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2 Applied Anatomy of the Nose and Sinuses

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The Nose

Introduction

The nose is a complex anatomical structure, externally, a strong aesthetic component of the face and internally is responsible for humidifying, warming and cleansing inspired air before it reaches the lower airways, and as a gateway to the base of skull. The olfactory areas are also located in the roof of the nose bilaterally and are responsible for our sense of smell. Anatomy of the nose is considered cephalic, caudal, lateral or medial (Fig. 2.1).

External Structure

The external structure of the nose is best thought of in thirds in the horizontal plane (Fig. 2.2). The upper third consists of bones, the middle and lower thirds of cartilage. All of these structures are draped with skin and its underlying soft tissues of fat, muscles and fascia.

Bones of upper third of nose:
Two paired nasal bones
Paired frontal processes of maxilla
Paired nasal processes of frontal bone

Sutures of upper third of nose (Fig. 2.3):
Fronto-nasal
Inter-nasal
Naso-maxillary
Fronto-maxillary

The middle third of the nose consists of the paired upper lateral cartilages, attached to the quadrangular cartilage of the nasal septum in the midline (Fig. 2.4). The cephalic borders of the upper lateral cartilages (ULCs) sit underneath the nasal bones (Fig. 2.5). The caudal edge of the ULCs curls back on themselves as a scroll.

The lower or tip third of the nose is comprised of the lower lateral cartilages (LLCs) and their association with the caudal end of the quadrangular septal cartilage (Fig. 2.6). The cephalic borders of the lateral crura of the lower lateral cartilages are in a scroll configuration with the caudal border of the upper lateral cartilages (Fig. 2.7).

Major tip support structures:
(1) The intrinsic integrity of the alar cartilages
(2) The medial crural footplates to the caudal septum
(3) The scroll junction between the upper lateral and lower lateral alar cartilages

Minor tip support structures:
Ligaments (interdomal, intercrural, Pitanguy's midline, pyriform, and a scroll ligament complex consisting of the longitudinal and vertical scroll ligaments)
Membranous septum
Anterior nasal spine
Attachment of alar cartilages to the overlying skin and musculature

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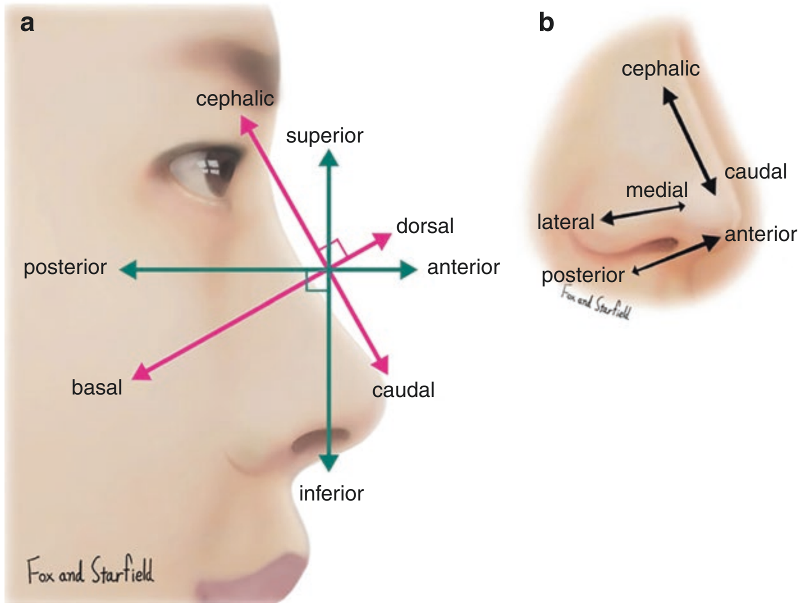

Fig. 2.1 Anatomical orientation when discussing the nose

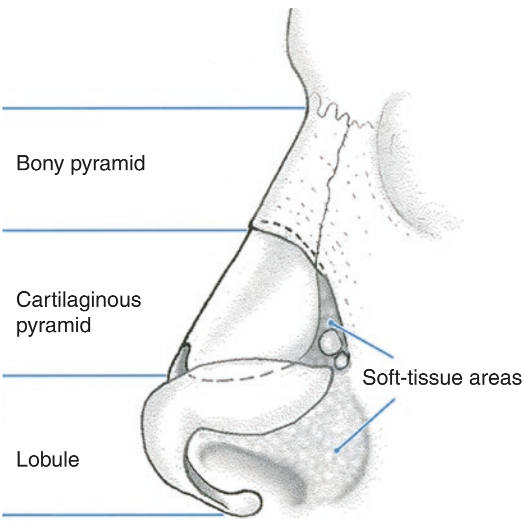

Fig. 2.2 The external structure of the nose in thirds

The Nasal Septum

The nasal septum separates the right nasal passage from the left and is cartilaginous anteriorly and bony posteriorly (Fig. 2.8). The bony septum is formed by the perpendicular plate of ethmoid above and vomer below. The septum sits in the crest of the maxilla in the midline and articulates with the rostrum of the sphenoid posteriorly. Superiorly, the cartilaginous septum forms the mid-third of the dorsum of the nose, and the perpendicular plate of the ethmoid attaches to the thin cribriform plate.

Key areas of the nasal septum (Fig. 2.9)**:**
Anterior septal angle
Posterior septal angle (attachment to anterior nasal spine)
K (keystone) area

The actual relationship between the cartilaginous septum, the bony perpendicular plate of the ethmoid (PPE), and the bony vomer, together with anatomical variants, is depicted in Fig. 2.10(10.1–10.3).

The Inferior Turbinate

The bone of the inferior turbinate is the inferior concha, articulating with the medial aspect of the maxilla and extending over the inferior maxillary hiatus like a bridge. Posteriorly, it articulates with the palatine bone and superiorly the uncinate process.

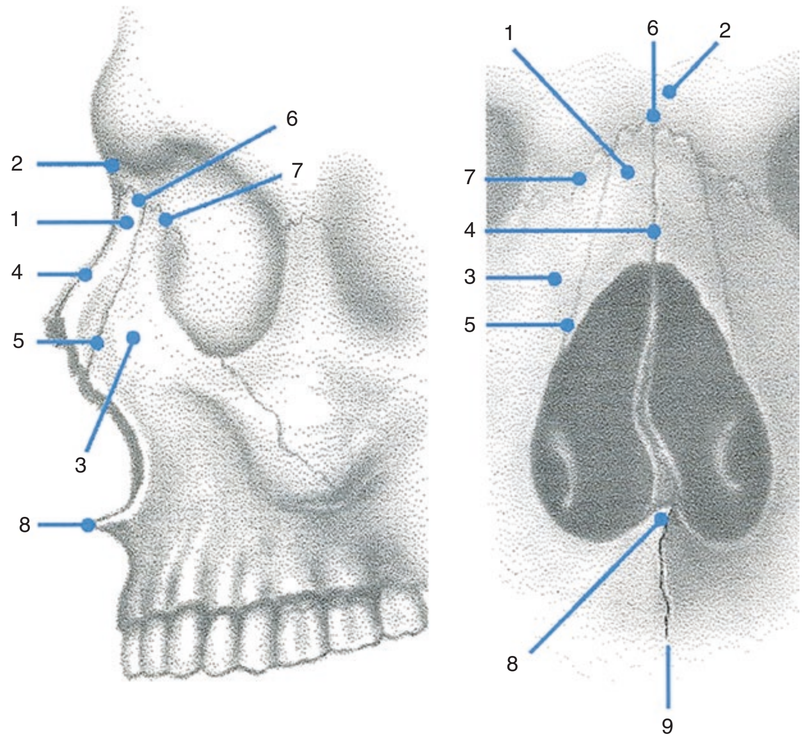

Fig. 2.3 Sutures of the nasal bones/upper third of nose:
Fronto-nasal suture 6
Inter-nasal suture 4
Naso-maxillary suture 5
Fronto-maxillary suture 7
Additional key numbers:
Nasal bone 1
Nasion 2
Frontal process of maxilla 3
Anterior nasal spine 8
Intermaxillary / median suture 9

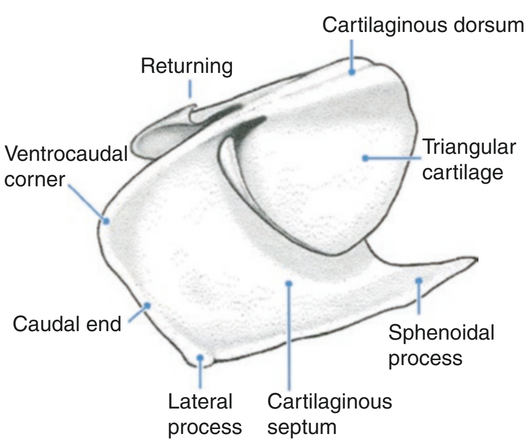

Fig. 2.4 The relationship of the upper lateral cartilages to the septal quadrangular cartilage

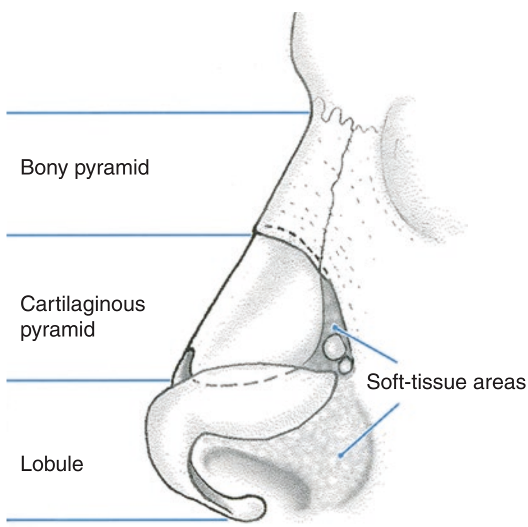

Fig. 2.5 The relationship of the upper lateral cartilages to the nasal bones

The scrolled bone of the inferior concha is covered by specialised erectile tissue and ciliated nasal mucosa. The erectile tissue contains vascular lakes that dilate (causing congestion) and constrict (causing decongestion) in response to the physiological nasal cycle.

The inferior turbinate is an extremely important structure and furnishes a sense of nasal health and well-being—it should be treated gently, with care, and mucosa should be preserved where possible. At its head it contributes to the internal nasal valve and awareness of nasal airflow. It should not be reduced excessively or aggressively as this may lead to the much feared 'empty nose syndrome'.

Allergens and irritants cause changes to both the mucosa of the inferior turbinate and to the functionality of the submucosal vascular lakes.

Inferolateral to the inferior concha is the inferior meatus.

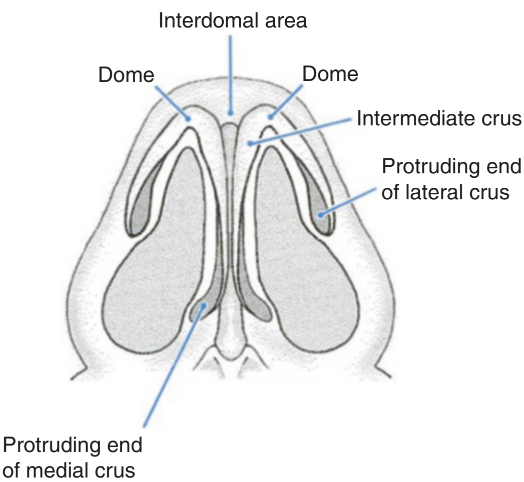

Fig. 2.6 The nasal tip cartilages and their association with the caudal end of the septal quadrangular cartilage

The nasolacrimal duct opens into the inferior meatus at the valve of Hasner, approximately 1 cm posterior to the head of the inferior turbinate (see below).

Sinonasal Mucosa

The mucosa of the nose and sinuses is of two types: largely a pseudostratified columnar ciliated respiratory variety, but with small areas of olfactory epithelium in the roof of the nose and adjacent nasal septum, middle and superior turbinates bilaterally.

Respiratory epithelium of the nose:
- Contains goblet cells that produce mucus
- Contains subepithelial vascular lakes that congest/decongest, warm and humidify inspired air
- Produces IgA that prevents microbes from attaching to and invading the mucosa
- Produces lysozyme which degrades pathogenic microbes

Olfaction

Olfactory neuroepithelium is located on the nasal surface of the cribriform plate and extends to the parts of the superior and middle turbinates and the superior nasal septum adjacent to the middle

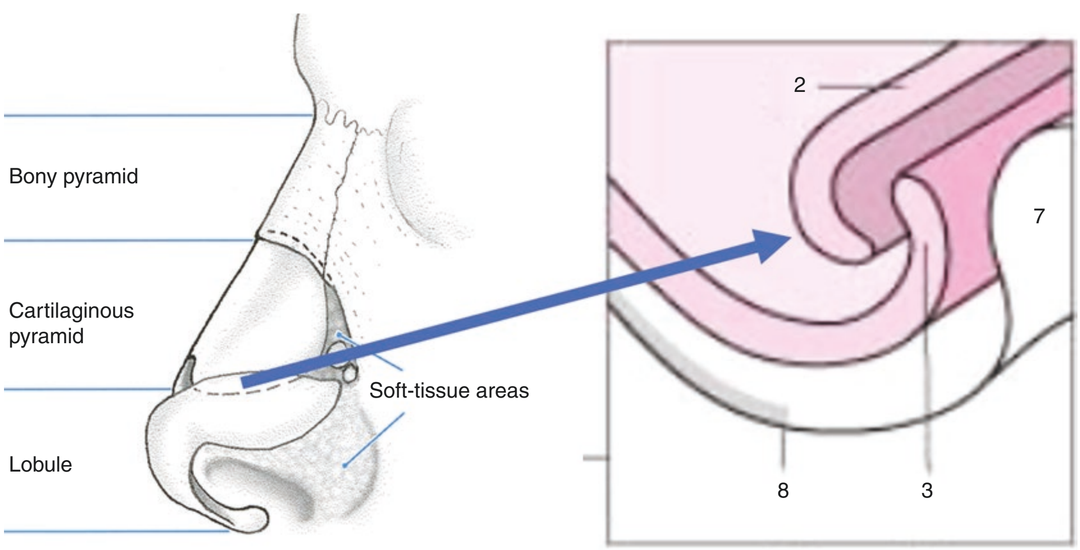

Fig. 2.7 The scroll configuration of the upper and lower lateral cartilages

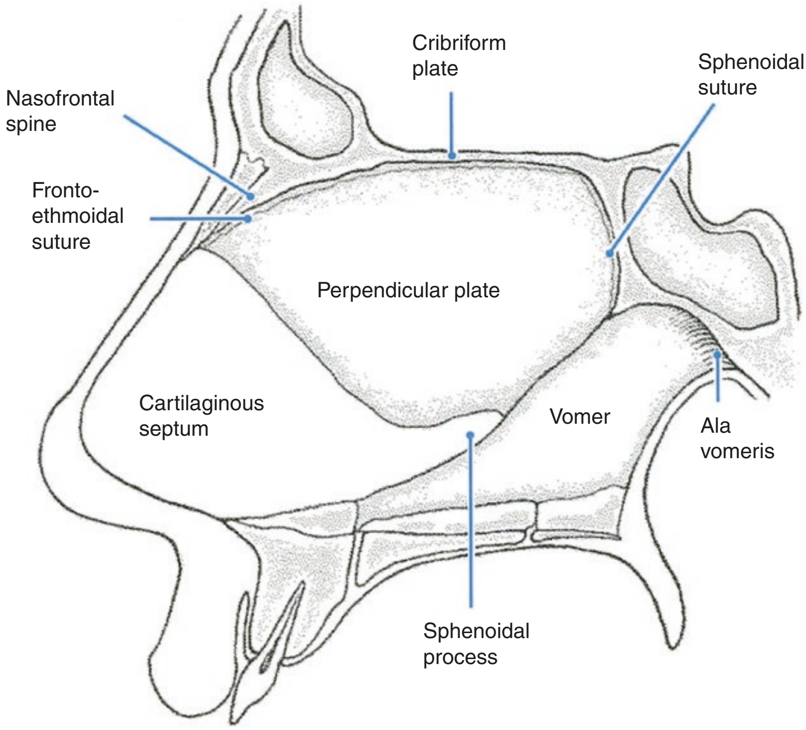

Fig. 2.8 The nasal septum

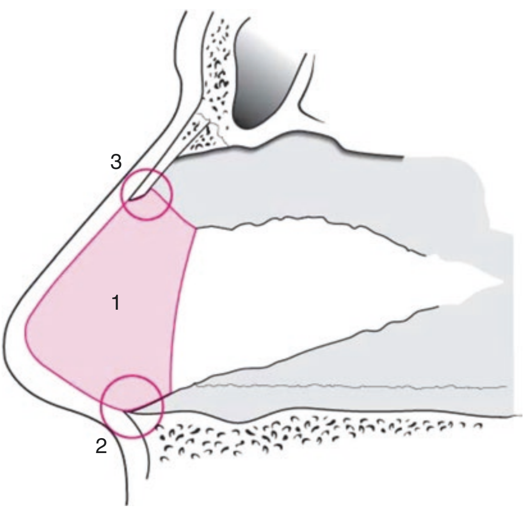

Fig. 2.9 Key areas of the nasal septum. 1 Septal quadrangular cartilage; 2 posterior septal angle; 3 K area

turbinate. Hence, turbinates should be preserved as far as possible.

Each olfactory cleft is 1–2 mm wide with 200–400 mm^2 of olfactory epithelium. The epithelium includes olfactory sensory neurones and supporting cells that include sustentacular, microvillar, globose basal, horizontal basal and duct cells, and Bowman's glands.

The olfactory sensory neurones give rise to fila that connect to the olfactory bulbs above the skull base. Within the olfactory bulbs, olfactory sensory neurones synapse with second order neurones (mitral and tufted cells). These project posteriorly as the olfactory tracts to various areas including the thalamus, the limbic system and the orbitofrontal neocortex (secondary olfactory cortex) (please refer to Chap. 41).

The primary olfactory cortex includes areas such as the anterior olfactory nucleus, the olfactory tubercle and the piriform cortex.

Projections of second-order neurones to the primary olfactory cortex are direct connections, with some neurones connecting in turn directly to the secondary olfactory cortex and some relaying via the thalamus between these two cortical areas.

Odour discrimination takes place in the secondary olfactory cortex, and affective responses are controlled by the limbic system.

After an odour passes into the nose, olfactory transduction relies on interaction between odour

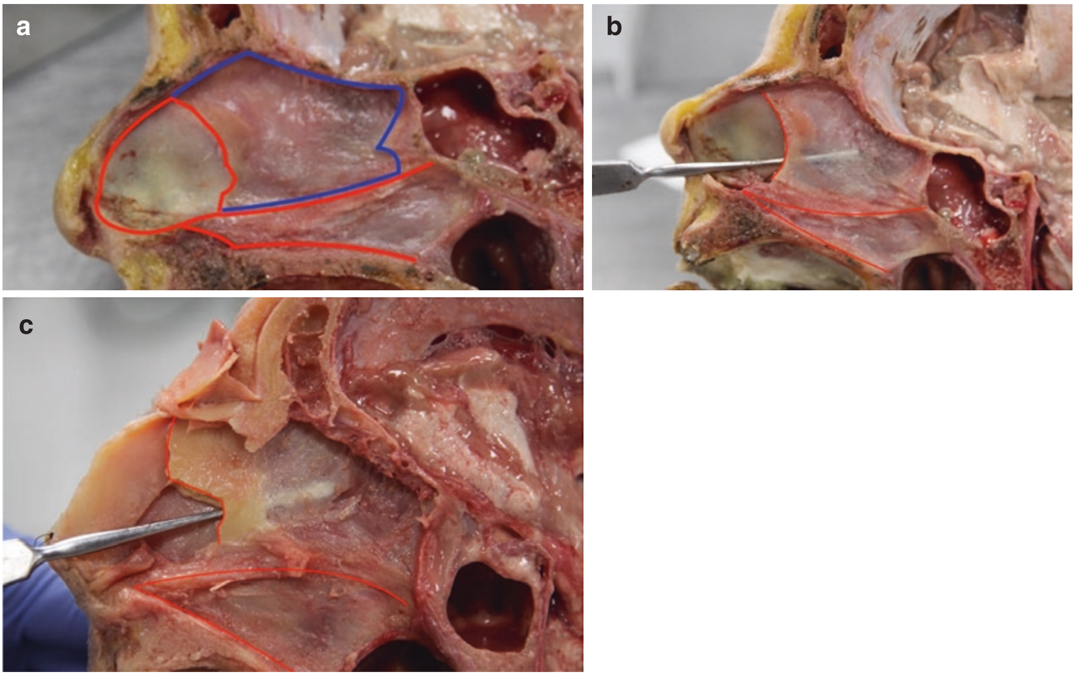

Fig. 2.10 Anatomy of the nasal septum. (Images of anatomical dissections prepared by Andrew C. Swift). (**a**) Sagittal cadaveric dissection of the nasal septum. The perpendicular plate of the ethmoid (PPE) is shown within the blue line. The quadrangular/quadrilateral cartilaginous septum is shown anterior to the PPE. The vomer is sited inferior to the PPE, outlined in red. (**b**) Cartilaginous septum separated from the PPE, demonstrating the junction between bone and cartilage and the thin, transparent area of the PPE. (**c**) Cartilaginous septum separated from the PPE, demonstrating the anatomical variant at the cartilaginous-osseous junction and the thick anterior bar of the PPE anterior to the paper-thin area of the PPE

molecules dissolved in the mucus layer and the transmembrane receptors of the cilia.

During *orthonasal* olfaction, up to 15% of an incoming air stream is directed towards the olfactory cleft during inhalation, facilitated by turbulence provided by the turbinates

Retronasal olfaction is the passage of food odours from the oral cavity whilst eating and accounts for approximately 80% of flavour perception

The Paranasal Sinuses

Introduction

There are four paired sinuses of unequal size: maxillary, ethmoid, sphenoid, and frontal. At birth, only the maxillary sinus and the ethmoid sinus are developed but not yet pneumatised. They are fully aerated by the age of 7. The sphenoid sinus appears at the age of 3. The frontal sinuses are the last to develop and may not be of significant size until adolescence.

The frontal sinuses may underdevelop or not develop at all. This should be noted during a preoperative appraisal of radiology.

The paranasal sinuses are thought to lighten the weight of the heavy skull and its contents, to provide resonance for voice, and to produce mucus. Mucus lubricates and protects the nose from pollutants, microorganisms, dust, and allergens.

Osteology

The nasal cavities are formed by the paired maxillary bones laterally and inferiorly and anteriorly with the paired nasal bones and the nasal process of the frontal bone.

The frontal bone is made up of two parts: the robust vertically oriented squamous part that forms the forehead and the thinner horizontally oriented orbital part that forms the roof of the orbit.

The pyriform aperture is the triangular-shaped opening into the anterior aspect of the nasal cavity, with the floor of the aperture formed by the anterior nasal spine and pre-maxilla and the sides formed by the ascending processes of the maxillae.

The maxilla bone is a major bone of the midface making up the upper jaw, the floor of the orbit and along with its opposite number, the bony hard palate. It contains the upper alveolus with their dental roots, common sources of infection and inflammation of the maxillary sinus.

The roof of the nasal cavity from medial to lateral is formed by the cribriform plate, the lateral lamella of the cribriform plate and the fovea ethmoidalis of the frontal bone.

The cribriform plate, the honeycombed ethmoid air cells, the middle conchae, the roof of the ethmoid, perpendicular plate and the lamina papyracea are extremely important anatomical structures that make up the ethmoid bone.

The lamina papyracea makes up the majority of the medial wall of the orbit, with the lacrimal bone anteriorly, the optic canal in the lesser wing of the sphenoid bone posteriorly and the frontal bone superiorly.

The nasal cavities are divided into left and right by the bony nasal septum (see above).

The lateral wall of the nose, from front to back, is formed by the ascending process of the maxilla, the lacrimal bone, the lamina papyracea of the ethmoid bone, the palatine bone, and the medial pterygoid.

The sphenoid bone bounds the nasal cavity posteriorly along with the ala of the vomer posteromedially.

The sphenoid bone is perhaps the most complex bone of the sinonasal cavity. Made up of greater and lesser wings, it connects the sinonasal cavity to the anterior, middle and posterior cranial fossae. A thorough understanding of the sphenoid bone is essential for extended sinus and endoscopic skull base surgery.

There are various canals, ducts, foramina and notches that permit the passage of major structures into the sinonasal cavity (see below). Critical neurovascular structures pass into and through the sphenoid bone.

The Maxillary Sinus

This is the largest of the four sinuses, shaped like a pyramid with its base forming a large part of the lateral wall of the nose.

It is pneumatised at birth but through childhood largely contains unerupted teeth.

Anterosuperiorly on its medial wall is the infundibulum of the maxillary sinus, the conical-shaped communication with the nasal cavity.

When entering the maxillary sinus, it is important to angle instruments downwards and laterally to avoid inadvertent penetration of the orbit. This complication may cause ecchymosis at the medial canthus.

The bone is dehiscent over the medial wall forming the fontanelles that are often covered with mucosa and fibrous tissue. They are generally divided into anterior and posterior by the shape of the uncinate process. Dehiscences are seen as accessory ostia and must not be confused with the natural ostium.

The infundibulum and free posterior margin of the uncinate process make up the hiatus semilunaris inferioris, an area richly populated by ciliated pseudostratified columnar respiratory and vitally important for mucociliary clearance. A heavy hand surgically in this area can adversely affect the function of three sinuses: maxillary, frontal and anterior ethmoid.

A careful uncinectomy and gentle anatomical middle meatal antrostomy will successfully treat the majority of sinusitis affecting these three sinuses.

The infundibulum may be further narrowed by an infraorbital air cell (previous terminology: Haller cell). This anatomical variant can be identified on preoperative CT scanning. It is dealt with by carefully marsupialising at the time of the middle meatal antrostomy.

Maxillary atelectasis (silent sinus syndrome) is a particularly treacherous situation where the uncinate process is plastered to the inferomedial orbit. Failing to recognise the orientation of the uncinate process and difficulty of uncinectomy in these cases will invariably result in an orbital injury.

The Ethmoid Sinuses

The complex ethmoid sinus cells sit lateral to the middle turbinate. It is imperative to have a complete understanding of the anatomy of the middle turbinate (see Key concepts below).

Superiorly is the ethmoid roof; laterally the lamina papyracea of the orbit; medially the lateral surface of the middle turbinate; and inferiorly the horizontal attachment of the middle turbinate. It is important to carefully skeletonise these structures during sinus surgery to ensure that a complete ethmoidectomy has been performed. Otherwise, there is a risk of refractory disease and mucocele formation.

They are divided into anterior and posterior by the basal (or third) lamella (see Key concepts below).

The bulla ethmoidalis comprises the anterior ethmoid air cell(s). It may be a simple projection off the lamina orbitalis laterally or a more complex configuration of cells.

Its drainage is into the hiatus semilunaris superioris medially.

Its upper part may extend to the skull base or fall short, forming a suprabullar recess. The attachment of the bulla superiorly, either to the skull base or not, influences the drainage pathway of the frontal sinus.

The anterior ethmoidal artery sits between the second and third surgical lamellae (see Key concepts below).

When performing an anterior ethmoidectomy, instruments must be angled laterally and away from the lateral lamella of the cribriform plate to avoid an iatrogenic CSF leak. Powered instrumentation must also be used with care, particularly in the region of the anterior ethmoidal artery and on the lamina papyracea. If at all possible, the latter should be avoided outside of the most experienced hands.

The posterior ethmoidal air cells often comprise one to four air cells of varying sizes. They drain posteriorly into the superior meatus.

When entering the posterior ethmoid, this should be done low-and-medial on the basal lamella at the point where it turns to become horizontal (Fig. 2.11). High-and-lateral sits the optic canal and its nerve; high-and-medial sits the skull base and lateral lamella of the cribriform plate; and low-and-lateral sits the lamina papyracea of the orbit.

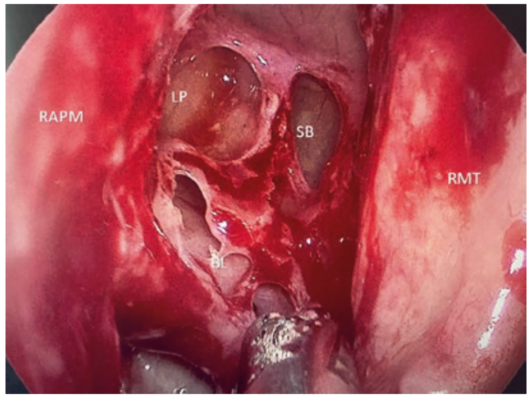

Fig. 2.11 Clinical image illustrating safe entry into the posterior ethmoid through the basal lamella. *RAPM* right ascending process maxilla, *LP* lamina papyracea, *SB* skull base, *RM* right middle turbinate, *BL* basal lamella

It is still possible to inadvertently penetrate the skull base when entering the posterior ethmoid from a low-and-medial point if the instrument being used is directed upwards rather than parallel to the hard palate.

With or without stereotactic navigation, it is sometimes difficult to identify the posterior ethmoid skull base and hence perform a complete clearance of air cells during an ethmoidectomy, especially with a low skull base. Here, identifying the level of the skull base in the sphenoid sinus and following forwards is extremely helpful.

The posterior ethmoid air cells should usually stop at the face of the sphenoid sinus and skull base above. Sometimes however, a posterior ethmoid air cell might extend beyond the face of the sphenoid sinus, forming a sphenoethmoidal (previous terminology: Onodi cell). These cells can be dangerous for a surgeon if unrecognised on preoperative CT imaging (please see Chap. 14).

An unrecognised sphenoethmoidal cell may lead to an iatrogenic injury of the optic nerve causing blindness.

It is not difficult to penetrate the ethmoid skull base at various sites to cause an iatrogenic CSF leak (see Table).

Weak points of the skull base:
- Cribriform plate/olfactory fossa
- Lateral lamella of the cribriform plate
- Fovea ethmoidalis
- Entry points into lateral lamella of anterior and posterior ethmoidal arteries

The Sphenoid Sinus

The sphenoid sinus is located in the sphenoid bone, with the left and right cells separated by the intersinus septum.

Superiorly is the planum sphenoidale and tuberculum sellae; posteriorly is the sella turcica and clivus; inferiorly is the rostrum of the sphenoid containing the vidian canal; and laterally is bone separating the sinus from Meckel's cave in the middle cranial fossa and containing the V_2 (maxillary division) of the trigeminal nerve, which exits the skull base through the foramen rotundum.

The sphenoid sinuses are often asymmetric in shape and size.

The sphenoid sinus may be variably pneumatised and is classified as conchal, pre-sella and sella varieties (Fig. 2.12).

In the conchal type, the area below the sella is solid bone without an air space extending below and behind into the clivus. This may give a very flat appearance to the sella, and neurovascular anatomical indentations may be impossible to discern. This is the commonest type in children but least common in adults.

In the pre-sella type, the sphenoid sinus has a moderate air space in front of the sella but without extension into the clivus below and posteriorly.

In the sella type, which is the commonest configuration in 85% of cases, the body of the sphenoid is well pneumatised, and so the sella and related neurovascular anatomy are well defined. Pneumatisation extends below and posteriorly into the clivus.

The most difficult for sella access during pituitary surgery is the conchal variety. Stereotactic navigation is almost mandatory in these cases.

The intersinus septum is positioned eccentrically and posterolaterally often attaches to the bony covering of the internal carotid artery (ICA). Vigorous manipulation of the intersinus septum may result in an iatrogenic injury to the ICA.

The sphenoid sinus drains into the nose through its natural ostium into the sphenoethmoidal recess. The sphenoid ostium is slit-like and is often obscured by the superior (or where present, supreme) turbinate.

The sphenoid ostium can usually be located 12–18 millimetres (mm) above the arch of the posterior choana (Fig. 2.13). Other reference points are very helpful and may prevent inadvertent penetration of the skull base (see Table).

Locating the sphenoid ostium using anatomical reference points:
12–18 mm above arch of posterior choana
Level with upper border of the maxillary ostium
Junction of mid- and lower thirds of the superior turbinate

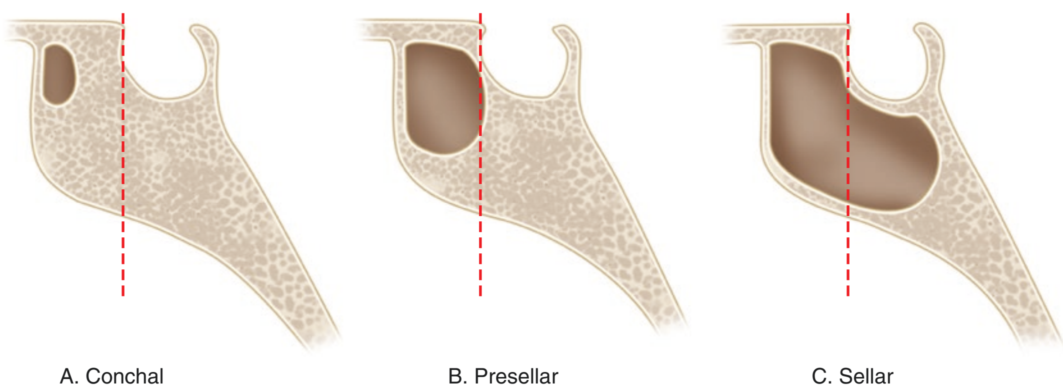

Fig. 2.12 Variations in sphenoid sinus pneumatisation. Sagittal view showing the types and degree of sphenoid sinus pneumatisation related to the anterior wall of sella turcica (red dashed line)

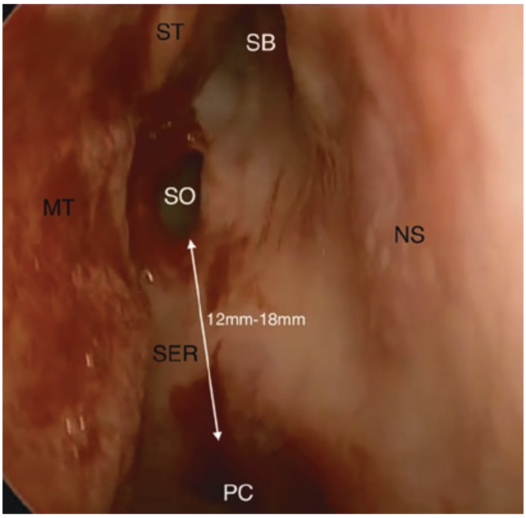

Fig. 2.13 Position of natural ostium of sphenoid sinus in the sphenoethmoidal recess. *SO* sphenoid ostium, *MT* middle turbinate, *ST* superior turbinate, *SB* skull base, *NS* nasal septum, *PC* posterior choana, *SER* sphenoethmoidal recess

If stereotactic navigation is not available, a diseased and contracted sphenoid sinus may be identified by opening into the normal side and traversing the intersinus septum or by following the vomer posteriorly as it becomes the intersinus septum. This latter technique will always ensure the sphenoid sinus is entered in the midline and away from critical neurovascular structures.

When entering the sphenoid sinus, instruments should be directed inferiorly, and the safest point of entry is via the natural ostium in the low and medial position on the face of the sinus. High-and-lateral is the optic canal and nerve; low-and-lateral is the ICA in its paraclinoid and cavernous segments; and high-and-medial is the skull base (planum sphenoidale).

The ICA may be dehiscent (absent of a bony covering) in 25–30% of cases. The optic canal may be dehiscent in 6% of cases. Both situations lend themselves to a high chance of an iatrogenic injury and should be recognised on careful appraisal of preoperative CT imaging.

The pituitary gland sits in the sella turcica, a midline structure in the posterosuperior sphenoid sinus. The optic chiasm sits above and behind the sella. The clivus sits below. Pituitary tumours, clival chordoma and chondrosarcoma, suprasellar pathologies such as craniopharyngioma and meningioma, and cavernous sinus and Meckel's cave pathologies can be accessed via a transsphenoidal corridor.

The Frontal Sinus

This is the sinus of the frontal bone. There are usually two frontal sinuses within the single frontal bone that is unique for humans. The frontal sinuses are often asymmetric in size and shape, and it is not unusual for there to be an overriding frontal sinus from one side.

Each frontal sinus is bounded anteriorly by its anterior table, posteriorly by its posterior table, medially by the intersinus septum, and inferiorly by the roof of the orbit.

The frontal sinus communicates with the nose via its hourglass-shaped infundibulum, through the frontal ostium and into the frontal recess. The infundibulum sits inferomedially in the frontal sinus. The opening into the nose is medial and anterior.

The frontal ostium is the narrowest part of this funnel-shaped communication, bounded anteriorly by the nasal process of the frontal bone (the frontal 'beak'), posteriorly by the frontal horn of the skull base, laterally by the orbit, and medially by the bony nasal septum (Fig. 2.14).

The frontal recess sits below the beak. It is an area bounded medially by the lateral surface of the middle turbinate, laterally by the orbit, anteriorly by the agger nasi, and posteriorly by either the bulla ethmoidalis or the suprabullar recess. Disease or scarring in this critical area may readily obstruct drainage and/or pneumatisation of the frontal sinus.

There may be massive pneumatisation into the frontal bone or very little pneumatisation at all. This is important to consider in patients that report a 'sinus headache' as an alternative cause for the headache should be sought in these cases.

It is imperative to accurately appraise preoperative CT imaging before contemplating surgery on either the frontal recess or the frontal ostium.

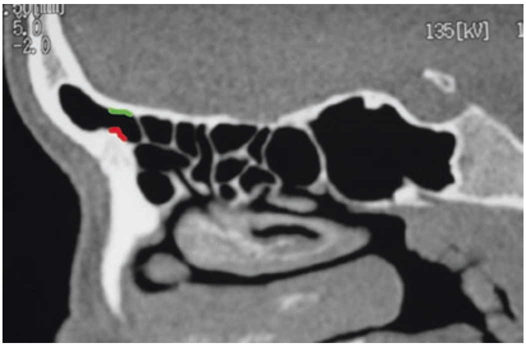

Fig. 2.14 Anatomical boundaries of the ostium of the frontal sinus. Posterior (green line), skull base; anterior (red line), nasal process frontal bone (frontal beak); inferior, agger nasi cell (or Kuhn 1 cell if present); lateral, lamina papyracea; medial, intraseptal cell

Failure to recognise frontal sinus agenesis or hypoplasia may lead to an iatrogenic CSF leak.

A supraorbital ethmoid air cell (SOEC) is pneumatisation into the orbital plate of the frontal bone. It may be confused for a frontal sinus. A SOEC opens posteriorly and laterally into the nose and may readily be confused for the natural ostium of the frontal sinus.

The frontal sinus should be managed carefully and by those with great experience. It is easy to cause more long-term harm than benefit if the drainage pathway is traumatised.

The mucosa of the natural ostium may be circumferentially damaged causing scarring and stenosis.

Fragments of the agger nasi or bulla ethmoidalis may be pushed upwards causing obstruction.

Inexperienced instrumentation may cause damage to the anterior ethmoidal artery, a CSF leak posteromedially, or orbital injury laterally with either exposure of orbital fat or dislocation of the trochlea and superior oblique extraocular muscle causing postoperative diplopia (please see Chap. 34).

It is often better to leave a frontal sinus and its drainage pathway untouched than to perform a partial, incomplete, or traumatic dissection. A significant volume of revision sinus surgery is a result iatrogenic obstruction of the frontal drainage pathway.

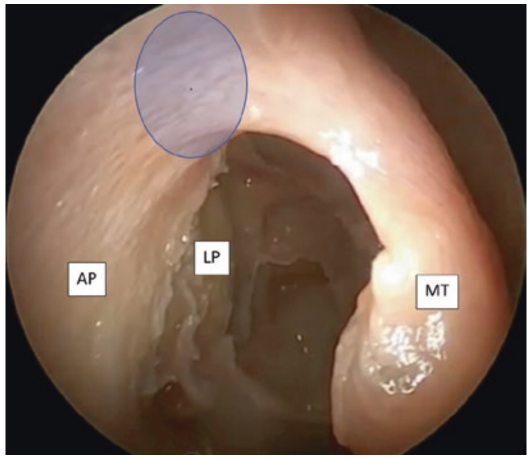

Fig. 2.15 Agger nasi 'bulge' in the axilla of the middle turbinate. *MT* middle turbinate, *LP* lamina papyracea, *AP* ascending process maxilla; shaded area—bulge of agger nasi cell

The Agger Nasi

This is the most anterior of ethmoid air cells and occurs in over 90% of individuals.

It sits at the upper aspect of the uncinate process and, when present, sits abutting the nasal process of the frontal bone. Its position causes a 'bulge' at the axilla of the middle turbinate (Fig. 2.15).

The degree of pneumatisation of the agger nasi and its relationship to the adjacent skull base and medial intraseptal pneumatisation may influence drainage from the frontal sinus and predispose to chronic frontal sinusitis.

The agger nasi and any associated frontal cells may be dissected with care and precision to aid ventilation and drainage of a diseased frontal sinus.

Frontal Cells and Classification

Several classification systems have been proposed for ethmoidal cells encroaching into the frontal sinus.

An effective frontal sinus cell classification system should:

- Aid clear and concise communication between clinicians
- Facilitate decisions regarding extent of surgery
- Be simple to apply
- Not be too complicated to remember
- Translate between countries

The most commonly in use are the Kuhn classification of frontoethmoidal cells and the International Frontal Sinus Anatomy Classification (IFAC) system (see Further reading).

The Kuhn classification has existed for some time now. Although it might not be considered to be perfect by all, it does permit decisions regarding interventions to be made easily. The classification does not, however, provide a direct link between anatomy and extent of surgery. The classification system talks of frontoethmoidal cells 1–4 (Fig. 2.16).

Type 1 Cell

A single air cell sits above the agger nasi. The degree of pneumatisation of this cell and of the agger nasi will push the frontal sinus drainage pathway posteriorly and medially. It can usually be accessed with an angled endoscope (70° or 45°) and a 90° frontal curette. Rarely, an axillary flap approach will be necessary if the pneumatisation is substantial.

Type 2 Cell

These are two or more (a tier) air cells sitting above the agger nasi. The frontal sinus drainage pathway is again pushed posteriorly and medially. The cap, uppermost part, of the topmost air cell is likely to be difficult to reach using a conventional uninarial frontal recess dissection with an angled endoscope and an angled curette. An axillary flap and rongeur excision of the axillary bone of the beak facilitates superb access to both the agger nasi and the type 2 cells.

Type 3 Cell

This is a much larger pneumatisation above the agger nasi, but it still only occupies less than 50%

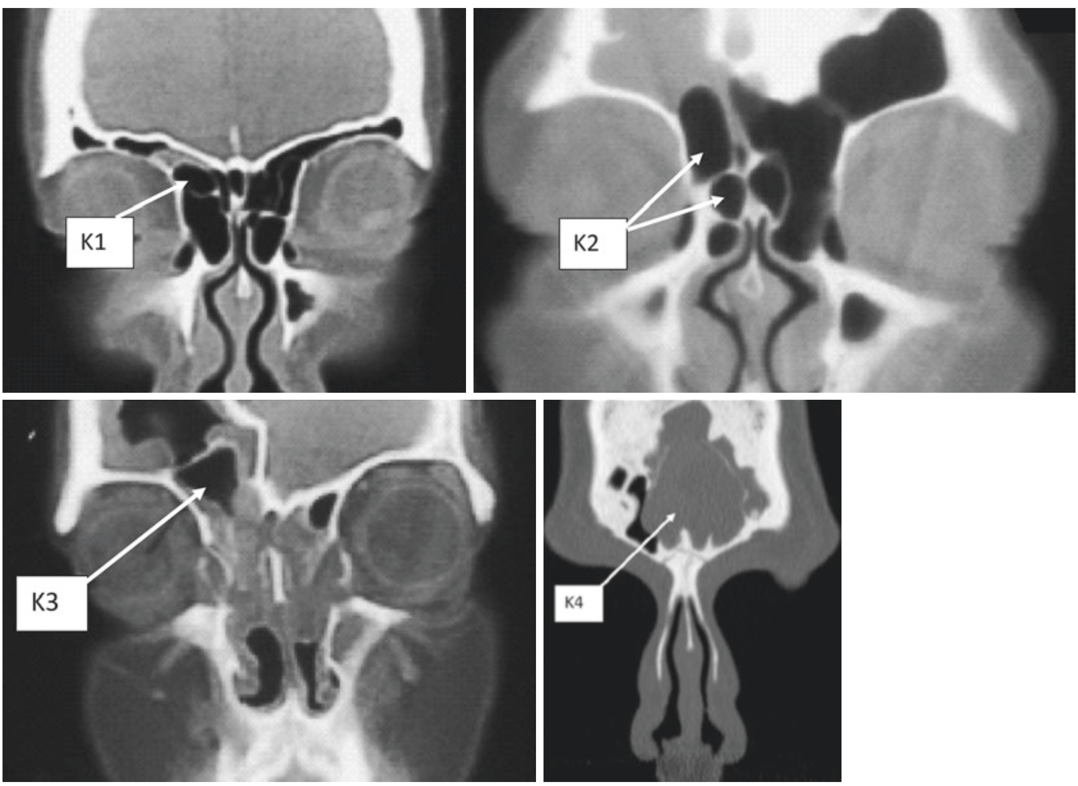

Fig. 2.16 Kuhn cells 1–4

of the height of the frontal sinus. In a uninarial approach, it is highly likely an axillary flap will be required to access the apex of the type 3 cell or alternatively, a more extensive frontal sinusotomy incorporating a degree of drill-out of the frontal beak. Occasionally, due to the restrictive anatomy of the nasal septum, the superomedial orbit and the skull base a bi-nostril approach (high-septal window and floor of frontal sinus drill-out) to a type 3 cell might be required, which facilitates a better 'cross-court' trajectory to the apex of the diseased cell and sinus.

Type 4 Cell

This is an exceptionally large pneumatisation above the agger nasi occupying more than 50% of the height of the frontal sinus. These cells are fortunately rare. Options to treat a diseased frontal sinus containing a type 4 cell are a frontal sinus drill-out or an osteoplastic flap, depending on the experience of the surgeon.

International Frontal Sinus Anatomy Classification (IFAC) system (Fig. 2.17).

Suprabullar Cell

This is a cell that sits above the bulla ethmoidalis and posterior to the frontal infundibulum upon which it impinges. They do not pass through the frontal ostium to enter the frontal sinus. A suprabullar cell pushes the frontal drainage pathway anteriorly. This is a complexity that should be identified on preoperative sagittal CT imaging. This cell or cells often must be addressed at the time of undertaking a frontal sinusotomy so as not to compromise the frontal outflow drainage pathway.

Frontal Bullar Cell

This is a cell arising above the bulla ethmoidalis which extends along the skull base to encroach on the frontal sinus by passing through the frontal ostium. It restricts the lumen of the frontal ostium from posteriorly and also pushes the frontal drainage pathway anteriorly. This is also a complexity that should be identified on preoperative sagittal CT imaging. This cell must also usually be addressed at the time of a frontal sinusotomy to optimise the frontal outflow drainage pathway.

Medial Intraseptal Cell

This is a pneumatisation at the upper aspect of the perpendicular plate of the ethmoid that constitutes the superior bony nasal septum. It pushes the frontal drainage pathway laterally. It is a cell that drains into one or other frontal recess—this should be identified on preoperative coronal CT imaging.

The IFAC system was developed to describe the extent of required surgery based on an anatomical classification of the frontal recess and sinus. In contrast to the Kuhn classification, the IFAC system proposed to reflect the different surgeries performed in a gradated manner in the frontal recess and frontal sinus during endoscopic sinus surgery.

Cells Defined in the IFAC

Anterior cells that push the drainage pathway of the frontal sinus medial, posterior, or posteromedially:

- Agger nasi cell
- Supra agger cell
- Supra agger frontal cell

Posterior cells that push the drainage pathway anteriorly:

- Supra bulla cell
- Supra bulla frontal cell
- Supraorbital ethmoid cell

Medial cells that push the drainage pathway laterally:

- Frontal septal cell

Grades 0–3 of IFAC extent of surgery relate to surgery of the frontal recess rather than surgery within the frontal sinus itself. These grades involve dilatation/fracture or removal of cells that obstruct the frontal ostium or frontal drainage pathway without enlargement of the bony frontal sinus ostium.

Grades 4–6 involve removal of bone to enlarge the bony frontal ostium.

Fig. 2.17 Summary of IFAC system and relationship to Draf classification

Grades 0 to 3

- relate to surgery of the frontal recess rather than surgery within the frontal sinus itself
- these grades involve dilation/fracture or removal of cells that obstruct the frontal ostium or frontal drainage pathway
- no enlargement of the bony frontal sinus ostium

Grades 4 to 6

- involve bone removal to enlarge the frontal ostium

Grade 0 = balloon dilatation
Grades 1 to 3 = equate to variations of Draf 1 procedure
Grade 4 = akin to a Draf 2a
Grade 5 = akin to a Draf 2b
Grade 6 = akin to a Draf 3/frontal drill-out/modified Lothrop

IFAC extent of endoscopic frontal sinus surgery:
Grade 0: Balloon dilatation, no tissue removal
Grade 1: Clearance of cells in the frontal recess, below the frontal ostium (no bone removal aka. Draf 1)
Grade 2: Clearance of cells obstructing the frontal ostium (no bone removal aka. Draf 2a)
Grade 3: Clearance of cells pneumatising through the frontal ostium (no bone removal aka. Draf 2a)
Grade 4: Clearance of a cell pneumatising through the frontal ostium into the frontal sinus with removal of bone of the frontal beak (aka. Draf 2a)
Grade 5: Enlargement of the frontal ostium from the lamina papyracea to the nasal septum (a unilateral frontal drill out aka. Draf 2b)
Grade 6: Removal of the entire floor of the frontal sinus with joining of the left and right frontal ostia into a common ostium with a septal window (aka. Draf 3/modified Lothrop)

The Palatine Bone

The palatine bone forms a key area of the lateral nasal wall. It is a slender bone sitting between the maxilla and the pterygoid processes of the sphenoid bone.

It has a horizontal plate contributing to the floor of the nose, a perpendicular plate contributing to the lateral nasal wall, and three processes: pyramidal, orbital, and sphenoidal.

Superiorly, between the orbital and sphenoidal processes, there is a notch, which forms the large part of the sphenopalatine foramen. A groove halfway down the perpendicular plate articulates with the inferior concha.

The medial end of the horizontal plate articulates with its opposite number to form the posterior nasal spine. This facilitates attachment of the muscles of the uvula and is a key bony landmark to lower when performing surgery at the mid- and lower thirds of the clivus.

Two important foramina in the palatine bone transmit neurovascular structures: the greater and lesser palatine canals. The former transmits the greater palatine nerve and blood vessels; the latter transmits the lesser palatine nerve and blood vessels to the soft palate and palatine tonsils.

The Nasolacrimal Apparatus

Tears are produced by the lacrimal gland superolaterally and drain inferomedially into the superior and inferior puncta.

The drainage system comprises of the upper and lower canaliculi that join to form the common canaliculus, the lacrimal sac and the nasolacrimal duct. The common canaliculus enters the lacrimal sac approximately 5 mm below the fundus.

There are two one-way valves: the valve of Rosenmuller at the entrance of the lacrimal sac and the valve of Hasner at the distal end of the nasolacrimal duct as it opens into the inferior meatus.

The lacrimal sac and duct can be accessed endoscopically via dissection of bone of the lateral nasal wall in cases of low obstruction. Due to its ease of exposure from a nasal route, the duct might also easily be damaged through excessive anterograde bone removal during uncinectomy and creation of a middle meatal antrostomy.

Two-thirds of the lacrimal sac and duct sit lateral to the ascending process of the maxilla, a third lateral to the lacrimal bone. The anterior aspect of the sac is covered by bone of the beak which also overlies the agger nasi. It is not unusual to open the agger nasi when performing an endoscopic dacryocystorhinostomy [see Chap. 49].

The sac and its fundus extend up to 9 mm above the axilla of the middle turbinate. Hence, it is important to carefully carry bony removal above the axilla to ensure that the area around common canaliculus is exposed for optimal surgical results. Similarly, dissection and opening of the nasolacrimal duct should continue low enough to avoid the risks of both tear reflux and sumping.

The Blood Vessels of the Nose

The sinonasal cavity is incredibly well supplied by blood vessels (Fig. 2.18). Both the internal and external carotid arteries send branches to supply the nose. This is perhaps why epistaxis can sometimes be alarming and intraoperative bleeding difficult to control, particularly in cases of tumour resection.

Internal Carotid Artery System

The common carotid artery bifurcates in the neck into the internal and external carotid arteries. The internal carotid artery (ICA) enters the base of the skull without giving off any branches in the neck. It immediately turns medially and slightly posteriorly in its petrous segment before turning vertically in its paraclival segment. Off this first

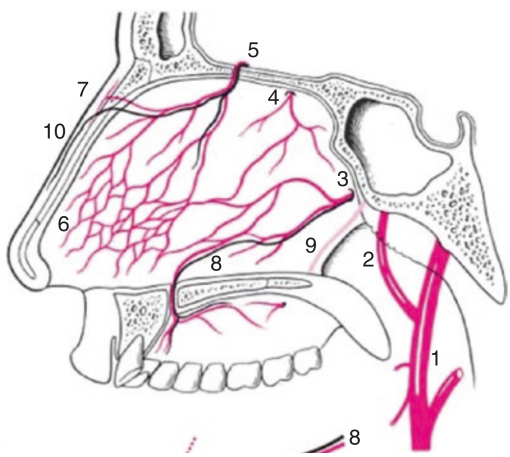

Fig. 2.18 Internal and external carotid artery supplies to the nose. External carotid artery 1 supply to the nose; 2 internal maxillary artery; 3 sphenopalatine artery; 8 greater palatine artery; 9 posterior septal artery. Internal carotid artery supply to the nose: 4 posterior ethmoidal artery; 5 anterior ethmoidal artery; 6 Kiesselbach's plexus; 7 dorsal nasal artery

genu comes the vidian artery. The vidian artery traverses anteriorly in its pterygoid canal with the vidian nerve to enter the pterygopalatine fossa posteriorly (see below). It is a key landmark to this first genu of the ICA during skull base surgery.

The paraclival ICA continues upwards to enter the cavernous sinus in its cavernous segment. It then moves to sit lateral to the sphenoid sinus before dipping medially and anteriorly in its paraclinoid segment. This forms the characteristic siphon, above which comes off the ophthalmic artery.

The ophthalmic artery passes through the superior orbital fissure into the orbit, giving off the posterior and anterior ethmoidal arteries. These arteries enter the roof of the ethmoid through their named foramina in the fronto-orbital suture of the medial orbital wall.

The posterior ethmoidal artery is most likely to sit in bone of the skull base. It may be absent in around 15% of individuals. The anterior ethmoidal artery may sit off the skull base in a bony mesentery. This can render it susceptible to injury during dissections of the frontal recess.

Both arteries traverse the roof of the ethmoid from lateral to medial to enter the lateral lamella of the cribriform plate. The arteries bifurcate to send a branch to the falx cerebri (falcine branch) and a branch into the nose (nasal branch).

A terminal branch of the ophthalmic artery is the angular artery of the nose. This vessel sits in the region of the nasal base line (medial canthus-alarfacial groove) and is often traumatised during external lateral osteotomies of the nose.

External Carotid Artery System

The external carotid system sends branches into the anterior and posterior nasal cavities from below and laterally. The superior labial artery is a branch off the facial artery. It supplies Kiesselbach's plexus in Little's area of the nasal septum.

The bulk of the blood supply to the nose comes via the **internal maxillary** (IMAX) branch of the external carotid system. The greater palatine artery comes off the IMAX in the retromaxillary space to enter its canal of the same name.

The IMAX becomes the **sphenopalatine artery** (SPA) once it crosses the sphenopalatine notch medially.

The SPA may divide into five or more branches in the lateral wall of the nose. Hence, in cases of intractable posterior epistaxis, it is important to seek out these additional vessels to give the best chance of control of bleeding.

A highly reliable surgical landmark to the SPA is the crista ethmoidalis of the palatine bone. The artery invariably sits within a few millimetres of the posterior edge of the crest. The crest may need to be excised to facilitate a better trajectory to the SPA.

The main external carotid supply to the nasal septum is the posterior septal branch, which crosses the face of the sphenoid from lateral to medial in the mucoperiosteum between the sphenoid ostium and the mucosal arch of the posterior choana. The posterior septal branch forms the basis of the pedicled nasoseptal flap used in reconstruction of skull base defects.

Vessels supplying Kiesselbach's plexus in Little's area of the nasal septum:

- Anterior ethmoidal artery
- Posterior ethmoidal artery
- Superior labial artery
- Greater palatine artery
- Sphenopalatine artery (via its nasal septal branch)

The Nerves of the Nose and Sinuses

The trigeminal nerve predominates in sensory innervation to the external and internal nose, whilst the facial nerve innervates the nasal musculature.

The olfactory nerve (CN 1) is responsible for the sense of smell. Olfactory fila from the olfactory bulbs pass through foramina in the cribriform plate into the roof of the nose. They supply the upper nasal septum and medial surfaces of the middle and superior turbinates.

The optic nerve (CN 2) passes out of the orbit via the optic canal in the lesser wing of the sphenoid bone and is responsible for vision. It is important to appreciate the anatomy of the optic canal during sinus surgery as unfamiliarity may lead to an iatrogenic optic nerve injury. The orbital apex sits lateral to the face of the sphenoid sinus, and the optic canal sits in the superolateral aspect of the sphenoid sinus. A sphenoethmoidal (Onodi) cell may render the optic nerve susceptible to injury in the posterior ethmoid.

External Nose

Sensation of the external nose is derived from the ophthalmic (V_1) and maxillary (V_2) divisions of the trigeminal nerve. The lacrimal, frontal and nasociliary nerves are the three main branches of the ophthalmic division. The infratrochlear nerve arises from the nasociliary nerve and supplies the superior aspect of the external nose. Another branch of the nasociliary nerve is the external nasal nerve which, after exiting between the nasal bone and the upper lateral cartilage, provides sensation to the nasal tip skin, the medial aspect of the nasal alae, and the dorsum of the nose. The maxillary division provides sensory input to the lateral dorsum and the alae of the external nose.

Internal Nose

Both V_1 and V_2 also supply sensation to the nasal mucosa. The anterior ethmoidal nerve is a branch of the nasociliary nerve and provides sensation to the vault and anterior nasal septal mucosa. The nasopalatine nerve is a branch of V_2 and supplies the posterior nasal septum. The greater palatine nerve (V_2) and the anterior ethmoidal nerve (V_1) innervate the mucosa of the lateral wall of the internal nose.

Sinuses

The paranasal sinus mucosa is innervated by the V_1 and V_2 divisions of the trigeminal nerve.

The maxillary sinus is innervated by the V_2 division of the trigeminal nerve. The infraorbital nerve is the terminal branch of V_2. It runs in its canal in the roof of the maxillary sinus and exits the orbit at the infraorbital foramen. It supplies the skin of the lower eyelid, anterior cheek, side of the nose, moveable part of the nasal septum, and upper lip.

The frontal sinus is innervated by the V_1 division of the trigeminal nerve.

The ethmoid sinuses are also innervated by V_1 via the ophthalmic nerve and nasociliary nerve that branches into the ethmoidal nerves.

The sphenoid sinus is innervated by both the V_1 and V_2 divisions of the trigeminal nerve.

Autonomic Nerve Supply to the Nose

The nerve of the pterygoid canal (Vidian nerve: named after Vidus Vidius 1509–1569) contains axons of both sympathetic and parasympathetic nerves. It is formed by the greater petrosal (a branch of the facial nerve) and deep petrosal (a branch of the internal carotid plexus) nerves within the foramen lacerum. The vidian nerve travels to the pterygopalatine fossa through the pterygoid canal in the sphenoid bone.

The preganglionic parasympathetic axons synapse in the pterygopalatine ganglion which contains the postganglionic secretomotor fibres to the lacrimal gland and to the nasal and palatine goblet cells.

The postganglionic sympathetic axons travel on the branches of V_2 to provide sympathetic innervation to blood vessels. They do not synapse in the pterygopalatine ganglion.

Key Concepts

The Internal Valve

This is a critical area of the nose, the narrowest part of the nasal airway, and is responsible for sensing airflow. It is formed by the caudal border of the upper lateral cartilage superiorly, the nasal septum medially, the floor of the nose inferiorly, and the head of the inferior turbinate laterally. Hence, abnormalities of any of these structures at the internal valve may impede airflow and cause a sense of nasal airflow obstruction.

Septum Attachment Points

The nasal septum has critical attachment points at the k (keystone) area, at the anterior nasal spine, and at the anterior septal angle.

The k area is formed at the confluence of the nasal bones, the upper lateral cartilages, the quadrangular cartilage of the septum, and the perpendicular plate of the ethmoid bone. It is critical for support in the roof of the nose. Any septorhinoplastic surgery in this area should be performed cautiously as disruption may lead to cosmetic deformity.

The quadrangular cartilage of the nasal septum is firmly attached to the anterior nasal spine of the pre-maxilla. Disruption of these fibrous attachments during septoplasty surgery may lead to rotation of the quadrangular cartilage causing a supratip deformity. If disturbed, the quadrangular cartilage must be fixed firmly back to the anterior nasal spine.

The anterior septal angle plays an important role to the nasal tip support, length of the nose, and internal nasal valve anatomy. Surgery in this area must be conducted with care, with the complex configuration of the anterior septal angle and lower lateral cartilages restored at the completion of surgery.

The Middle Turbinate

Understanding the anatomy of the middle turbinate is key to successful sinus surgery. It is imperative to work lateral to the middle turbinate during sinus surgery to avoid inadvertent penetration of the skull base. It should be noted whether polyps are arising from lateral to or medial to the middle turbinate. Any polyps or polypoid mucosal change medial to the middle turbinate should be excised with extreme care as the cribriform plate is easily injured at this site. This is a particularly dangerous situation in revision sinus surgery.

The middle turbinate derives from the ethmoid bone. It has three parts: anterior, middle, and posterior thirds. The anterior third is oriented vertically and attaches to the lateral lamella of the cribriform plate. The middle third turns laterally and attaches to the lamina orbitalis. It is the junction of the anterior and posterior ethmoids. The posterior third is attached to the crista ethmoidalis of the maxilla on the lateral wall of the nose.

Careless instrumentation towards the frontal sinus in the anterior third of the middle turbinate may lead to an iatrogenic CSF leak if instruments are inadvertently turned medially.

The transition from anterior to posterior ethmoids happens at the basal lamella. This is otherwise known as the third surgical lamella and is described below.

The posterior attachment of the middle turbinate to the lateral nasal wall is a reliable landmark to identifying the sphenopalatine artery.

The middle turbinate should be respected during sinus surgery. It should be excised only as a very last resort. Excision can lead to lateral scarring, to loss of smell, and to confusion during revision surgery when trying to identify the frontal ostium. It should not be moved excessively during sinus surgery as this may lead to a ‘floppy’ turbinate that easily lateralises and causes sinus occlusion. Similarly, the horizontal attachment of the middle turbinate should be preserved when passing from the anterior to the posterior ethmoids as this will provide rigidity to the structure of the middle turbinate, again avoiding floppiness.

Often, the middle concha may contain a large air cell, called a concha bullosa. The lateral lamella only needs to be excised if sinus function is compromised. In the healthy state, a concha bullosa may be left intact.

Sometimes, a middle concha pneumatisation may occur further back producing an interlamellar cell. This type of pneumatisation may cause a variance of the frontal sinus drainage pathway and should be noted on the preoperative CT scan.

The middle turbinate may be curved laterally, called a paradoxic curvature. This is usually related to a deviation of the perpendicular plate of the nasal septum. A paradoxic curvature may be difficult to diagnose without decongestion of the nasal mucosa. It may certainly be missed by those less experienced in nasal endoscopy. A paradoxically curved middle turbinate may lead to disease of the maxillary and anterior ethmoid sinuses. For reasons alluded to above, the treatment of choice in these cases should relate to the septum, uncinate process, and bulla ethmoidalis rather than to excision of the middle turbinate.

The Ostiomeatal Complex

This is a key drainage area where disease might adversely impact the function of three sinuses: maxillary, ethmoid, and frontal sinuses. It is comprised of, from medial to lateral, the lateral surface of the middle turbinate, the frontal recess, the hiatus semilunaris superioris, the bulla ethmoidalis, the uncinate process, the hiatus semilunaris inferioris, the ethmoid infundibulum, and the maxillary ostium. Hence, a careful and complete uncinectomy with an anterior ethmoidectomy may successfully treat the large majority of cases of sinus disease involving the maxillary, anterior ethmoid and frontal sinuses without need for further, more complicated intervention.

The Surgical Lamellae

The complex ethmoidal labyrinth can be reduced into a series of obliquely oriented lamellae based on embryologic precursors. There are four in number and are broadly parallel to each other.

The 4 surgical lamellae:
1st: Uncinate process
2nd: Face of the ethmoid bulla
3rd: Third lamella (also known as the basal or ground lamella)
4th: Superior turbinate (some might refer to the face of the sphenoid as the fourth lamella)

It is imperative for dissection to proceed safely in primary sinus surgery that the surgical lamellae are dissected in sequence from 1 to 4. The only exception to this is in cases of isolated sphenoid sinus disease, where the middle turbinate may be gently lateralised to approach the sphenoid ostium directly via the sphenoethmoidal recess.

Pterygopalatine Fossa

This is a key area in the superomedial retromaxillary space, important for identifying the vidian nerve and the vidian canal in cases of infra- and suprapetrous dissection of the ICA. The boundaries are:

- Anterior: infratemporal surface of maxilla
- Posterior: root of the pterygoid and anterior surface of the greater wing of the sphenoid bone
- Medial: perpendicular plate of the palatine bone and its orbital and sphenoidal processes
- Lateral: pterygomaxillary suture
- Inferior: pyramidal process of the palatine bone

Contents of the pterygopalatine fossa:
IMAX (terminal third)
Maxillary nerve (V2)
Vidian nerve
Pterygopalatine ganglion suspended by nerve roots from V_2

The pterygopalatine fossa is readily accessed endoscopically by removal of bone in the region of the sphenopalatine notch (after ligating the SPA) and the adjacent medial pterygoid. The vidian nerve is a substantial nerve and should not be confused with the palatovaginal nerve, which is more readily identified but has a completely different, perpendicular course to the vidian nerve.

Infratemporal Fossa

This is another key area that sits in the superolateral retromaxillary space. It is where tumours, such as juvenile angiofibroma and meningioma, may extend to. Its boundaries are:

- Anterior: infratemporal surface of the maxilla
- Posterior: styloid and condylar processes
- Superior: greater wing of sphenoid containing the foramen ovale (which transmits the mandibular branch of the trigeminal nerve) and foramen spinosum (which transmits the middle meningeal artery)

- Inferior: medial pterygoid muscle
- Medial: lateral pterygoid plate
- Lateral: ramus of the mandible

Contents of the infratemporal fossa:
Muscles:
- Temporalis
- Lateral pterygoid
- Medial pterygoid

Vessels:
- IMAX
- Pterygoid venous plexus

Nerves:
- Mandibular (V3)
- Posterior superior alveolar
- Chorda tympani
- Lesser petrosal nerves
- Otic ganglion

The infratemporal fossa (ITF) is readily accessed endoscopically by first performing an endoscopic medial maxillectomy and then removing the posterior wall of the maxillary sinus to establish a corridor to the retromaxillary space—lateral is the ITF.

It is usually necessary to control the IMAX to avoid excessive bleeding. Fat in the ITF may also need to be excised to facilitate accurate identification of anatomical structures.

A trans-septal approach or canine fossa puncture may facilitate a better angle of approach to the ITF in either two- or four-handed surgery.

Essential Learning Points
- Understanding nasal and sinus anatomy is key to mastering surgery in these areas.
- Many surgical failures and complications happen due to a lack of understanding of critical anatomy.
- This chapter forms a basis for theoretical knowledge; this *must* be expanded upon by participating in dissection courses, observing experienced surgeons, recognising and learning from anatomical variants whenever seen, and being open to learning, irrespective of age or seniority.

Further Reading

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