food can take place without compromising breathing. During the initial phase of swallowing, the soft palate is elevated, closing off the nasopharynx and, momentarily, interrupting breathing. One other function of the nasal cavity, in conjunction with the paranasal sinuses, is to contribute to resonance of speech.

The importance of adequate patency of the nasal cavity is demonstrated by the effects of pathological obstruction which, apart from impairment of the above functions, may also lead to secondary sinus and eustachian tube problems. In spite of there being an apparently adequate alternative upper airway through the mouth, oxygen tension levels in the blood are significantly reduced in nasal obstruction.

Bony structure

The nasal cavity extends from the external nares (nostrils), anteriorly, to the posterior choanae where it becomes continuous with the nasopharynx. The nasal septum is a midline partition which divides the cavity into two halves. In the prepared skull, the anterior opening of the nasal cavity presents as a single pyriform aperture because of the deficiency of the bony septum anteriorly. The cavity is wide across its floor, but narrows to a maximum of 5 mm across the cribriform plate in its roof. The medial walls are formed by the nasal septum, and the lateral walls are characterized by the presence of horizontal, curved bony projections called nasal turbinates. The paired maxillary, frontal, ethmoid and sphenoid sinuses communicate with the nasal cavity of the same side.

The roof is concave in an anteroposterior direction, with the nasal bones and the supporting nasal septum forming the sloping anterior (frontonasal) portion. The central part is made up of the cribriform plate of the ethmoid bone, while the posterior, sloping part of the roof is formed by the floor of the sphenoid sinus. In the midline posteriorly, the vomerine portion of the bony septum flares out on either side as the alae of the vomer, which articulate laterally with the medial (vaginal) process of the medial pterygoid plate and the sphenoidal process of the palatine bone. Higher up, the front of the body of the sphenoid projects as a prominent midline ridge called the rostrum, which articulates with the vertical plate of the ethmoid at the upper part of the septum. Although the bony septum may be deviated, the rostrum itself is invariably in the midline and, as such, forms an important landmark in
transethmoidal or trans-sphenoidal hypophysectomy. However, its posterior projection, which forms the intersphenoid sinus septum, is almost always deviated to one side or the other.

The posterior nasal apertures (choanae) are thus divided medially by the free posterior edge of the vomer. Their roof is formed by the body of the sphenoid with the overlapping, flared alae of the vomer and the vaginal process of the medial pterygoid plate. Their lateral walls are formed by the medial pterygoid plate, and the floor by the free posterior edge of the horizontal plate of the palatine bone.

The floor of the nasal cavity is concave from side to side and slightly concave in an anteroposterior direction. The anterior three-quarters is formed by the palatine processes of the two maxillae, and the posterior quarter by the horizontal plate of the palatine bones. Anteriorly, close to the base of the septum, is the incisive fossa. In the upper part of the fossa are two lateral incisive canals and two median incisive foramina. The lateral incisive canals represent the site of the embryonic communication between the nasal and oral cavities, and thus define the line of union on the palate of the premaxilla with the maxillae. The incisive foramina transmit the nasopalatine (long sphenopalatine) nerve and the terminal branch of the greater palatine artery.

The lateral wall of the nasal cavity has a complex anatomical contour as a result of the presence of three scroll-like projections, the superior, middle and inferior turbinate bones. Anteriorly, the wall is formed by the inner aspect of the nasal bone, the frontal process and by the anterior part of the body of the maxilla, and is overlapped by the anterior end of the inferior turbinate. The medial wall of the ethmoidal labyrinth forms the upper middle part of the lateral wall, with its superior turbinate bone projecting from the posterosuperior part and the middle turbinate from the anterior and middle surfaces.

The superior turbinate is the smallest of the turbinates and may be reduced to only a small ridge about 1.25 cm below the cribriform plate. The sphenoid sinus ostium opens above and behind the superior turbinate into a small depression, the sphenethmoidal recess. Occasionally, a fourth rudimentary turbinate bone - the supreme turbinate - may lie above and behind this recess.

The middle turbinate bone is large and its anterior part extends forward to articulate with the ethmoidal crest on the frontal process of the maxilla. The posterior edge extends as far back as the medial surface of the perpendicular plate of the palatine bone. The line of attachment is like an inverted ‘V’, that is with a short, almost vertical anterior limb and a long, sloping posterior limb. The free edge is directed downwards and medially, and overhangs the middle meatus.

The inferior turbinate is a separate bone, unlike the superior and middle turbinates which are projections from the ethmoid labyrinth. It extends from the body of the maxilla to the ethmoidal crest on the perpendicular plate of the palatine bone. Its central portion is arched so that the inferior meatus, which it overhangs, is both wider and higher at this point; the anterior and posterior ends are narrowed.

The spaces overhung by the turbinates are called the meatus, whose lateral walls can be studied on removal of the turbinate bones at their attachments. The superior meatus has
one opening from the posterior ethmoid sinus, and below and posterior to this is the sphenoethmoidal recess into which the sphenoid sinus drains.

The middle meatus has a number of important landmarks and openings on its lateral wall. The highest point of the attachment of the middle turbinate at the angle of its anterior and posterior limbs lies above the frontal recess, into which the frontal sinus and some of the anterior ethmoidal cells may drain. Behind this, the sloping posterior ramus of the middle meatus overlies the uncinate process, the hiatus semilunaris and the bulla ethmoidalis. The uncinate process is a sharp, curving ridge of bone projecting upwards from the anterior extremity of the ethmoidal labyrinth to articulate with the ethmoidal process of the inferior turbinate. The posterosuperior border of the uncinate process partially covers the opening of the maxillary sinus (antrum of Highmori), and forms the lower boundary of a curved fissure, the hiatus semilunaris. The hiatus semilunaris leads into the ethmoidal infundibulum, which is the vertical groove between the lateral nasal wall and the uncinate process. Its average depth, depending on the height of the uncinate process, is about 5 mm. The anterior ethmoidal cells open into the infundibulum anteriorly, and behind these is the opening of the maxillary sinus. Posteriorly, the infundibulum becomes continuous with the middle meatus; anteriorly, it is directly continuous with the ostium of the frontal sinus. The lateral wall of the infundibulum and adjacent parts of the lateral nasal wall may be membranous and, in up to 40% of cases, there may be accessory ostia leading into the maxillary sinus (Hollinshead, 1982).

The upper border of the hiatus semilunaris is formed by the bulla ethmoidalis, which is a rounded projection immediately below the middle turbinate. This swelling is produced by the bulging of one or more middle ethmoidal cells which open on to or above the bulla. The anterior border of the uncinate process articulates with the lacrimal process of the inferior turbinate and the turbinate process of the lacrimal bone, which together form the medial bony wall of the nasolacrimal duct. Behind the posterior end of the middle turbinate is the sphenopalatine foramen leading into the pterygopalatine fossa.

The inferior meatus is the largest of the three meatus, and the only structure of importance to open into it is the nasolacrimal duct. The ostium is usually situated quite high on the lateral wall in the anterior part of meatus, just below the attachment of the inferior turbinate bone. The shape of the ostium varies from a narrow oval slit to a rounded opening, and may tend to be larger when it is placed at a higher level in the meatus (Hollinshead, 1982). Narrow openings may be protected by a fold of mucous membrane, the plica lacrimalis or valve of Hanser.

The nasal septum is made up of a cartilaginous anterior portion and a larger, bony, posterior part consisting of the vertical plate of the ethmoid and the vomer below. The anterior, free caudal border of the septum or columnella contains the paired medial crura of the alar cartilages, which are connected to the septal cartilage by the membranous septum. The perpendicular plate of the ethmoid articulates with the nasal spine of the frontal bones and with the nasal bones anterosuperiorly behind this. It is continuous with the cribiform plate and it articulates posteriorly with the crest of the sphenoid. Posteroinferiorly it articulates with the vomer and anteroinferiorly with the septal cartilage. Its size varies inversely with the size of the septal cartilage.
The vomer forms the posterior part of the nasal septum, articulating inferiorly with the nasal crest of the maxilla and palatine bone. Posterosuperiorly, it flares out to form two alae which spread out on the undersurface of the sphenoid, lying between the vaginal processes of the medial pterygoid plates. The rostrum of the sphenoid bone - a small anteriorly directed wedge of bone projecting from the body of the sphenoid bone - fits in between the posterior junction of the vomer and ethmoid bones. The anterior border of the vomer is grooved to support the posterior edge of the septal cartilage. Anatomical variation and deformities of the septovomerine junction and deviations of the septal cartilage are common in humans, but are unusual in lower primates and other vertebrates. Lateral ridges may also occur along the maxillary crest and vomeroethmoidal articulation, thereby contributing to nasal obstruction. The perichondrium of the septal cartilage and the periosteum fuse along the groove, but mobility of the cartilaginous septum is facilitated by looser connective tissue between the cartilage and the bone, in which there may be fat (Aymard, 1917).

Nasal cavity lining

Each half of the nasal cavity can be divided into four parts: the vestibule, the atrium, and the respiratory and olfactory regions. The vestibule is the anterior portion of the nasal cavity bounded laterally by the ala of the nose. It is lined with skin containing sebaceous and sweat glands, which are more abundant in the lower part. Strong hairs, or vibrissae, project into the vestibule from its medial wall and floor to trap coarse inhaled particles. The skin of the roof and lateral wall is thinner, and the vibrissae here are much finer. The inner margin of hairs across the roof and lateral wall correspond to the cephalic margin of the alar cartilage. The vestibule is demarcated from the rest of the nasal cavity by a ridge across its roof - the limen nasi (limen vestibuli) - which is formed by the caudal margin of the upper lateral cartilage. The narrowed airway at this point is often referred to as the inner nasal valve and corresponds to the margin of transition from the skin of the vestibule to the mucous membrane of the remainder of the cavity. On the medial wall of the vestibule, the thicker skin changes more abruptly to mucous membrane at the level of the valve, and can be easily identified. Anterior to this line, the skin is tightly bound by connective tissue to the underlying cartilage, which makes surgical elevation more difficult. Incisions are best made at the mucocutaneous junction, as behind this line the mucous membrane is delicate and more easily torn.

Behind the posterior aspect of the limen nasi, the lateral wall of the nasal cavity forms a shallow depression corresponding to the atrium. This space is limited posteriorly by the anterior edge of the middle turbinate and superiorly by a ridge - the agger nasi - which runs from the upper end of the middle turbinate, above the atrium and then downwards towards the vestibule. The agger nasi is most marked in the newborn and represents the nasoturbinate bone which is found in many mammals. The groove above the agger nasi, leading up to the olfactory region, is called the olfactory sulcus.

The olfactory region corresponds to the upper third of the nasal cavity and is bounded by the superior turbinate, the upper part of the septum and the cribriform plate. The remaining portion of the nasal cavity forms the respiratory region.

The mucous membrane of the nasal cavity is tightly applied to the periosteum and perichondrium of its walls. Moreover, the mucosa is continuous through the sinus ostia and
also lines the paranasal sinuses. It is thick and vascular and contains numerous goblet cells. Over the turbinates, the septum and the floor, the mucous membrane is especially vascular and thickened, but in the paranasal sinuses it is relatively thin. This respiratory mucosa (Schneiderian membrane) is covered by pseudostratified, columnar, ciliated epithelium, but its structure does vary in different parts of the nasal cavity. In the newborn, the epithelium is almost all of the columnar ciliated type. However, as a response to the drying effect of inspiration, the anterior third of the nasal cavity, to a point about 1 cm behind the anterior end of the inferior turbinate, gradually loses its cilia. The squamous epithelium of the vestibule progresses through transitional epithelium (stratified epithelium with cuboidal surface cells covered by microvilli) in the atrium area, through pseudostratified columnar epithelium (few ciliated cells), to the typical ciliated columnar type of epithelium (Mygind, 1978). This metaplastic change in the epithelium may be partially reversed when the nasal airway is obstructed.

Numerous goblet cells are present in the epithelium, beneath which is an almost continuous layer of mucous and serous glands. In addition, there are aggregations of lymphoid tissue, particularly prominent at the posterior edge of the nasal septum.

Over the medial surfaces of the inferior and middle turbinates, the lamina propria is very vascular and its deeper layer contains a rich plexus of large veins or cavernous sinusoids. This vascular network, similar to erectile tissue, is of great functional importance in controlling the patency of the nasal airways.

The olfactory region is covered by specialized olfactory epithelium, and has a yellowish appearance in man. It is covered by non-ciliated epithelium containing bipolar olfactory nerve cells and supporting cells with oval nuclei. Beneath the olfactory epithelium is a layer of serous, tubular, branched nasal glands. The mucous membrane lining the paranasal sinuses is thin, relatively avascular, and loosely applied to the underlying bone. It is covered with typical columnar ciliated respiratory epithelium.

Near the floor of the nose, on the lower part of the septum, a small depression or pit, which marks the site of the vomeronasal organ, may be found. An extensive study by Johnson, Josephson and Hawke (1985) has shown that in 39% of subjects, at least one vomeronasal pit was identified, and in 9% this was present bilaterally. The mean distance from the anterior naris to the pit was found to be 22 mm. Sectioning of the adult septum shows a much higher prevalence of a vomeronasal structure (70%), compared with clinical examination. The pit is lined with thin mucoperichondrium and extends posterosuperiorly for a variable distance to end as a blind diverticulum. The thin strip of vomeronasal cartilage is closely related to the organ at the lower border of the cartilaginous septum. Although the vomeronasal organ has a well-recognized chemoreceptor function as an accessory olfactory organ in many species, its function among primates is probably limited to the New World monkeys. Olfactory epithelium in this organ has not been identified in humans.

Mucus secreted by the glands in the respiratory mucosa is cleared efficiently from the sinuses and nasal cavity by ciliary activity. In the sinuses this is directed towards the ostia, and in the nasal cavity the direction of ciliary beat is backwards and downwards, carrying the mucus towards the nasopharynx. Ciliary activity may be greatly reduced by changes in temperature and by various chemicals.
Blood vessels

The nasal cavity derives its blood supply from both the internal and external carotid arteries, through various branches. The anterior and superior quadrants of the lateral wall and septum receive branches of the anterior and posterior ethmoidal arteries from the ophthalmic artery, which comes from the internal carotid. The vestibular area is supplied laterally by twigs from the facial artery and medially by the septal branch of the superior labial artery. The posterior and inferior quadrants are supplied on the lateral wall by branches of the sphenopalatine artery, through its large lateral nasal branches which run along the middle and inferior turbinates. A septal branch of the sphenopalatine artery passes across the anterior aspect of the sphenoid bone to descend diagonally down the septum towards Little's area (Kiesselbach's plexus), where it anastomoses with branches of the superior labial, greater palatine and anterior ethmoidal arteries. The sphenopalatine artery is given off the maxillary artery in the pterygopalatine fossa. Another branch is the greater palatine artery, which descends through the greater palatine canal to emerge on the oral surface of the palate through the greater palatine foramen. It runs forwards in a groove on the palatal surface of the maxilla to the incisive canal, and branches pass through this canal to anastomose over Little's area. In the greater palatine canal, a number of branches penetrate the perpendicular plate of the palatine bone, and anastomose on the lateral wall with the lateral nasal branches of the sphenopalatine artery.

The arrangement of blood vessels in the mucous membrane consists of a superficial venous plexus and a deeper arteriolar system, arranged parallel to the long axis of the nose (Swindle, 1935; 1937). The arterioles do not contain an internal elastic membrane, so that their endothelial basement membrane is continuous with that of the smooth muscle cells. Also, the increased porosity of the nasal blood vessels means that the subendothelial musculature of these vessels is influenced by agents, such as histamine, in the blood more readily than elsewhere (Mygind, 1978). The cavernous sinusoids are usually found in the contracted state, but can rapidly dilate. Other arteriovenous anastomoses are also found in the nasal mucosa so that blood can bypass the capillary bed.

Venous drainage is to the neighbouring sphenopalatine vein, the anterior facial vein, the anterior and posterior ethmoidal veins and to the cerebral veins through the cribriform plate. A communicating vein may pass through the foramen caecum, which lies between the crista galli and the frontal crest, and when this foramen is patent, the vein opens into the superior sagittal sinus.

Nerve supply

The olfactory mucous membrane contains the cells of origin of the olfactory nerve fibres and is lined with neuroepithelium. The basal parts of the cells are thin and pass upwards to form a dense plexus of non-myelinated nerve fibres, from which about 20 olfactory nerves are formed. These nerves pierce the cribriform plate and pass to the olfactory bulb on each side of the crista galli. The number of fibres in the olfactory nerve begins to decrease shortly after birth at a rate of about 1% a year (Smith, 1941; 1942). Smith found that over 60% of the fibres had been lost in 55% of adults, and no olfactory fibres could be identified in 13%. He concluded that the fibres had been lost partly in consequence of
degenerative changes with age and partly in consequence of pathological changes in the mucosa.

General sensory fibres to the respiratory mucous membrane are derived from the ophthalmic and maxillary divisions of the trigeminal nerve. The anterior ethmoidal branch of the nasociliary nerve (ophthalmic division) supplies the anterosuperior lining of the nasal cavity on the lateral wall and septum. Branches of the infraorbital nerve innervate the lateral wall of the vestibule. The anterior superior alveolar branch, the nerve of the pterygoid canal, the long sphenopalatine (nasopalatine) nerve, the greater palatine nerve and nasal branches of the sphenopalatine ganglion complete the maxillary nerve innervation of the nasal cavity.

In addition to tactile and sensory fibres, these nerves also carry secretomotor fibres to the mucous and serous glands of the palate, nose and paranasal sinuses. The chief autonomic nerve supply of the nasal cavity is through the pterygopalatine (sphenopalatine) ganglion, which is a relay station between the superior salivatory nucleus in the pons and the nasal cavity mucous membrane. The autonomic root is through the nerve of the pterygoid canal (Vidian nerve) which is formed by the union between the greater superficial petrosal nerve, containing parasympathetic secretomotor fibres, and the deep petrosal nerve, containing sympathetic vasoconstrictor fibres from the carotid plexus. These two nerves join to form the nerve of the pterygoid canal, which runs forwards to the ganglion to be distributed through its various branches. Only the parasympathetic fibres relay in the ganglion and, therefore, each branch to the nasal cavity contains sensory, postganglionic, parasympathetic, secretomotor fibres and sympathetic fibres.

The paranasal sinuses

The paranasal sinuses are a group of air-containing spaces that surround the nasal cavity, extending superiorly to the skull base and laterally to encompass the medial wall and floor of the orbit. At birth, they are mostly rudimentary and their development continues during childhood into early adult life. Because of their origin and growth as pneumatic diverticula from the primitive nasal cavity, their mucous membrane lining is continuous with and similar in structure to that of the nose. The pseudostratified, ciliated, columnar epithelium, however, is thinner, less vascular and contains fewer mucous glands than that of the nasal mucosa. The cilia direct the mucous blanket in a spiral fashion towards the ostium and, although gravity does not play a role in drainage of the normal sinus, negative air pressure during inspiration does assist ciliary clearance in the maxillary sinus.

The arterial blood supply of the paranasal sinuses comes from branches of the internal and external carotid arteries which supply the adjacent midfacial structures. The veins and the lymphatics, however, pass through the sinus ostia to drain into the venous and lymphatic plexuses in the nasal cavity. This may be of great significance in inflammatory and allergic conditions of the nasal cavity, where venous and lymphatic congestion may lead to congestion of the sinus openings, with secondary sinus pathology as well as impaired mucus drainage.

The function of the paranasal sinuses is not clear, and most suggestions are speculative rather than factual. They do improve resonance of the voice, but they are also well developed in many silent animals. One of the their functions may be to allow warming of the inspired
air in the nasal cavity, while they act as insulators to prevent cooling of the surrounding structures.

Maxillary sinus (antrum of Highmore)

The maxillary sinus is the largest of the paranasal sinuses and is contained within the body of each maxilla on either side of the nasal cavity. It is pyramidal in shape with its apex directed laterally, extending into the zygomatic process of the maxilla or into the zygomatic bone itself. Its base lies medially and forms the lateral wall of the nasal cavity. The bone of the medial wall is thin and is composed of the medial wall of the maxilla, the maxillary process of the inferior concha, the perpendicular plate of the palatine bone, the uncinate process of the ethmoid bone and the descending portion of the lacrimal bone. The roof slopes downwards from medial to lateral and is formed by the orbital surface of the maxilla. It is ridged in the sagittal plane by the canal of the infraorbital nerve. The anterior and posterior walls of the sinus are the corresponding surfaces of the maxilla, and are directly related to the facial surface of the cheek and the infratemporal fossa respectively.

The floor of the sinus consists of the alveolar and palatine processes of the maxilla. In the adult, it lies at a level 1.0-1.2 cm below that of the floor of the nasal cavity, but in the child and also in the edentulous skull, the level corresponds more with the floor of the nasal cavity. The size of the maxillary sinus varies considerably, but average dimensions in the adult skull are 33 mm in height, 23 mm in width and 34 mm in anteroposterior depth. The approximate volume is 14.75 mL but a large antrum may hold 30 mL. The sinuses are usually equal in size; on rare occasions, they may be virtually absent.

The relation of the maxillary sinus to the teeth depends not only on age and the state of dentition, but also on the degree of development of the sinus into the alveolar process. The canine tooth raises a ridge on the anterior surface of the maxilla but does not indent the sinus which lies behind it. The three molar teeth are most constantly directly related to the floor of the sinus and the premolars less frequently (Schaeffer, 1910). The floor of the sinus in relation to these teeth may be ridged or smooth, depending on the projection of the root. Normally the roots are covered with a layer of compact bone, but when this is absent the root lies in direct contact with the mucous membrane. Extraction of these teeth might easily result in oroantral fistulae, the majority of which close spontaneously.

The ostium of the maxillary sinus is situated high up on its posteromedial wall and opens indirectly into the middle meatus of the nasal cavity through the narrow ethmoidal infundibulum. It is 3-4 mm in diameter, but in the prepared skull, the bony ostium is larger because the opening is normally partially covered by membrane. Van Aylea (1936) found that in the 163 specimens he examined, 83.4% of ostia were situated in the posterior third of the infundibulum or at the adjacent tip of the uncinate groove; only a small portion were found
in the anterior or middle third of the infundibulum. Accessory ostia are present in about 30% of specimens in the adjacent, thin nasal wall (Schaeffer, 1920a; Myerson, 1932; Van Aylea, 1936).

The blood supply to the maxillary sinus is through small arteries that pierce its bony walls, mostly originating from the maxillary, facial, infraorbital and greater palatine arteries. Its largest artery is a branch of the superior artery on the inferior concha which enters the ostium of the sinus (Hollinshead, 1982). Veins accompany these vessels and drain mainly to the anterior facial vein and the pterygoid plexus. The lymphatic drainage of the sinus is mainly through the ostium into the nasal cavity or through the infraorbital foramen, but all lymphatics drain to the submandibular lymph nodes.

The mucous membrane of the sinus is innervated by the superior alveolar nerves (anterior, middle and posterior), the anterior palatine nerve and the infraorbital nerve. All are branches of the second (maxillary) division of the trigeminal nerve and they supply sensation to the upper teeth and sinus, as well as secretomotor fibres to the mucous membrane through branches from the pterygopalatine ganglion.

**Frontal sinus**

The frontal sinus is the last of the paranasal sinuses to develop. There is dispute as to whether it is a separate sinus or merely one of the more extensive anterior ethmoidal outgrowths from the frontal recess, growing into the frontal bone. Normally there are two frontal sinuses which lie deep to the supraciliary ridges. They are of unequal size and are divided by a thin, intersinus bony septum which is seldom in the midline and may occasionally be deficient. Two or more frontal sinuses may be present on each side, but a more common finding is the presence of partial or incomplete septa which give the roof of the sinus a scalloped radiological appearance on the occipitofrontal projection. In the sagittal plane, the sinus has a pyramidal shape, based inferiorly, where there is usually prolongation of the sinus posteriorly over the orbital roof or even a separate accessory frontal (or anterior ethmoidal) sinus. Superiorly, the sinus extends to a variable degree between the inner and outer table of the frontal bone; it is usually larger in men than in women, but there is great individual variation. Occasionally, the sinuses may be absent.

The anterior wall of the sinus is composed of diploic bone and is fairly thick (1-5 mm), but the posterior wall which separates the sinus from the anterior cranial cavity is thinner and formed of compact bone. This thin bone may easily be eroded by mucocoele compression, infection or careless operative technique. The floor separates the sinus from the orbital cavity and slopes downwards and medially towards the opening of the frontonasal duct. The bone here is also thin and is the most frequent site of erosion secondary to mucocoele formation.

The frontonasal duct runs downwards through the front of the ethmoidal labyrinth to open into the middle meatus. In 100 dissections, Kaspar (1936) found that in 62% the duct opened into the frontal recess, and in the remaining 38% it drained directly, or indirectly by way of an anterior ethmoidal cell, into the ethmoidal infundibulum. The duct may, therefore, vary in length and diameter, depending on the distribution of the anterior ethmoidal cells which sometimes bulge into the floor of the frontal sinus. Van Aylea (1946) suggested that
the presence of these cells adjacent to the ostium may compromise drainage of the frontal sinus.

The innervation of the frontal sinus is from branches of the supraorbital nerve which pierce the roof of the supraorbital foramen, and there are also branches direct from the nasociliary nerve. The main blood supply is from the supraorbital artery, by way of its diploic branch, and the anterior ethmoidal artery. The venous drainage follows the arterial pattern to the supraorbital veins of the nose. In addition, there are connections with the superior ophthalmic vein, and through the diploic veins to the veins of the scalp and dura. These connections probably account for the spread of osteomyelitis of the frontal bone from frontal sinus infection, and the occurrence of Pott's puffy tumour. Lymphatic drainage is to the submandibular lymph nodes.

**Ethmoidal sinus**

The ethmoidal sinuses lie within each lateral mass of the ethmoid bone, situated between the nasal cavity and the orbit. Each sinus consists of a variable number (3-18) of air-containing cavities - the ethmoid air cells - which together form a honeycomb network called the ethmoidal labyrinth. In the midline between the two labyrinths is the vertical portion of the ethmoid bone, consisting of the crista galli and the vertical plate of the bony septum which project above and below the cribriform plate respectively. A small part of the roof of each ethmoidal labyrinth is formed medially by lateral bony projections of the cribiform plate (fovea ethmoidalis), but the main part is formed by the frontal bone with which it articulates. The roof has an undulating contour, as a result of the bulging of the domes of the ethmoid air cells, and it slopes gradually downwards at an angle of 15° in an anteroposterior direction. Each ethmoidal sinus has a pyramidal shape based posteriorly, and is 4-5 cm in length. Its height is 2.5-3 cm and its width is 1.5 cm posteriorly, narrowing to 0.5 cm anteriorly (Mosher, 1929; Van Aylea, 1942, 1951).

The bony labyrinth is contained within a delicate but rigid framework. On its lateral aspect is the lamina papyracea which separates it from the orbit. This part of the ethmoid bone is deficient anteriorly where the ethmoid cells are bounded laterally by the lacrimal bone. The lamina papyracea articulates inferiorly with the maxilla, posteriorly with the lesser wing of the sphenoid and superiorly with the frontal bone. This latter suture line is an important landmark in external ethmoid surgery as it indicates the plane of the roof of the ethmoid air cells. Medially, the sinus is bounded by the middle and superior turbinate bones, and posteriorly it is separated from the sphenoid sinus by a thin, bony septum. The middle turbinate bone is continuous superiorly with the fovea ethmoidalis at the lateral aspect of the cribiform plate.

The internal framework of the ethmoid sinus is composed of incomplete, irregular portions of thin bone - the basal lamellae - which traverse the sinus from the medial aspect of the lamina papyracea to the middle and superior turbinates. They divide the ethmoid cells into anterior and posterior air cells whose ostia drain into the middle and superior meatus respectively. Some of the anterior cells behind the hiatus semilunaris form a convex bulge on the lateral wall of the middle meatus, the bulla ethmoidalis. These bullar cells, which vary in number from one to four, are often referred to as the middle ethmoid cells (Van Aylea, 1939).
The anterior ethmoid cells may otherwise be categorized according to their position and the site of their drainage into the middle meatus. The most anterior of the infundibular cells are the agger cells (one to four in number), which lie laterally to the agger nasi ridge and may invade the lacrimal bone and ascending ramus of the maxilla. Above these, the three to four frontal recess cells invade superiorly into the frontal bone, encroaching on the frontal sinus. As their name implies, they open into the frontal recess. The bullar cells are the most constant of the ethmoid cells and usually open from the medial or anterior surface of the bulla directly into the meatus. The posterior ethmoid cells vary in number from two to six and tend to be larger than the anterior cells. Posteriorly, they may grow into the sphenoid bone and may even largely displace the sphenoid sinus. The close proximity of the optic nerve to the posterior ethmoid cells is a very important surgical relation in ethmoidectomy and also may account for possible retrobulbar neuritis in ethmoid infections. The ostia of the posterior cells are usually found in the upper anterior recess of the superior meatus; they vary in diameter from 1 to 2 mm, although they are usually larger than the anterior ethmoid cell openings.

The main arterial supply to the ethmoid sinus is from the anterior and posterior ethmoidal branches of the ophthalmic artery and from the sphenopalatine artery. The ethmoidal arteries pass medially across the roof of the ethmoidal cells, often forming a ridge, but sometimes they lie in a bony canal suspended by a thin bony mesentery from the roof. As such, they should be distinguished from an incomplete bony septum at ethmoidectomy, as they may otherwise be accidentally divided.

The nerve supply is from the maxillary branch of the trigeminal nerve and nasociliary branches of the ophthalmic nerve which form the anterior and posterior ethmoidal nerves. Lymphatic drainage of the anterior and middle cells is to the submandibular lymph nodes, and from the posterior cells to the retropharyngeal node.

*The sphenoid sinus*

The sphenoid sinus is rudimentary at birth but begins to grow after the third year, expanding within the body of the sphenoid bone. Occasionally it invades laterally in the greater and lesser wings and the medial and lateral pterygoid plates of the sphenoid. Posterior extension may occur into the basilar part of the occipital bone. The two sinuses are separated by a bony septum which is rarely in the midline. Other partitions may be present which partially divide the sinus into several large, intercommunicating cells as well as into lateral recesses. The overall size of the sinus varies enormously and its capacity may range from 0.5 to 30 mL, with an approximate average size of 7.5 mL. Van Aylea (1944) found that in 100 sinuses, the dimensions varied in length from 4 to 44 mm, in height from 5 to 33 mm and in width from 2.5 to 34 mm.

The ostium from each sinus drains into the sphenoethmoidal recess above the superior turbinate. The openings lie in the centre of the sphenoideal turbinates (bones of Bertin) which were originally associated with the primitive nasal capsule. These bones cover the anterior walls of the sinus and, although they are separate bones initially, they fuse with the rest of the body of the sphenoid after the tenth year.

The anatomical relations of the sphenoid sinus are of great surgical importance, especially as the sinus forms the most accessible approach to the pituitary gland. The gland
lies in the sella turcica in the roof of the sinus posteriorly, and on either side of this the optic nerves are closely related and sometimes indent the roof more anteriorly. Laterally, the sinus is directly related to the cavernous sinus, the internal carotid artery and divisions of the trigeminal nerve. The posterior wall is usually thick, and separates the sinus from the pons and basilar artery. Inferiorly, the floor of the sinus is related to the roof of the nasopharynx. The close lateral relation of the sinus may become more evident in well pneumatized bones where they form ridges on the lateral wall. Van Aylea found that 65% of the sinuses he examined had a prominent ridge on the posterolateral wall caused by the internal carotid artery. In some cases, the bony wall may be absent at this site (Dixon, 1937). The optic canal may indent the sinus in up to 40% of cases (Van Aylea, 1941), sometimes presenting dehiscences. The maxillary nerve may ridge the sinus in most cases and, more inferiorly, the nerve of the pterygoid canal may also cause an indentation in 48% of cases (Van Aylea, 1941).

The blood supply to the sphenoid sinus is from the posterior ethmoid and the sphenopalatine artery, and its innervation is from branches of the pterygopalatine ganglion. Veins drain into the nasal cavity and accompany lymphatics through the ostium, the latter draining to the retropharyngeal lymph node.