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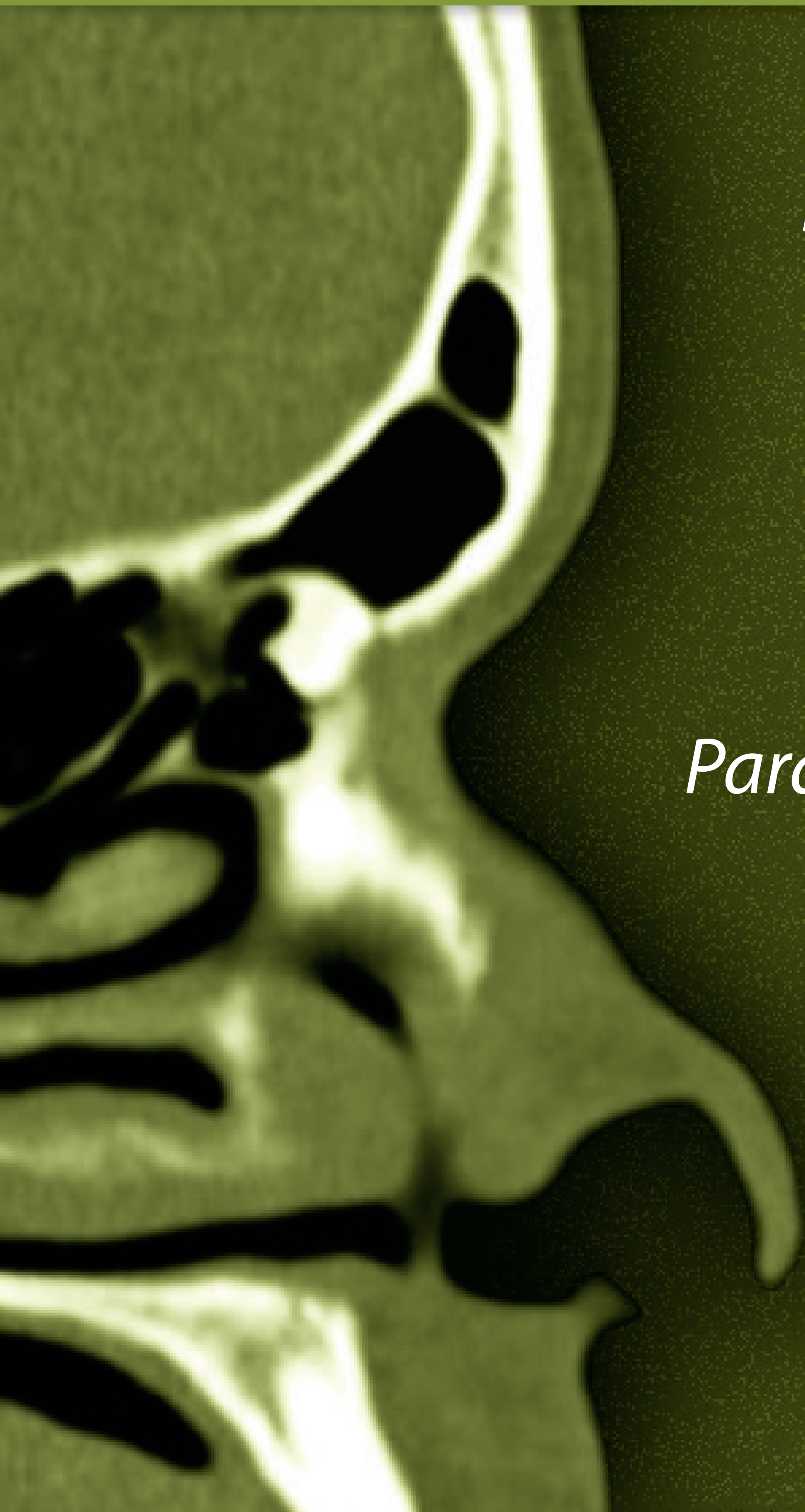

European Position Paper on the Anatomical Terminology of the Internal Nose and Paranasal Sinuses

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et al.

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European Position Paper on the Anatomical Terminology of the Internal Nose and Paranasal Sinuses

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Abstract

The advent of endoscopic sinus surgery led to a resurgence of interest in the detailed anatomy of the internal nose and paranasal sinuses. However, the official Terminologica Anatomica used by basic anatomists omits many of the structures of surgical importance. This led to numerous clinical anatomy papers and much discussion about the exact names and definitions for the structures of surgical relevance. This European Position Paper on the Anatomical Terminology of the Internal Nose and Paranasal Sinuses was conceived to re-evaluate the anatomical terms in common usage by endoscopic sinus surgeons and to compare this with the official Terminologica Anatomica. The text is a concise summary of all the structures encountered during routine endoscopic surgery in the nasal cavity, paranasal sinuses and at the interface with the orbit and skull base but does not provide a comprehensive text for advanced skull base surgery. It draws on a detailed review of the literature and provides a consensus where several options are available, defining the anatomical structure in simple terms and in English. It is recognised that this is an area of great variation and some indication of the frequency with which these variants are encountered is given in the text and table. All major anatomical points are illustrated, drawing on the expertise of the multi-national and multi-disciplinary contributors to this project.

Key words: anatomy, terminology, nose, paranasal sinuses

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The full document can be downloaded for free on the website of this journal: http://www.rhinologyjournal.com
A 3-planar flight through the frontal recess highlighting the frontal drainage pathway by Professor Heinz Stammberger may also be accessed via this website: http://www.rhinologyjournal.com

Acknowledgements

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Contents

Introduction

But chiefly the anatomy
You ought to understand
If you will cure well anything
That you do take in hand !
John Halle, English Surgeon 1529-1568

The importance of anatomy is hardly a new concept and much of the basic anatomy of the nose and sinuses has been well known since the days of Gruenwald, Killian, Onodi and other luminaries of the late 19th and early 20th centuries [1-3]. However, with new techniques comes new terminology and the advent of endoscopy and computed tomography in the 1980's led to a renaissance in rhinology and a revival of interest in the detailed surgical anatomy and physiology, which was revealed by these techniques. Unfortunately, the official Terminologia Anatomica [4] gives scant consideration to the detailed sinonasal anatomy, which so fascinates the rhinologic surgeon and a lack of uniformity in the terminology and definitions being used around the world resulted in the International Conference on Sinus Disease: Terminology, Staging and Therapy published in 1994 [5]. Despite many thousands of publications on endoscopic sinus surgery since then, there have been few attempts to reconsider these aspects of nomenclature and we felt that after 20 years it would be worth revisiting this topic. As you will see, we have confined ourselves to the anatomy most pertinent to endoscopic sinus surgery with the intention of undertaking a similar exercise for the anatomy which underpins septorhinoplasty in the future. Thus certain structures such as the septum are not encompassed in this document.

Our aim was to provide a succinct summary of the main areas of basic internal sinonasal* anatomy, which would be of use to the general rhinologist or trainee, and which was clear and easily accessible. It is not meant to replace the many excellent textbooks that provide the fine detail that a specialist might subsequently require. For these, we would refer you to the list of Further Reading on page 34. However, we have tried to cover all the salient areas of interest with accompanying illustrations.

We invited colleagues to join the consensus group who have demonstrated an interest in this topic through their work and publications as surgeons, radiologists and anatomists but even in this expert group, there were, inevitably, areas of considerable debate that cannot be completely resolved and these are shown as discussion points.

Controversy regarding terminology has a long and distinguished history. A good example is the preface provided by TB Layton to the publication of the Onodi Collection at the Royal College of Surgeons of England in 1934 [6]. In this, he discusses at some length the application of the terms 'infundibulum' and 'hiatus semilunaris' to several areas in the lateral wall of the nose, including to each other. This confusion was exacerbated by the use of Latin, English, German and French to describe the anatomy and resulted in Layton's recommendation that both terms be abandoned. Although we have not followed this advice, we have tried to avoid the Latin terminology where possible and have also removed the many eponyms, much beloved by medical students, in favour of an anatomical descriptor.

We have deliberately avoided extensive detail about the embryological origins of the various structures but there was a lively debate regarding the method by which sinus cavities arise which could be summarised as 'aeration versus pneumatization'. According to the concept of evo-devo (evolution and development) popularised by Jankowski, the ethmoid bone and the paranasal sinuses (i.e the frontal, maxillary and sphenoid sinuses) may be of different origin [7]. The ethmoid, the more anterior bone of the midline cranial base, develops during fetal life from the folding of the olfactory cartilaginous capsule into the olfactory clefts and ethmoid complexes, and is aerated after birth. However, the paranasal sinuses develop after birth through pneumatization. Pneumatization is a biological mechanism by which the bone marrow of some bones in the body of animals, including humans, is gradually replaced by the formation of multiple gas-forming cavities, the gas being finally released into the nasal airstream through a small opening or 'ostium'. The view that the ethmoid is phylogenetically, anatomically, embryologically and functionally different from the other paranasal air-containing structures has also been endorsed by other authors [8].

This document cannot resolve all controversies intrinsic to this area but we hope to have clarified some areas of confusion, provided a common terminology to assist surgeons both in undertaking procedures and writing about them and if nothing else, facilitated a re-examination of one of the most fascinating regions of anatomy of the body (not that we are in any way biased!).

*Sinonasal has been used in preference to 'sinunasal' throughout this document. Although the latter may be grammatically more correct, the former is utilised more frequently in common and scientific parlance.

Internal Sinonasal Anatomy

[ ] Refers to anatomical structures in Table 1.

Inferior meatus [1.4.1]: The area of the lateral wall of the nose covered medially by the inferior turbinate, into which the nasolacrimal duct opens.

Inferior turbinate [1.4]: This is composed of a separate bone that articulates with the inferior margin of the maxillary hiatus via its maxillary process. It also articulates with the ethmoid, palatine and lacrimal bones where it completes the medial wall of the nasolacrimal duct. The bone has an irregular surface due to the impression of vascular sinusoids, to which the mucoperiosteum attaches. The dimensions of the turbinate bone have been shown by digital volume tomography to be a mean length of 39mm ± 4mm and mucosal length 51mm ± 5mm. There was only 1mm difference in bone length between men and women in this Caucasian population. The mean bone thickness varied from 0.9 - 2.7mm depending on the position, being thickest in the mid-portion [29] (Figure 1).

Uncinate process [9]: the uncinate process is a thin, sickle-shaped structure which is part of the ethmoid bone and runs almost in the sagittal plane from anterosuperior to posteroinferior [5]. It has a concave free posterior margin that usually lies parallel to the anterior surface of the ethmoidal bulla (Figure 2). Posteroinferiorly it attaches to the perpendicular process of the palatine bone and the ethmoidal process of the inferior turbinate. Anteriorly it is attached to the lacrimal bone and in the sagittal plane, may have a "common" attachment to the me-

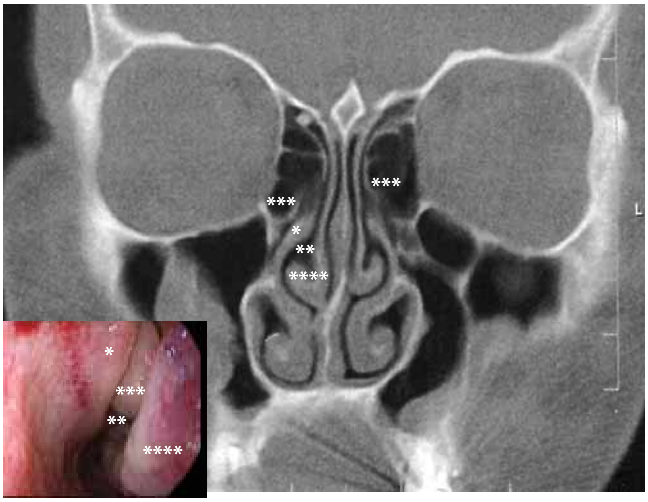

Figure 1. Right uncinate process (*), middle meatus (**), ethmoidal bulla (***) and middle turbinate (****).

Figure 3. Right uncinate process attached to skull base (*) and left attached to middle turbinate (**).

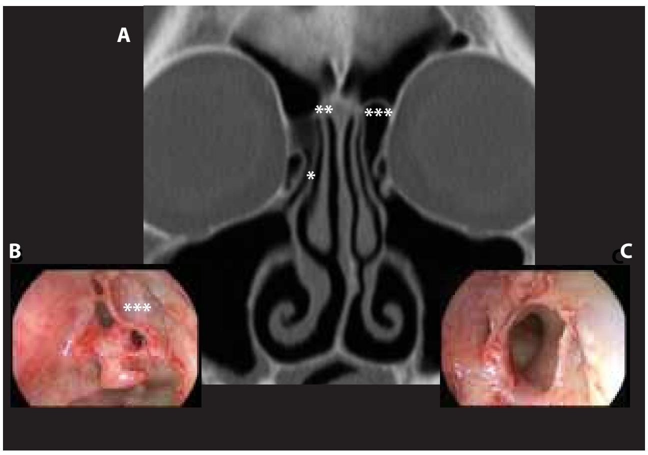

Figure 2. A) Right uncinate process (*) attached to skull base (**). Left terminal recess (***) B) Left terminal recess (***) C) View into frontal sinus after resection of left termninl recess.

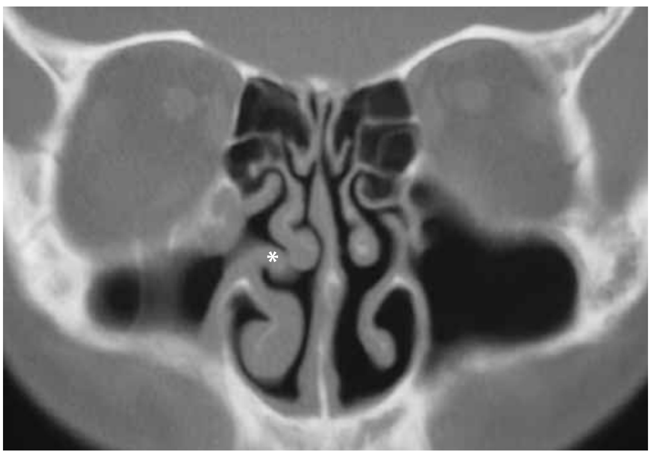

Figure 4. Everted left uncinate process.

dial surface of the agger nasi cell and the middle turbinate. Its superior attachment is very variable, with 6 variations identified [30, 31]. The most common superior attachments are to the lamina papyracea (up to 52% [31, 32], and/or to skull base or to middle turbinate (Figure 3-4) , but there are multiple variations seen which may alter the frontal sinus drainage pathway [33].
Variations of the uncinate process include: medialised; everted (paradoxical) [34]; occasionally aerated (uncinate bulla) [16]; and rarely a lateralized, concave uncinate may narrow the infundibulum leading to an atelectatic infundibulum (Figure 5-8).

Surgical note: it is important to check the CT scan for the distance from the uncinate process to the medial wall of the orbit to evaluate the width of the ethmoidal infundibulum.

Agger nasi [8.1]: the agger nasi is the most anterior part of the ethmoid, and may be seen on intranasal examination as a small prominence on the lateral nasal wall just anterior to the attachment of the middle turbinate [30]. It is thought to be the most superior remnant of the first ethmoturbinal (nasoturbinal) [5]. It has a variable degree of pneumatisation, depending on the method of assessment; around 70-90% is quoted in the literature. A large agger nasi cell may narrow the frontal recess posteriorly and/or laterally abut the nasolacrimal duct or directly pneumatise the lacrimal bone [35,36] (Figure 8).

Discussion – the agger nasi cell, if present, is the first pneumatisation seen on sagittal and coronal CT, posterior to the lacrimal bone and anterior to the free edge of the uncinate process. It is still debated whether the agger nasi cell drain into the ethmoid infundibulum or into the frontal recess or elsewhere (variable). (See 3-planar CT video on www.rhinologyjournal.com)

Basal lamellae [1.5.1,9.3,9.5.2,11.2]: all turbinates have a basal lamella reflecting their embryology. The basal lamella of the middle turbinate is the third basal lamella of the ethmoturbinals [5]. The ethmoturbinals first appear during weeks nine and ten of gestation as multiple folds on the developing lateral nasal wall [30]. Over the following weeks, the folds fuse into three or four ridges, each with an anterior (ascending) and a posterior (descending) ramus, and separated by grooves. The first ethmoturbinal develops into the agger nasi (see above) and the uncinate process. The second probably becomes the ethmoidal bulla though this is debated (see below). The third is known as the basal lamella of the middle turbinate. The fourth is inconstant but develops into the superior (and supreme, if present) turbinate. The basal lamella of the middle turbinate separates the anterior ethmoid (anterior to the basal lamella) from the posterior ethmoid (posterior to the basal lamella).
The term 'ground' lamella has been abandoned in surgical anatomy.

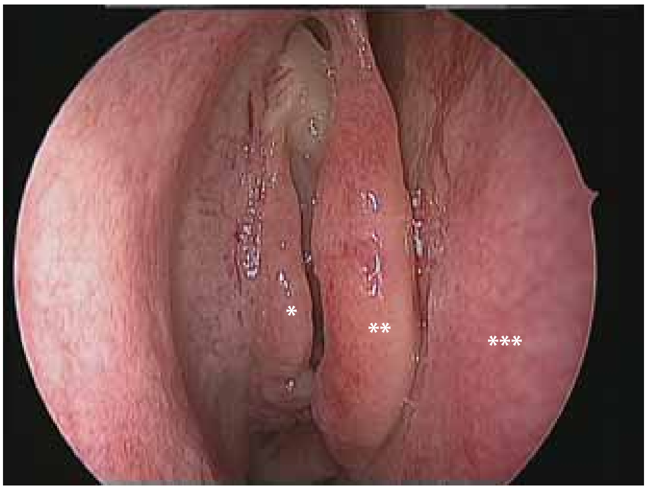

Figure 5. Right everted uncinate process (*), middle turbinate (**) and nasal septum (***).

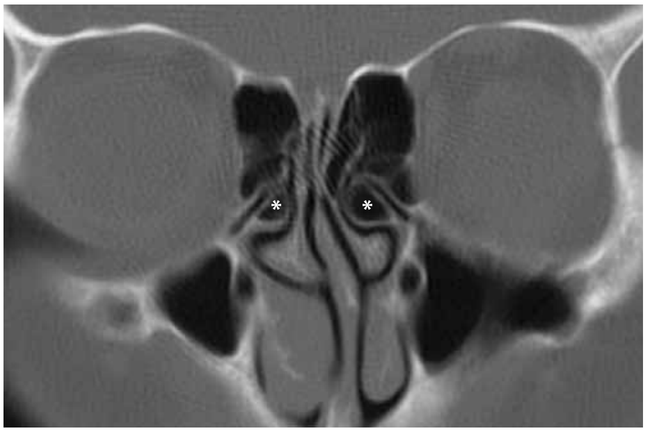

Figure 6. Aerated uncinate process (*) both sides.

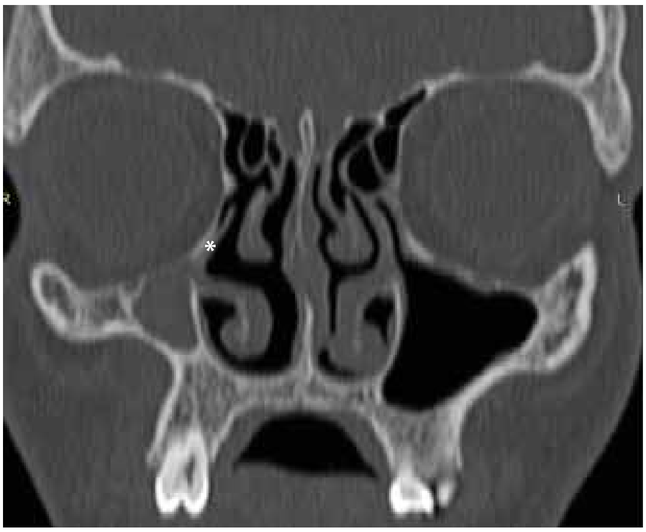

Figure 7. Right concave uncinate process (*) - atelectatic infundibulum and hypoplastic maxillary sinus.

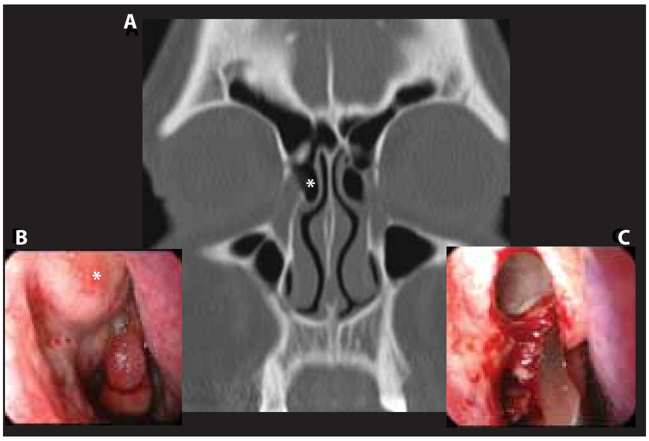

Figure 8. A) The agger nasi (*) is the most anterior part of the ethmoid, and may be seen on intranasal examination as a small prominence on the lateral nasal wall just anterior to the attachment of the middle turbinate. B) Agger nasi cell prior to resection. C) Agger nasi cell post opening.

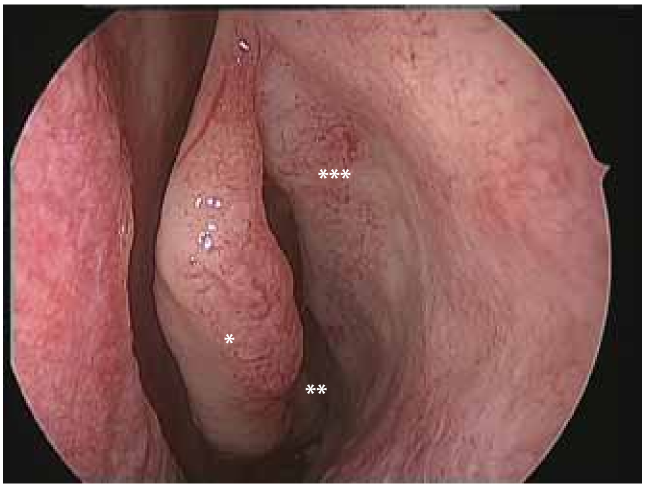

Figure 9. Left middle turbinate (*), middle meatus (**) and uncinate process (***).

Middle turbinate [1.5]: this is an integral component of the ethmoid bone, having a number of attachments. Anteriorly and posteriorly it attaches to the lateral wall of the nose, and superiorly it has a vertical attachment to the skull base at the lateral border of the cribriform plate. The vertical attachment is in a paramedian sagittal plane, the posterior attachment is more or less in the horizontal plane and these are connected by a portion of bone, referred to in surgical anatomy as the basal lamella (see above). This rotates to lie in the coronal plane and attaches to the medial orbital wall, dividing the ethmoidal cells and recesses into an anterior and posterior group relative to the basal lamella. The most anterior part of the middle turbinate fuses with the agger nasi inferiorly to form the so-called 'axilla' (Figure 9). The posterior attachment is to the lamina papyracea and/or medial wall of the maxilla, and the superior attachment is in continuity with the lateral lamella of the cribriform plate.

Middle meatus [1.6]: the area of the lateral wall of the nasal cavity covered medially by the middle turbinate, receiving drainage from the anterior ethmoid, frontal and maxillary sinuses (Figure 9).

Ostiomeatal complex [1.7]: the ostiomeatal complex is a functional unit and physiological concept comprising the clefts and drainage pathways of the middle meatus together with the anterior ethmoid complex, frontal and suprabullar recesses, and ethmoidal infundibulum [12,37,38].

Maxillary sinus [6]: the maxillary bone has a body and four processes - zygomatic, frontal, alveolar and palatine. It articulates with the frontal, ethmoid, palatine, nasal, zygoma, lacrimal, inferior turbinate and vomer as well as the maxillary bone on

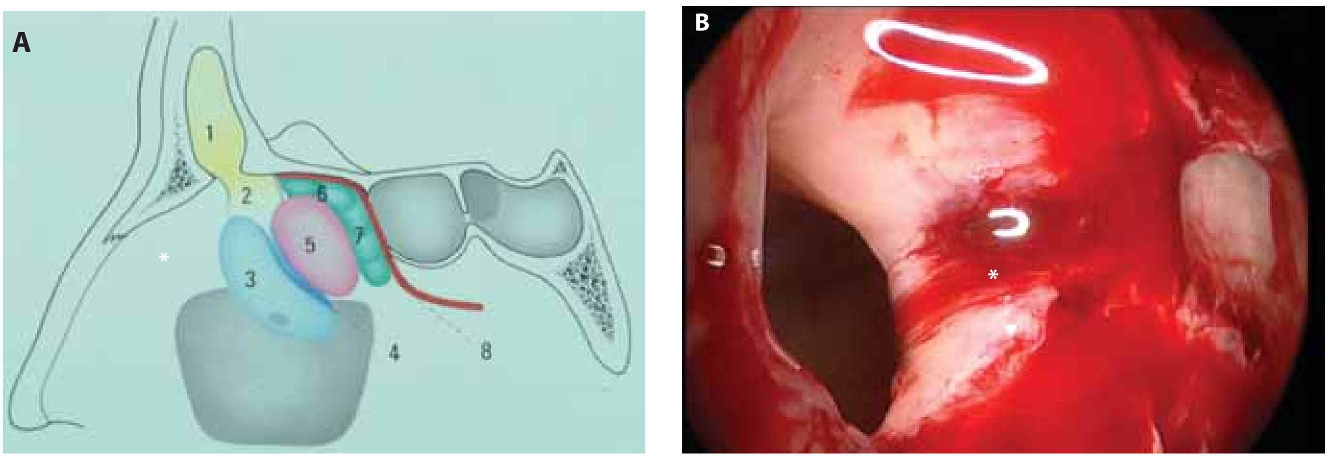

Figure 10. A) Schematic, simplified drawing of structures of the middle meatus after removal of the middle turbinate. 1 = frontal sinus, 2 = frontal recess, 3 = uncinate process over ethmoidal infundibulum, 4 = hiatus semilunaris, 5 = ethmoidal bulla, 6 = suprabullar recess, 7 = retrobullar recess, 8 = basal lamella of middle turbinate. B) Right maxillary sinus ostium (untouched) and transport of secretion over posterior margin (*).

the opposite side. The maxillary sinus occupies the body and is pyramidal in shape, the apex extends into the zygomatic process (forming the zygomatic recess) and the base of the pyramid forming part of the lateral wall of the nasal cavity. This wall contains a large defect, the maxillary hiatus (see below). The natural ostium of the maxillary sinus is located immediately posterior to the nasolacrimal duct at the base of the ethmoidal infundibulum and is covered by the transition of the uncinate process from its vertical to horizontal parts [6.1] (Figure 10A-B). It is orientated slightly offset from the parasagittal plane facing posteriorly and is usually around 5mm in diameter. However, the size can vary from 3mm to 10mm and the shape and precise position of the maxillary sinus ostium is variable [39,40]. The roof of the sinus forms the majority of the orbital floor and is traversed by the infraorbital canal (Figure 11), which may be dehiscent [6.2] (Figure 12). The canal contains the infraorbital nerve and vessels and opens on the anterior surface of the maxilla at the infra-orbital foramen.

Surgical note: In some cases the infraorbital nerve may be inferiorly displaced and attached to the roof of the maxillary sinus by a bony mesentery. Occasionally the nerve may be significantly displaced from the roof and the infraorbital foramen may exit relatively inferiorly on the canine fossa. In such a case access to the maxillary sinus through the canine fossa may be impossible without risk to the nerve.

The floor of the sinus is formed by the alveolar process of the maxilla and can be encroached upon by the roots of the second premolar and/or the molar teeth. The floor of the sinus lies on average 1.25cm below the level of the nasal cavity in an adult.

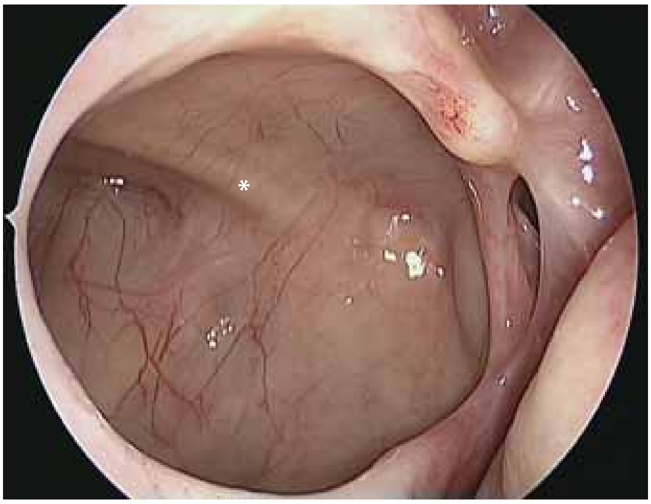

Figure 11. Infraorbital nerve seen through a large middle meatal antrostomy.

The posterior surface of the bone is grooved and pierced by the posterior superior alveolar nerves. Septations may be found within the sinus, arising from the floor and/or often involving the region of the infraorbital canal (Figure 13), in addition to encroachment from the ethmoidal complex into the sinus cavity. The blood supply derives from the maxillary artery via the infraorbital, greater (descending) palatine, posterosuperior and anterosuperior alveolar arteries.

Maxillary hiatus [6.1.2]: an anatomical term referring to a large natural opening in the medial wall of the disarticulated maxillary bone. In life, this is largely filled by other bony structures - the uncinate process (anteriorly), bulla ethmoidalis (superiorly), inferior turbinate (inferiorly), palatine bone (posteriorly) and

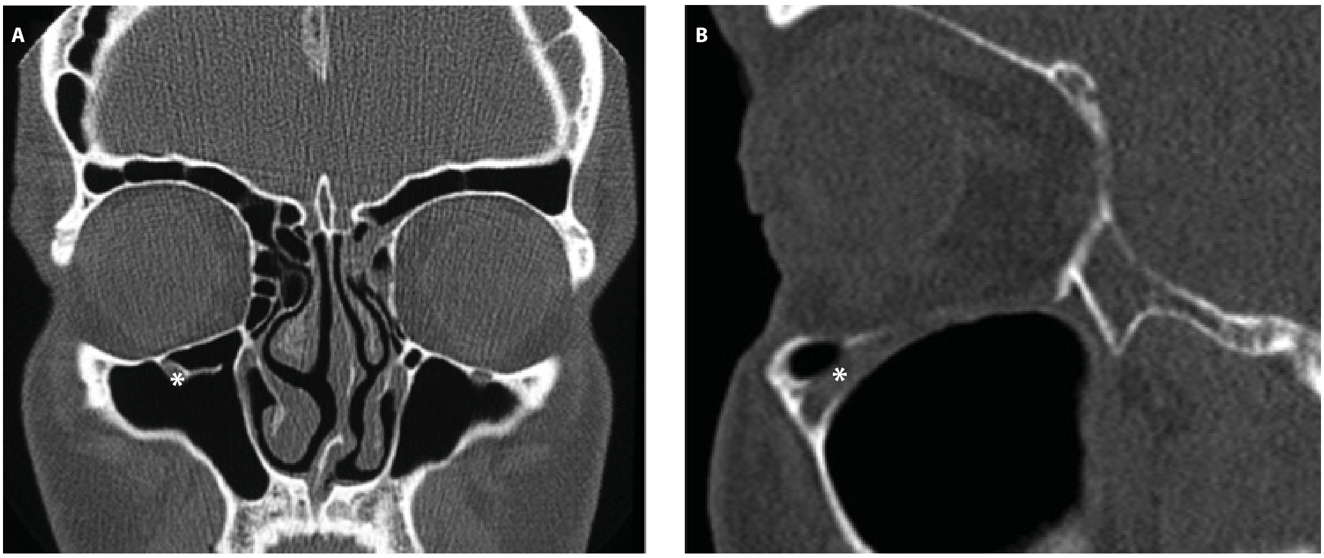

Figure 12. A) and B) The infraorbital nerve may be inferiorly displaced and attached to the roof of the maxillary sinus by a bony lamella (*).

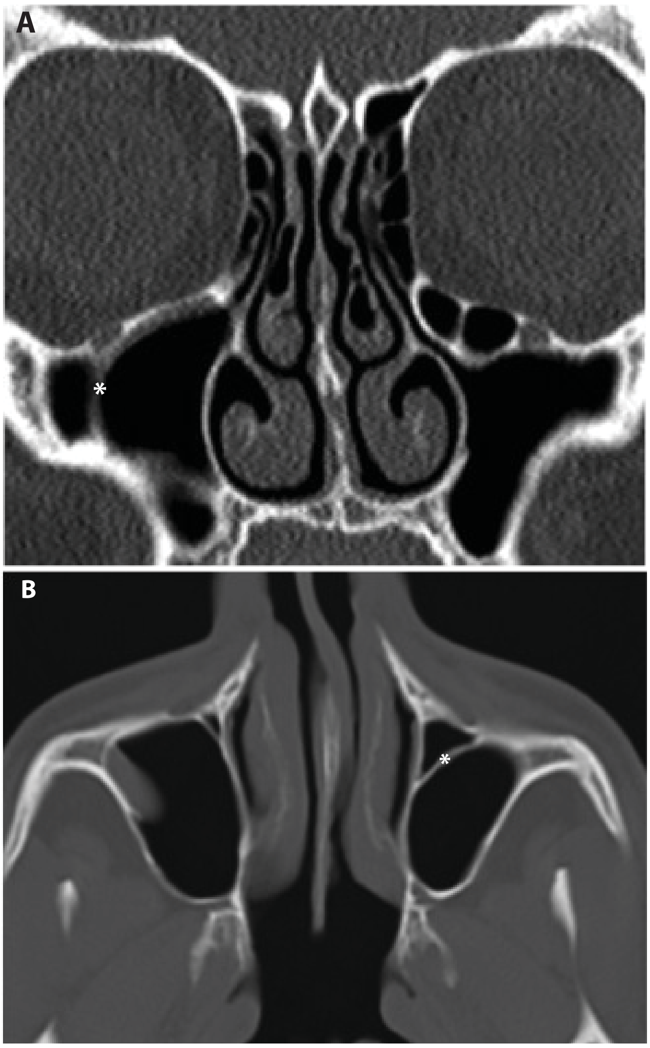

Figure 13. A) and B) Septations (*) may be found within the maxillary sinus (right), arising from the floor and/or often involving the region of the infraorbital canal.

lacrimal bone (antero-superiorly), and covered by mucosa and connective tissue. The ethmoidal infundibulum leading into the maxillary ostium is the only physiologic opening of the maxillary sinus, though breakdown of areas of natural weakness in the non-bony areas may result in accessory ostia (see below).

Semilunar hiatus (inferior & superior)[9.4,9.4.1]: the semilunar hiatus is a crescent-shaped cleft between the concave posterior free edge of the uncinate process and the convex anterior face of the ethmoidal bulla, forming the entrance to the ethmoidal infundibulum [30]. It was originally described as the "inferior semilunar hiatus"; the "superior semilunar hiatus" is a second crescent-shaped cleft between the posterior wall of ethmoidal bulla and the basal lamella of the middle turbinate, through which the retrobullar recess, if present, may be accessed [1,5].

Anterior & posterior fontanelles [6.8,6.9]: the fontanelles are the areas of the medial maxillary wall lying just above the inferior turbinate not filled in by other bones [5]. The anterior fontanelle lies anterior and/or inferior to the free edge of the uncinate process; the posterior fontanelle is posterior and/or inferior. They are closed with mucosa, connective tissue and in continuity with the maxillary periosteum but may be sites of accessory ostia (Figure 14-15), seen in approximately 5% of the normal population and up to 25% of patients with chronic rhinosinusitis [30][6.1.1]. The size of the accessory ostia vary from a pinhole to 1cm in diameter, the majority occurring in the posterior fontanelle.

Surgical note: the natural ostium of the maxillary sinus lies between the anterior and posterior fontanelles of the maxillary sinus and cannot usually be seen with a 0 degree endoscope without remo-

Figure 14. Accessory ostium in the anterior fontanelle (*) and paradoxically bent middle turbinate (**).

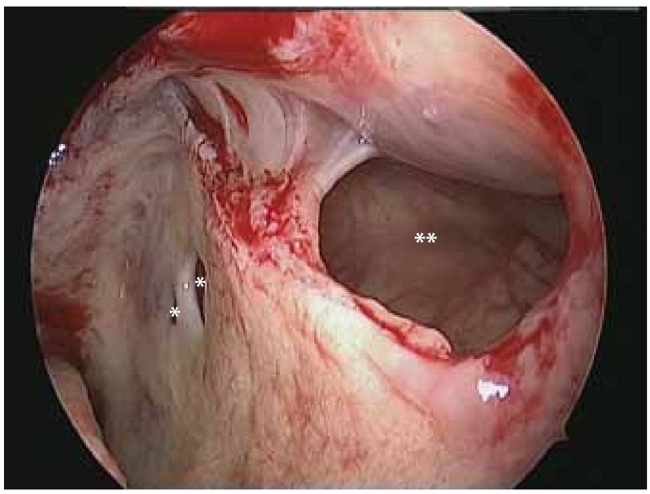

Figure 15. Accessory ostia in the posterior fontanelle (*) and left maxillary sinus ostium (**).

ving the uncinate process mainly due to its oblique orientation in the sagittal plane; if an ostium is seen, it is most likely an accessory ostium (in the absence of previous sinus surgery).

Ethmoidal bulla [9.5]: the largest anterior ethmoid cell but is occasionally under- or undeveloped (in 8% of cases) [19] (Figure 16). A number of ethmoidal configurations have been described, the commonest of which comprises a single cell opening into the superior semilunar hiatus or retrobullar recess (68%) [41]. Rarely the cell may open into the ethmoidal infundibulum (3%). Otherwise there can be multiple cells with multiple openings, one of which is almost always into the superior semilunar hiatus (98.4%). The anterior face of the bulla forms the posterior border of the inferior semilunar hiatus, ethmoidal infundibulum and frontal recess (see below) [30]. See below for relationship to the anterior ethmoid artery (Figure 17).

Surgical note: if the bulla is poorly or non-pneumatized, the medial wall of the orbit is potentially at risk. It is also important that the surgeon appreciates the proximity of the skull base when the bulla is pneumatised superiorly.

Suprabullar recess [9.5.3]: if the ethmoidal bulla reaches the ethmoidal roof, it forms the posterior border of the frontal recess. If it does not, a suprabullar recess (Figure 18-19) is present between the superior aspect of the bulla and the ethmoidal roof [5,30]. Thus the recess is an air containing space, bordered inferiorly by the roof of the ethmoidal bulla, medially by the middle turbinate, laterally by the lamina papyracea and superiorly the roof of the ethmoid. Laterally it may give rise to an air-containing cleft extending above the orbit, known as a supraorbital recess (Figure 20).

Retrobullar recess [9.5.4]: a retrobullar recess is formed when the posterior wall of the ethmoidal bulla is separate from the basal lamella of the middle turbinate, creating a cleft between the two [42]. The medial wall is the middle turbinate and the lateral wall is the lamina papyracea. It opens medially into thje middele meatus via the superior semilunar hiatus. The supra- and retrobullar recesses may be contiguous or separated by bony lamellae. They have also been referred to as the "sinus lateralis" but this term has been abandoned [1]. A separate and discrete retrobullar recess was found in 93.8% of cadavers, whereas 70.9% had a single discrete suprabullar recess in one cadaver study [20,43].

Ethmoidal infundibulum [9.6]: a three-dimensional space in the ethmoidal labyrinth of the lateral nasal wall (30). Its lateral border is the lamina papyracea, occasionally completed by the frontal process of the maxilla and lacrimal bone anterosuperiorly [5]. The posterior border comprises the anterior face of

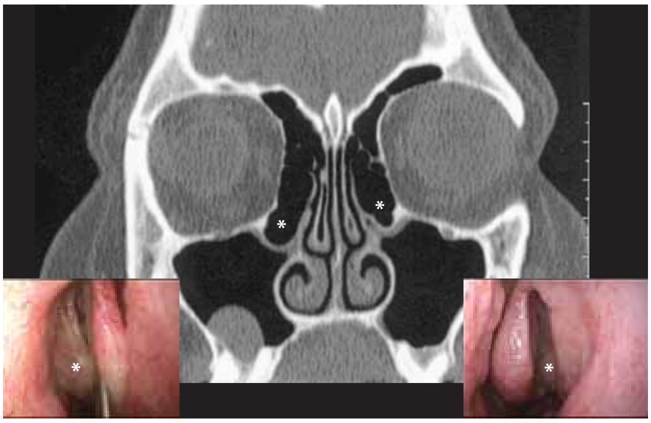

Figure 16. Enlarged ethmoidal bulla (*).

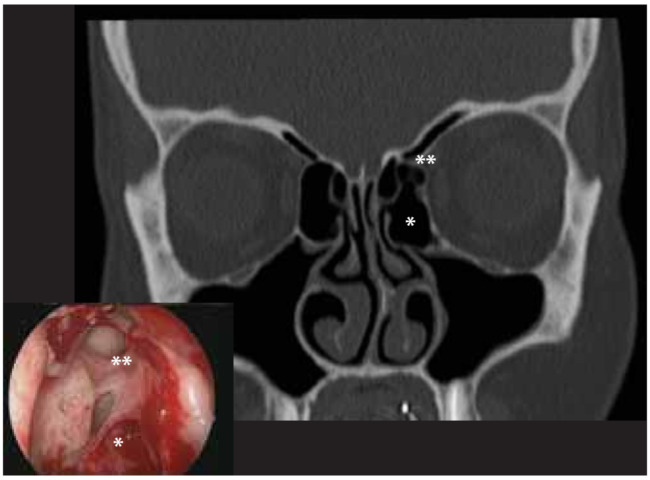

Figure 17. Ethmoidal bulla (*) and relationship to anterior ethmoidal artery (**).

Figure 18. A (diseased) suprabullar recess (*) is present between the superior aspect of the ethmoidal bulla (**) and the ethmoidal roof (***).

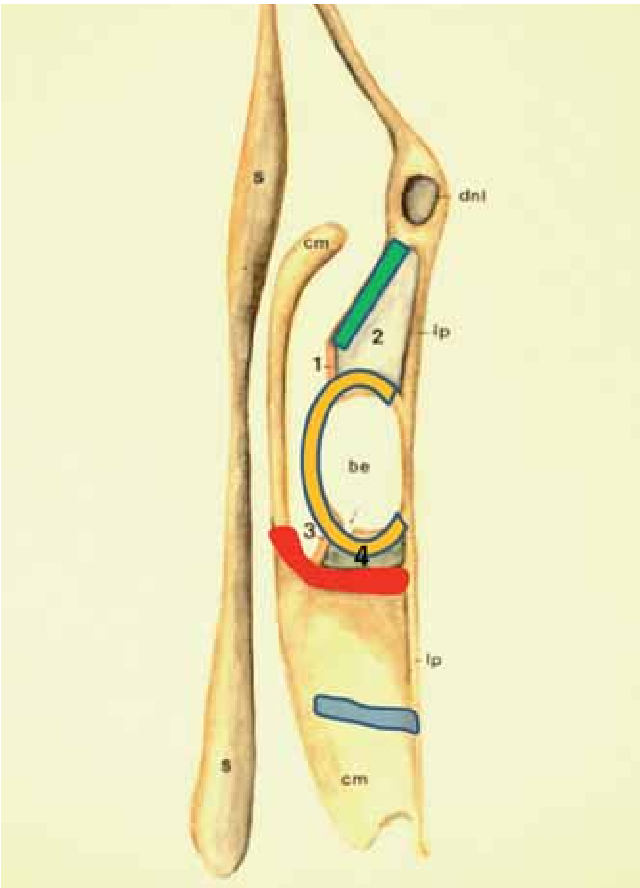

Figure 19. Schematic drawing in the axial plane through the frontal portion of the basal lamella of the middle turbinate (red). Green : Uncinate process; Yellow : Ethmoidal bulla; Blue : Basal lamella of superior turbinate. s = nasal septum, cm = concha media / middle turbinate, dnl = nasolacrimal duct, lp = lamina papyracea. 1 = hiatus semilunaris (inferior), 2 = ethmoidal infundibulum, 3 = hiatus semilunaris superior, 4 = retrobullar recess. be = ethmoidal bulla.

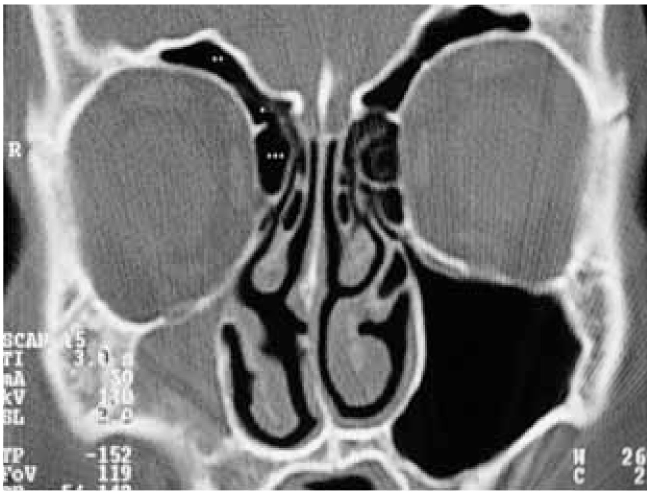

Figure 20. A suprabullar recess (*) may give rise to an air-containing cleft extending above the orbit. This is a supraorbital recess (**), formerly known as supraorbital cell; ethmoidal bulla (***).

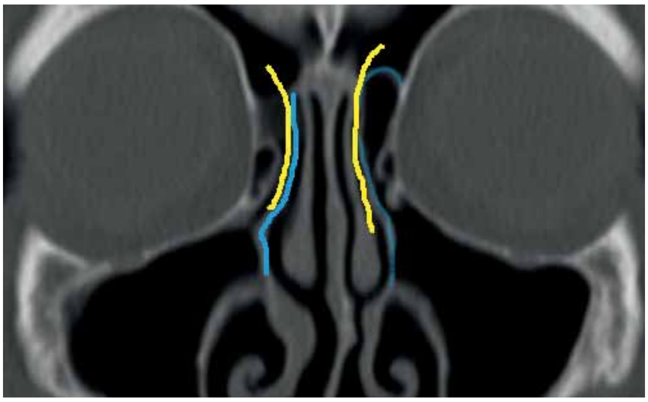

Figure 21. If the uncinate process (blue line, right side) attaches to the skull base, the infundibulum will be continuous with the frontal recess superiorly (yellow line). If the uncinate process (blue line, left side) attaches to the lamina papyracea, the infundibulum will end blindly in the terminal recess. The maxillary sinus opens into the ethmoidal infundibulum , the frontal drainage pathway (yellow line) is medial to the uncinate process.

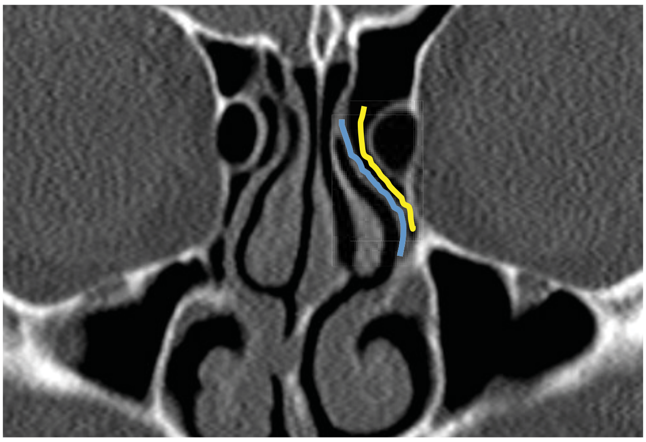

Figure 22. If the uncinate process (blue line) attaches to the middle turbinate, the infundibulum will be continuous with the frontal recess superiorly (yellow line), the frontal drainage pathway thus being lateral to the uncinate process (as on right side in Figure 21).

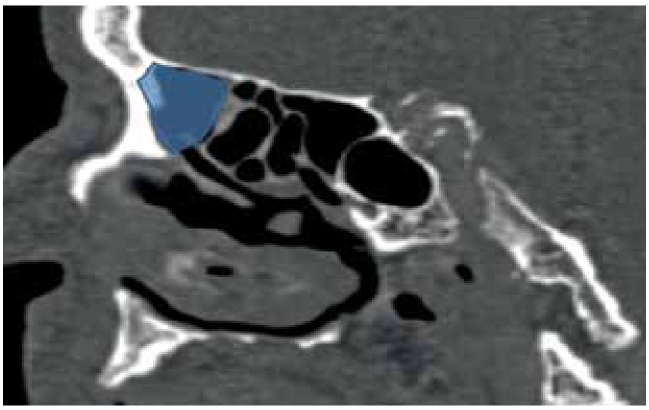

Figure 23. In this patient with agenesis of the frontal sinus, the frontal recess is “empty”, with no cells encroaching into it. In an oversimplified fashion to aid understanding, the inverted funnel structure of the frontal recess in the sagittal plane can be appreciated here (shaded blue).

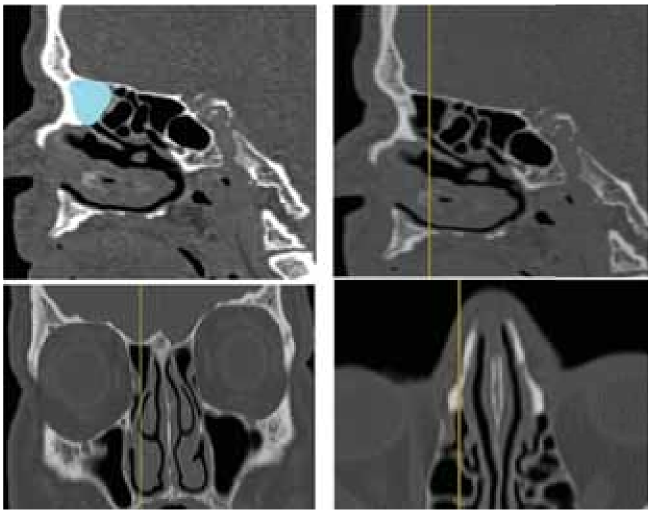

Figure 24. In a triplanar display however, this frontal recess can be seen reaching the skull base (anterior ethmoidal roof) superiorly, the anterior wall of the bulla posteriorly, extending anteriorly to the agger nasi and passing inferiorly into the ethmoidal infundibulum.

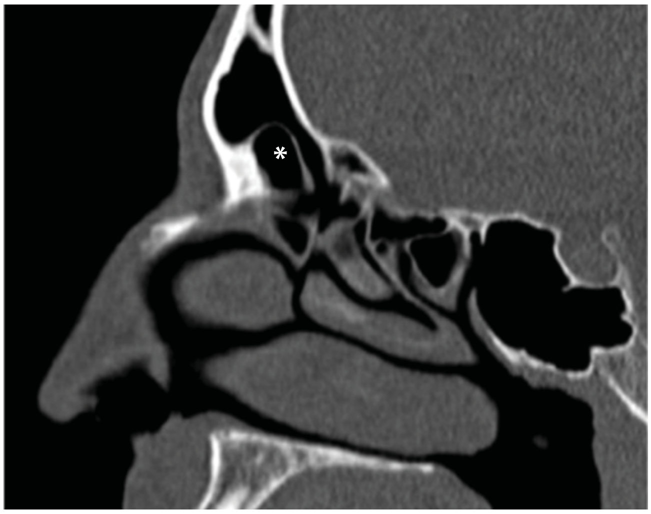

Figure 26. Anterior frontoethmoidal cell (*).

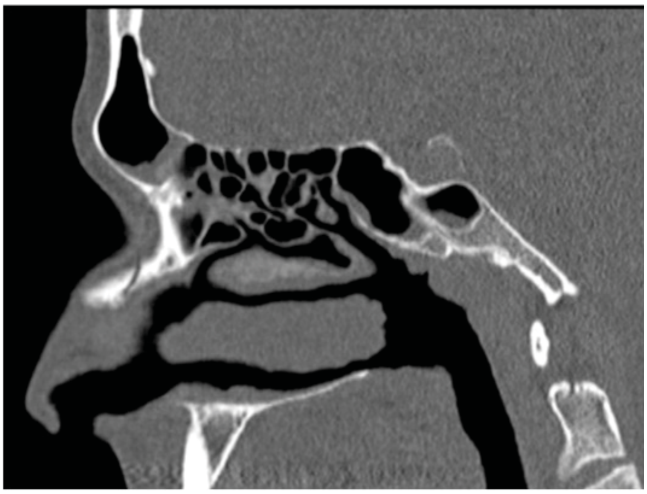

Figure 25. It is virtually impossible to give appropriate names to the air-spaces and structures in this patient's ethmoidal complex, especially the frontal recess, if one does not have at least coronal CT scans as well as additional sagittal views.

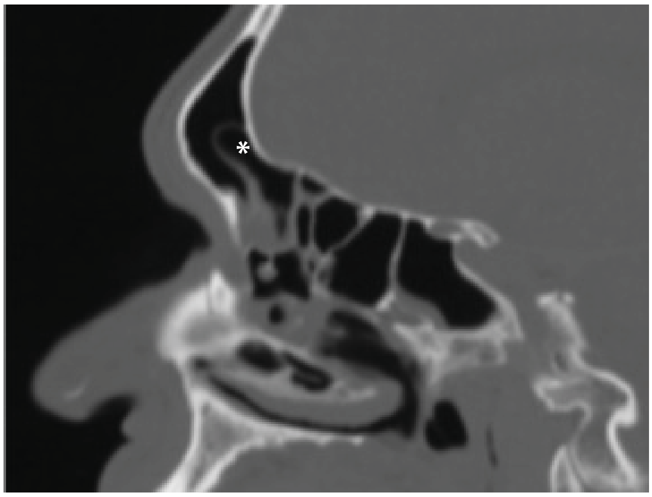

Figure 27. Posterior frontoethmoidal cell (*).

the ethmoidal bulla, opening into the middle meatus via the inferior semilunar hiatus. The uncinate process forms the medial wall, and it attaches to the lateral nasal wall anteriorly at an acute angle where the infundibulum ends blindly. The superior configuration of the infundibulum depends on the superior attachment of the uncinate process. If the uncinate process attaches to the skull base (Figure 21) or the middle turbinate (Figure 22), the infundibulum will be continuous with the frontal recess superiorly. If the uncinate process attaches to the lamina papyracea (Figure 21), the infundibulum will end blindly in the terminal recess (see below). The maxillary sinus opens into the ethmoidal infundibulum, usually inferiorly into the third quarter of the infundibulum [9].

Terminal recess [9.6.1]: the terminal recess (recessus terminalis) of the ethmoidal infundibulum, is formed if the superior attachment of the uncinate process is onto the lamina papyracea or the base of an agger nasi cell, thus forming a blind end to the ethmoidal infundibulum superiorly (Figure 2A-C).

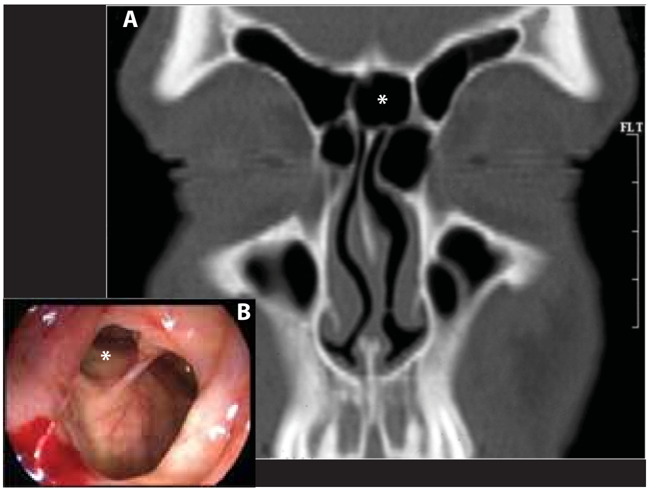

Figure 28. A) and B) Medial frontoethmoidal cell (*). (Postoperative view in B).

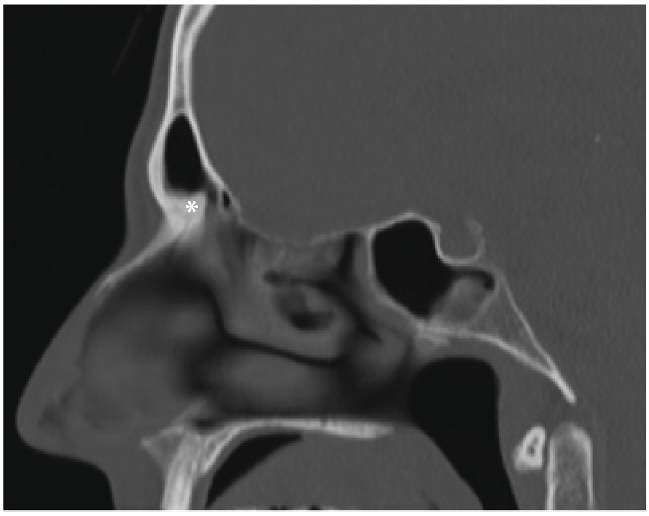

Figure 29. Nasal beak (*).

Figure 30. The frontal sinuses vary considerably on an inter- and intra-individual basis in pneumatisation (*=aplasia), size, shape, position of the intersinus septum, and the presence of other septations and cells.

Frontal recess [9.7]: this term has been defined in various ways over many decades and remains disputed, but is generally accepted to be the most anterosuperior part of the ethmoid, inferior to the frontal sinus opening (defined below). The term is often used synonymously with the 'frontal sinus drainage pathway', but the drainage of the frontal sinus through the frontal recess is complex, altered by the configuration of air cells within it and the differing attachments of the uncinate process [(44)] (Figure 21-23). The terms 'frontal recess' and 'frontal sinus drainage pathway' usually refer to two separate entities. The opening of the frontal sinus is best defined in sagittal section on CT; here the contours of the frontal sinus and frontal recess have been described as forming an hourglass, the narrowest part of which is taken as the frontal sinus opening [(19)] (Figure 24).
The frontal recess is delimited posteriorly by the anterior wall of the ethmoidal bulla (if this reaches the skull base), anteroinferiorly by the agger nasi, laterally by the lamina papyracea and inferiorly by the terminal recess of the ethmoidal infundibulum, if present. If the uncinate process attaches to the skull base or turns medially, the frontal recess opens directly into the ethmoidal infundibulum.
The use of the term 'ostium' in relation to the opening of the frontal sinus is incorrect, as it implies a two-dimensional structure [10.6]. The term 'nasofrontal' or 'frontonasal duct' has been abandoned as the drainage pathway of the frontal sinus is not a true duct [9.7.3,9.7.6].

Surgical note: the frontal recess is best studied in all three planes on CT, but especially the sagittal views. On endoscopic examination, the access to the frontal sinus is medial to the attachment of the uncinate process in the majority of cases.

Pneumatised structures encroaching on the frontal recess can be seen to extend from the agger nasi, ethmoidal bulla or the terminal recess of the ethmoidal infundibulum (Figure 25). If these cells do not extend into the frontal sinus they are called 'anterior ethmoidal' cells; if they do enter the frontal sinus they should be termed 'frontoethmoidal' cells.

Frontoethmoidal cells [10.3]: much debate took place regarding the classification of these cells [(45,46)]. Our suggestion is to classify them as anterior (Figure 26) or posterior (Figure 27), and medial (Figure 28) or lateral, with respect to the frontal recess/inner walls of the frontal sinus. An intersinus septal cell is therefore a medial frontoethmoidal cell. This classification replaces the term 'bulla frontalis' [(28,47)].

Supraorbital recess [9.5.5]: a lateral extension of the suprabullar recess (see above), or another aerated part of the ethmoidal roof, over the orbit.

Discussion. This is thought by some to be a separate cleft or cell [(48)].

Surgical note: when using CT to identify and understand this area, use the coronal plane to identify the relationship of the frontal sinus, recess and middle meatus, and cross correlate with the images in the sagittal plane to delineate the relationships of the frontal sinus, frontal beak, agger nasi and ethmoidal bulla.

Surgical note: to identify the frontal sinus drainage pathway, the cells within the frontal recess must be identified. The most important thing is appreciating and understanding the complexity of the anatomy rather than the classification systems used!

Frontal beak [10.7]: the thick bone underlying the nasion comprising the nasal process of the frontal bone medially, the frontal process of the maxilla laterally [(49)] with a potential contribution from the nasal bone infero-anteriorly (Figure 29).

Frontal sinus [10]: The frontal bone forms the roof of the orbit and completes the roof of the ethmoidal complex which leaves impressions on the inferior aspect of the bone. The bone is pneumatised by the frontal sinuses which vary considerably on an inter- and intra-individual basis in size, shape, position of the intersinus septum, and the presence of other septations and cells (Figure 30). The blood supply to the frontal sinus comes from the supraorbital and anterior ethmoidal arteries.
Surgical note: diploic valveless veins from the frontal sinus drain into the sagittal and sphenoparietal venous sinuses, facilitating intracranial spread of infection from an acute frontal bacterial sinusitis.

Olfactory cleft [4]: the olfactory cleft is that part of the superior nasal cavity where the majority of the olfactory epithelium is present. This encompasses a variable area but is bounded superiorly by the cribriform plate, medially by the superior nasal septum, laterally by the superior part of the medial aspect of the middle turbinate and superior turbinate.

Olfactory fossa [17.1]: this contains the olfactory bulbs and tracts and is bounded inferiorly by the cribriform plate, laterally by the lateral lamella of the cribriform plate and medially by the crista galli (Figure 31). Differences in the depths of the olfactory fossa between right and left side are present in 11% of men compared to 2% of women [(50)].

Cribriform plate [17.2]: The cribriform plate of the ethmoid bone is that part of the anterior skull base through which the olfactory fibres pass from the olfactory cleft into the olfactory fossa. It is bordered anteriorly by the inferior aspect of the nasal and frontal bones, posteriorly by the anterior process of the sp-

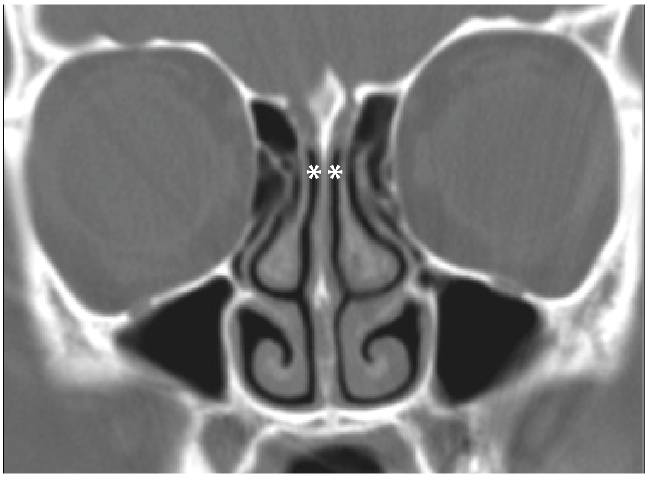

Figure 31. The olfactory cleft (*) encompasses a variable area but is bounded superiorly by the cribriform plate, medially by the superior nasal septum, laterally by the superior part of the medial aspect of the middle turbinate and superior turbinate.

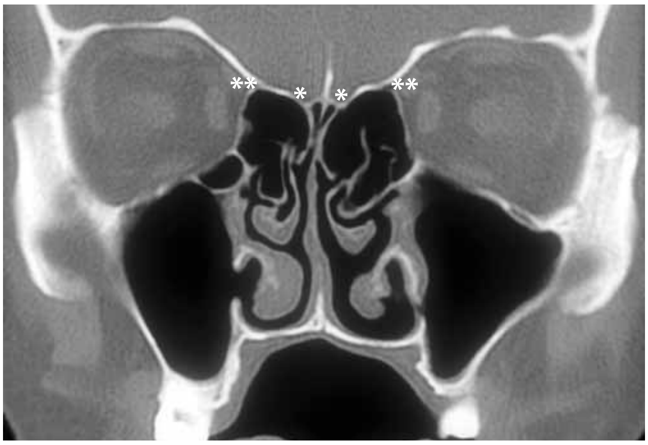

Figure 32. The lateral lamella (*) of the cribriform plate is one of the thinnest parts of the skull base. In this case, the lateral lamella is very short rendering the olfactory fossa almost flat (1-3mm) (30%). Anterior ethmoidal artery (**). Note previous inferior meatal antrostomies.

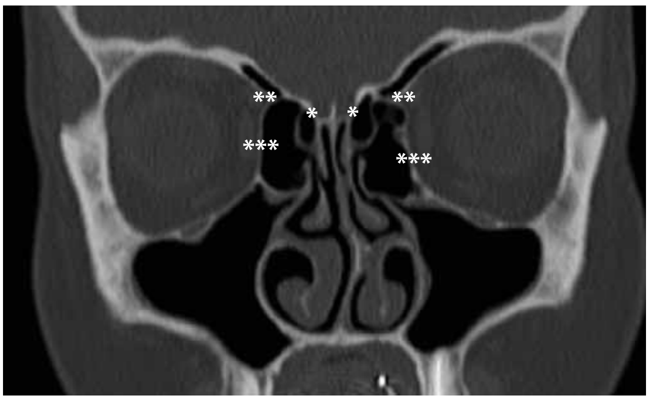

Figure 33. In this case, the lateral lamella (*) is longer, creating a moderately deep fossa (4-7mm)(49%). Anterior ethmoidal artery (**). Lamina papyracea (***).

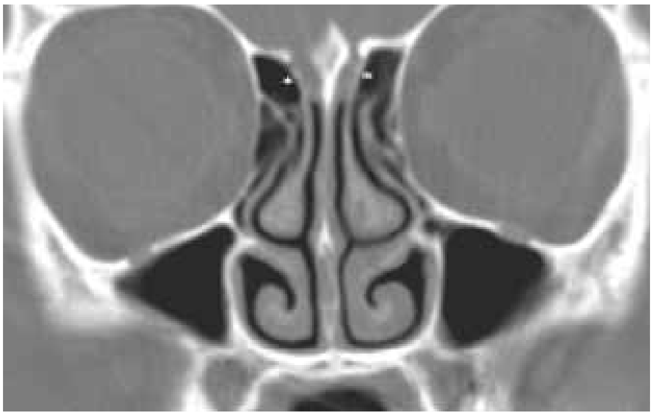

Figure 34. The lateral lamella (*) of the cribriform plate is one of the thinnest parts of the skull base. In this case, it is very long producing a deep olfactory fossa (21%).

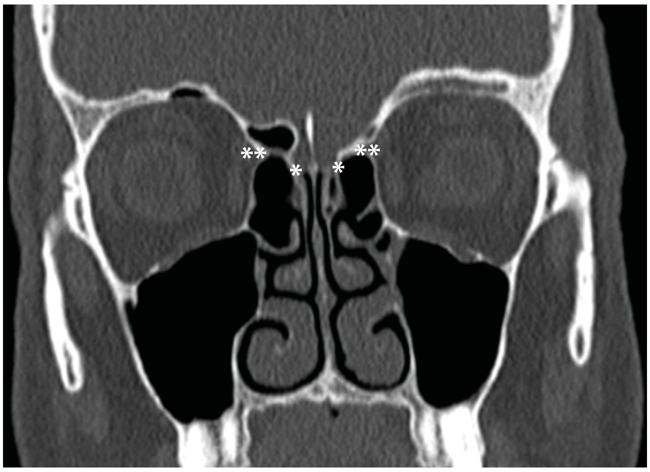

Figure 35. The lateral lamella (*) has a variable degree of angulation towards the ethmoidal roof and there may be asymmetry of the height of the roof due to variation in the height of the lateral lamella, estimated to occur in 10-30% of a Caucasian population. Anterior ethmoidal artery (**).

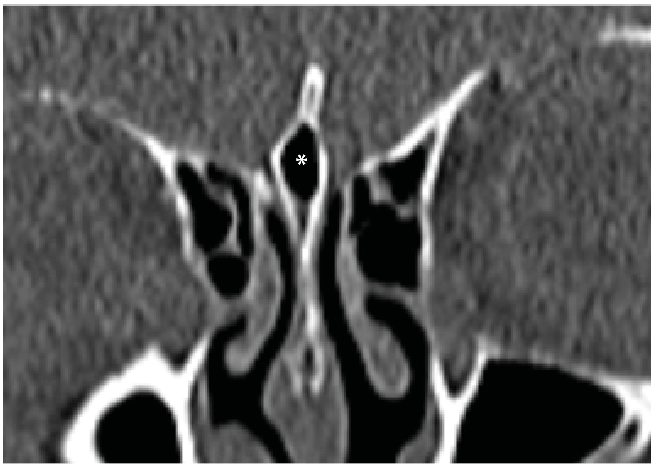

Figure 36. The crista galli (*) (pneumatised variant) sits anteriorly in the midline above the cribriform plates.

henoid bone, medially by the nasal septum and laterally by the superior and middle turbinates. The lateral lamella of the plate is one of the thinnest parts of the skull base [17.2.2]. The height of the lamella and thereby the depth of the olfactory fossa, varies considerably and has been classified accordingly by Keros into 3 different types [51]: (Figure 32-34).

1. The lateral lamella is very short rendering the olfactory fossa almost flat (1-3mm)(30%) (Figure 32),
2. The lateral lamella is longer, creating a moderately deep fossa (4-7mm)(49%) (Figure 33),
3. The lateral lamella is very long (8-16mm) producing a very deep olfactory fossa (21%)[52,53] (Figure 34).

There may be some ethnic variation in the height of the lateral lamella e.g. more shallow olfactory fossae have been described in a Malaysian population [54]. The height of the lateral lamella usually decreases from anterior to posterior. The lateral lamella has a variable degree of angulation towards the ethmoidal roof. There may be asymmetry of the height of the roof due to variation in the height of the lateral lamella, estimated to occur in 10-30% of a Caucasian population [55-57] (Figure 35).

Surgical note: this area is probably at greatest risk of injury and subsequent CSF leak by surgical instruments, due to the variation of anatomy and thinness of the bone.

Crista galli [17.4]: the crista galli sits anteriorly in the midline above the cribriform plates. The falx cerebri attaches to its thin and slightly curved posterior border, whereas its shorter thicker anterior border is joined to the frontal bone by 2 small alae, completing the margins of the foramen caecum. The crista galli is pneumatised in 13% of the patients, all from either the left or right frontal sinuses [28] (Figure 36).

Ethmoidal roof [17.3]: the orbital plate of the frontal bone, which provides the majority of the roof of the ethmoid complex and bearing the impression of the individual ethmoid cells or clefts on its inferior surface. The ethmoidal roof is completed medially by the lateral lamella of the cribriform plate.

Anterior ethmoidal artery [7.4]: the anterior ethmoidal artery is a branch of the ophthalmic artery, passing between the superior oblique and medial rectus muscles, through the anterior ethmoidal foramen into the anterior ethmoidal complex. It crosses the anterior ethmoidal complex either at the level of the roof or as much as 5mm below this level in a mucous membrane mesentery or a thin bony lamella (Figure 17, 32-35). This may be dehiscent inferiorly in 40% or more [58]. The artery traverses the roof, often taking an oblique route from posterolateral to anteromedial; the most common site to find the artery is the suprabullar recess (85%) and not directly behind the frontal sinus opening as is often suggested. The mean distance from the posterior aspect of the frontal sinus opening to the artery has been shown to be 11mm (range 6-15mm) [59]. Variations depend on the degree of pneumatisation in this area; in the presence of a supraorbital recess, the artery is very likely to be exposed in its posterior margin. The artery then enters the anterior cranial fossa through either the lateral lamella of the cribriform plate or where this attaches to the frontal bone. Once it enters the intracranial compartment, it turns anteriorly, forming a groove in the lateral lamella, the anterior ethmoidal artery sulcus, to enter the nose through the cribriform plate [60]. The length of the sulcus can vary from 3 to 16mm. The anterior ethmoidal artery has nasal branches, which supply the anterior superior part of the septum and the middle turbinate, and the anterior meningeal artery that enters intracranially.

Surgical note: due to the variation in the location of the anterior ethmoidal artery, it is not safe to use it as a landmark for endoscopic interventions, especially in locating the frontal sinus opening.

Surgical note: CT landmarks for identifying the location of the anterior ethmoidal artery:

1. *The sulcus of the anterior ethmoidal artery: the only well defined corticated break in the anterior lamina papyracea (Figure 32-35).*
2. *The plane at the posterior globe and the last 0.5 cm of the crista galli*
3. *The coronal plane where the superior oblique and the medial rectus muscle are at their largest diameters*

Surgical note: care must be exercised when operating in the vicinity of the anterior ethmoidal artery especially if using powered instrumentation as if damaged, the artery may retract into the orbit producing an intra-orbital haematoma.

Surgical note: in severe epistaxis, when the sphenopalatine artery has already been ligated, the anterior nasal branch of the anterior ethmoidal artery should be considered as an additional source of bleeding.

Surgical note: spontaneous CSF leaks are often located near the point where the anterior ethmoid artery traverses the cribriform plate.

Posterior ethmoidal artery [7.6]: the posterior ethmoidal artery passes through the posterior ethmoidal canal into the anterior cranial fossa and divides into lateral and medial branches supplying the superior part of the posterior septum and lateral nasal wall. It usually crosses within the ethmoidal roof, in front of the most superior aspect of the anterior wall of the sphenoid sinus, and is therefore less vulnerable during surgery as it is almost never found below the level of the skull base. In 25-50% of the cases the corticated sulcus of this artery is identifiable on the coronal CT examination (Figure 37).

Variations in both the course and numbers of ethmoidal arteries have been described in the literature. Either artery can be absent on one or both sides (14% and 2% respectively) and may be multiple in up to 45% of individuals [15, 61-64].

The mean distances in millimetres between the anterior ethmoidal artery, the posterior ethmoidal artery and the optic canal have been described as 24, 12 and 6 respectively [65] or more recently as

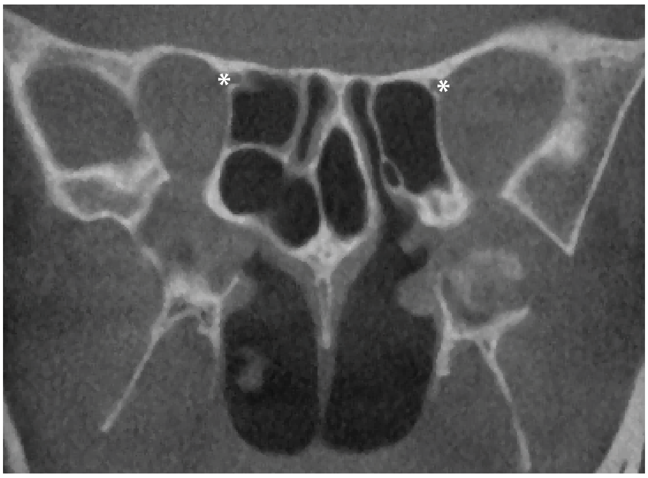

Figure 37. The posterior ethmoidal artery usually crosses within the ethmoidal roof, in front of the most superior aspect of the anterior wall of the sphenoid sinus. In 25-50%, the corticated sulcus of this artery (*) is identifiable on the coronal CT examination.

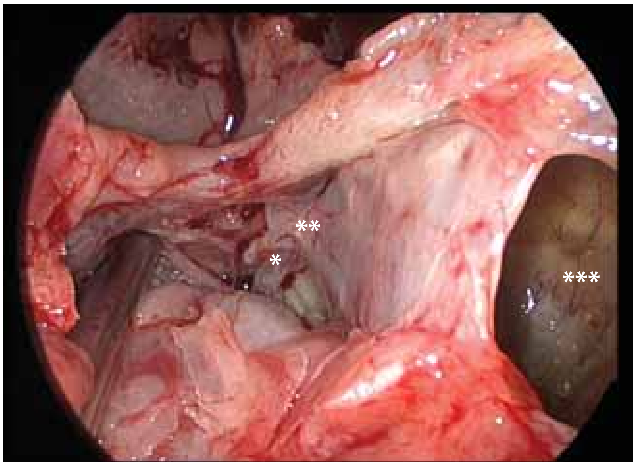

Figure 38. The sphenopalatine foramen (* , with artery emerging from it) is found on the lateral wall of the nose, bounded above by the body of the sphenoid, in front by the orbital process of the palatine bone, behind by the sphenoidal process and below by the upper border of the perpendicular plate of the palatine bone. The anterior margin of the foramen is related to a projection of the palatine bone, referred to in surgical anatomy as the 'ethmoidal crest' (**). Maxillary sinus (***).

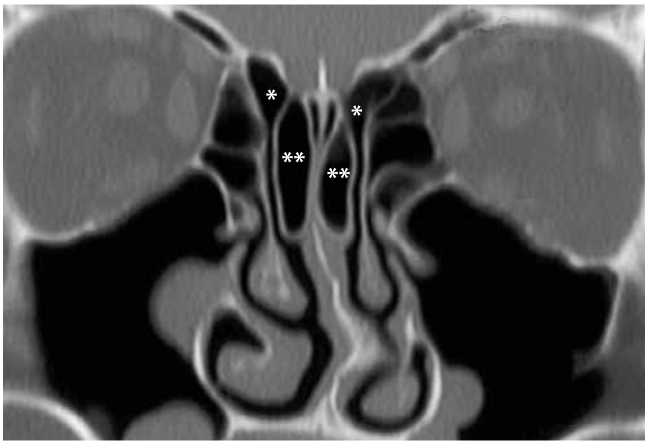

Figure 39. Superior meatus (*) and superior turbinate, which is pneumatised (**).

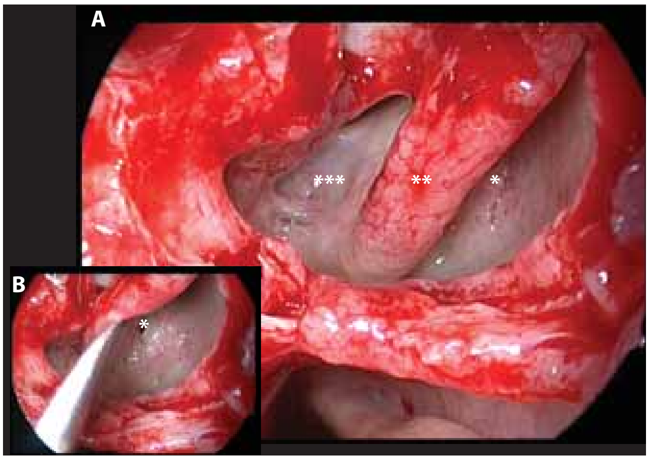

Figure 40. A) Sphenoethmoidal recess (*), superior turbinate (**) and posterior ethmoid (***). B) Sphenoid sinus ostium (*). Right side.

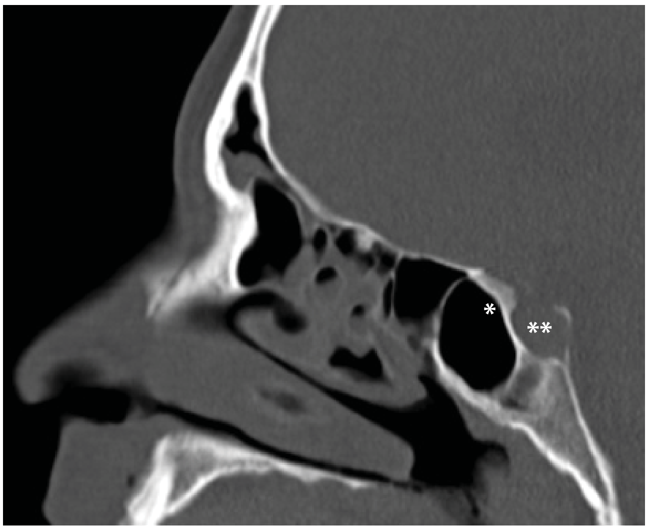

Figure 41. Sphenoid sinus: A pre-sellar sinus extends as far as the anterior bony wall (*) of the pituitary fossa (**).

23, 10 and 4 (62). However, the ranges for each distance are wide with considerable overlap.

Surgical note: when brisk bleeding is encountered at the level of the posterior ethmoidal roof, it should be assumed that there is a breach in the skull base until proven otherwise by close inspection.

Sphenopalatine foramen [3]: this is found on the lateral wall of the nose, bounded above by the body of the sphenoid, in front by the orbital process of the palatine bone, behind by the sphenoidal process and below by the upper border of the perpendicular plate of the palatine bone. The anterior margin of the foramen is related to a projection of the palatine bone, referred to in surgical anatomy as the 'ethmoidal crest' (Figure 38), to which the root or posteroinferior base of the middle turbinate attaches but it is variable in its exact position and size (66,67). In the majority of cases the sphenopalatine foramen opens into the middle and superior meati. The foramen transmits the sphenopalatine artery(ies), veins and nasopalatine nerve. The sphenopalatine artery is the terminal branch of the maxillary artery. It usually divides beyond the foramen into two main branches: posterior lateral nasal and posterior septal (68). However, in 39% it was found to divide before the foramen, presenting 2 or even 3 trunks (68,69). In other studies between 1 and 10 branches of the sphenopalatine artery have been described with a median of 3 or 4 branches (70). These may pass above and/or below the ethmoidal crest and the majority (>97%) of individuals had 2 or more branches medial to the crest, 67% had 3 or more branches and 35% had 4 or more branches. An accessory foramen has also been observed in 5-13% of individuals, usually inferior to and smaller than the sphenopalatine foramen. The nasopalatine artery, a branch of the maxillary artery, leaves the pterygopalatine fossa through a canal inside the palatine bone and runs parallel to the nasopalatine nerve. It ends in the incisive canal where it anastomoses with the greater palatine artery.

Surgical note: when attempting to control bleeding from the sphenopalatine artery, the foramen may be approached beneath the horizontal attachment of the middle turbinate.

Surgical note: a wide dissection of the lateral wall of the nose posterior to the posterior wall of the maxillary sinus will assist identification of the variable number of arterial branches and foramina.

Superior meatus [1.9]: the area of the lateral wall of the nose covered medially by the superior turbinate (Figure 39), receiving drainage from the posterior ethmoid. The superior turbinate is an integral part of the ethmoid, lying above the middle turbinate and bearing olfactory epithelium on its medial surface. There may also be a supreme turbinate.

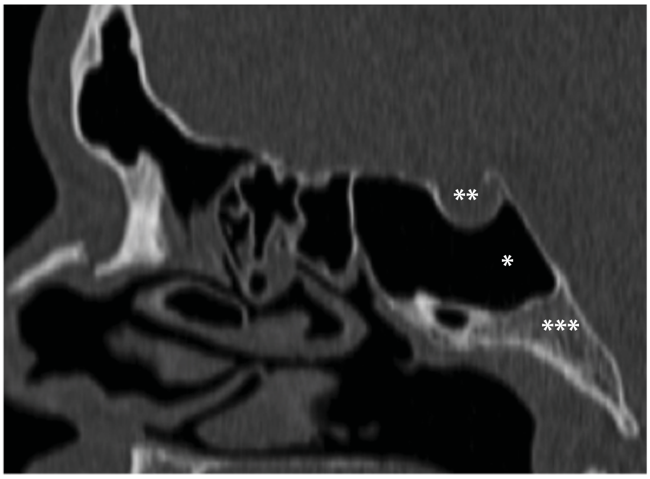

Figure 42. Sphenoid sinus (*) that extends posterior to the pituitary fossa (**). Clivus (***).

Sphenoethmoidal recess [2]: the sphenoethmoidal recess lies in front of the anterior wall of the sphenoid and medial to the superior turbinate of the ethmoid (Figure 40A). The natural ostium of the sphenoid sinus opens into it at the level of the superior turbinate in most (Figure 40B), but not all, cases (71)[12.3]. The ostium is located medial to the posterior end of the superior turbinate in 83% and laterally in 17%. The bony opening is larger than the ostium seen in life due to the overlying mucosa (72).

Surgical note: the sphenoid sinus ostium may be medial to the superior turbinate and easy to identify, or lateral and more difficult to find, depending on the lateral extent of the sphenoethmoidal recess (73). It is approximately located at the level of the inferior one third of the superior turbinate and along a horizontal plane through the floor of the orbit.

Sphenoid sinus [12]: The sphenoid bone divides the anterior and middle cranial fossa and is composed of a body, two wings (greater and lesser) and two plates (lateral and medial pterygoid). The body is pneumatised by two sphenoid sinuses, often asymmetric both in size and the position of the intersinus septum (9). In addition, septations are frequently encountered which may attach to the supero-lateral wall in the region of the internal carotid artery and/or optic nerve tubercle. Depending on the degree of pneumatisation, the form of the sinus has been

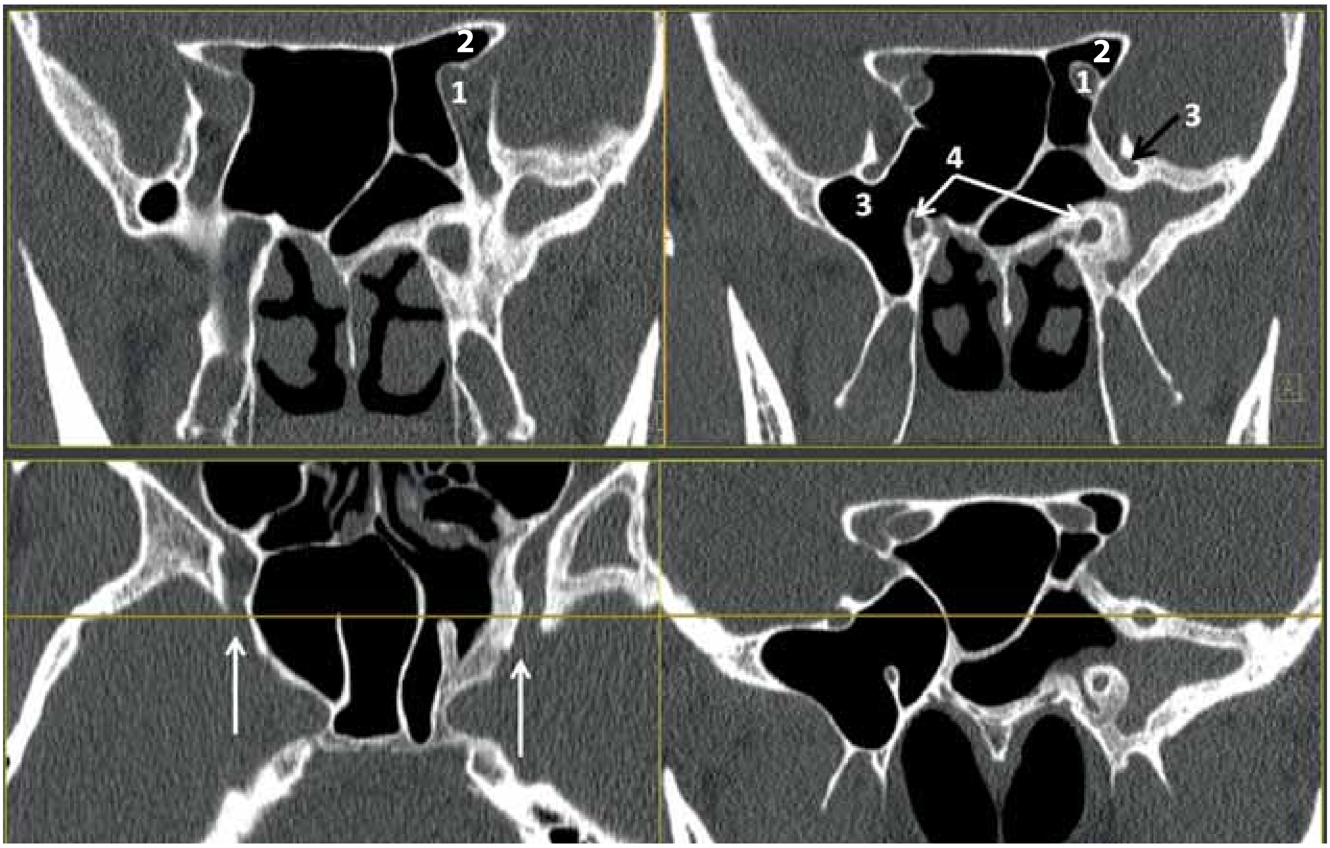

Figure 43. Complex sphenoid anatomy with extensive pneumatisation. Clockwise: 1 = (bulge of) optic nerve, 2 = pneumatised clinoid process. Please note, that in contrast to an optico-carotid recess, here pneumatisation towards the anterior clinoid goes superior to the optic nerve, 3 = foramen rotundum, 4 = Pterygoid (Vidian) nerve. When the axial CT level is placed through the foramen rotundum bilaterally, the corresponding canals can be seen on either side (arrows). Note "crab eye" appearance of (Vidian) nerve in pterygoid canal. There is bone thickening following long standing chronic sphenoiditis on the left side.

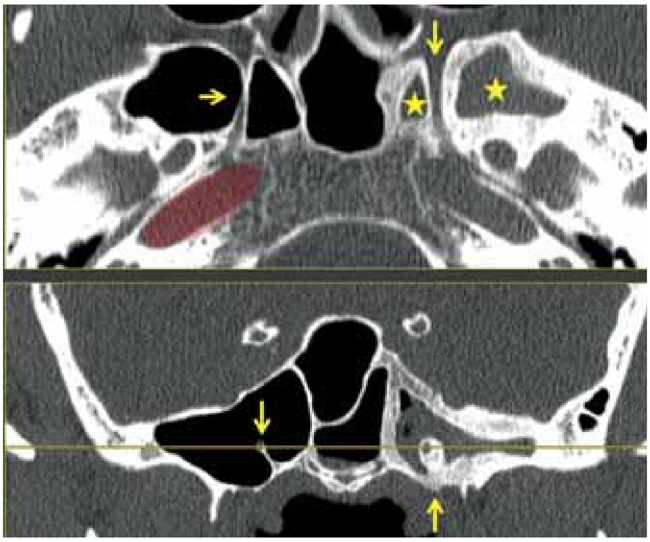

Figure 44. Axial cut through the level of the pterygoid canals with nerve and artery (arrows). Note the relationship to the horizontal carotid (shaded red on the right), just where this curves up into its vertical para-clival segment. Asteriks: Opacified lateral recess of sphenoid on the left.

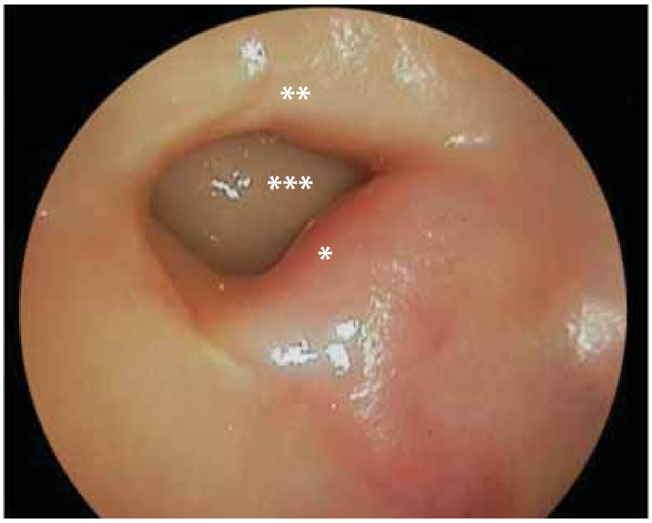

Figure 45. View into right sphenoid sinus. Internal carotid artery (*), optic nerve (**) and optico-carotid recess (***).

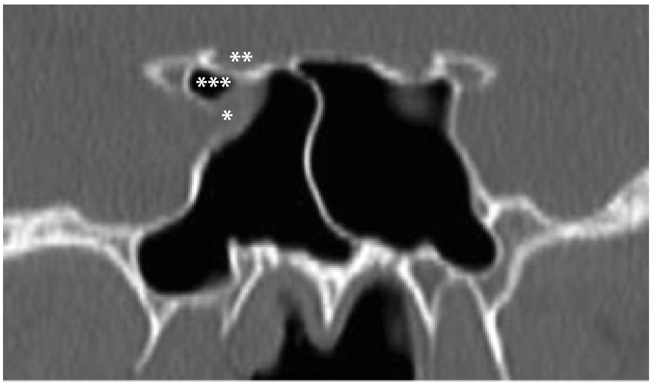

Figure 46. Coronal CT cut through sphenoid sinuses. Internal carotid artery (*), optic nerve (**) and optico-carotid recess (***).

classified by various authors:

- Agenesis of the sinus is said to occur in 0.7% of individuals [24,74,75].
- A small rudimentary conchal sinus confined to the anterior part of the sphenoid is found in <5%
- A pre-sellar sinus extends as far as the anterior bony wall of the pituitary fossa in 11-28% (Figure 41).
- A sellar sinus that extends posterior to the pituitary fossa is found in the rest (Figure 42).

A more recent classification of the sellar sphenoid sinus has been described based on the direction of pneumatisation: sphenoid body, lateral clival (Figure 43), lesser wing, anterior into the rostrum and combined [76] (Figure 49).

Surgical note: the recesses and prominences produced by the patterns of pneumatisation of the sphenoid offer routes of endoscopic access.

The anterior wall of the sphenoid is often thin and is crossed inferiorly by the posterior nasal artery (septal branch of the sphenopalatine artery). The mean distance between the sphenoid ostium and the supero-lateral angle of the posterior choana is 21 ± 6mm (range 10-34mm) [77]. The lateral wall can be elevated over the optic nerve, maxillary nerve (V2) and the internal carotid artery; inferiorly the floor may be indented by the (Vidian) nerve of the pterygoid canal. The degree of pneumatisation will affect the prominence of these structures and may extend to the clivus, clinoid processes, lesser wing and root of the pterygoid process, with close proximity to the middle cranial fossa and infratemporal fossa when very pneumatized.
The blood supply to the sinus comes mainly from the posterior ethmoidal arteries.

Surgical note: the nasoseptal muco-periosteal flap is pedicled on the posterior nasal artery (septal branch of the sphenopalatine artery) [78]. The artery may be damaged by inferior enlargement of the sphenoid ostium.

Optico-carotid recess (OCR) [12.9.3]: The optico-carotid recess lies on the posterolateral wall of the sphenoid sinus, between the optic nerve above and the internal carotid artery below (Figure 45). The recess is of variable depth depending on the degree of pneumatisation of the optic strut and which may extend all the way into the anterior clinoid process [5]. This may be regarded as the lateral OCR due to the recent recognition of a medial OCR, which is a key landmark in the ventral skull base [79]. The bone overlying the internal carotid artery is said to be dehiscent (Figure 46) in up to 25% of the population but these figures were based on imaging and anatomical dissections [30,80]. Bone resorption also occurs with age and thinning of the bone in these regions is found in 80% of people >85 years old.

Optic nerve canal [12.9.1] : This runs from its orbital opening (apertura orbitalis canalis optici) in the superomedial corner of the orbital apex at the junction of the medial wall and roof in a slightly medial direction towards its intracranial opening (apertura intracranialis canalis nervi optici). Its length varies from 5-11mm [81]. It transmits the optic nerve, ophthalmic artery and ocular sympathetics [11.6]. Although various classifications have been suggested, the relationship of the optic nerve to the sphenoid and posterior ethmoid can be thought of as either not impinging on the sinus or impinging to a variable degree dependant on the degree of pneumatisation of these airspaces [82]. The bony canal walls in these areas may be extremely thin and dehiscences have been described [15,83,84]. In a study of Chinese individuals, the optic nerve was reported to have a close relationship with the posterior ethmoid complex in 65% [85], much higher than that seen in Caucasians.
In ~ 80% of cases of anterior clinoid process pneumatisation, the optic nerve will be in the superolateral corner of the sphenoid sinus with an associated dehiscent wall [82]. When there is significant pneumatisation, the optic nerve canal may be completely exposed within the cavity for several millimetres of its course.

Optic nerve tubercle [12.9]: The optic nerve tubercle is the bulge of thicker bone overlying the medial aspect of the optic canal, at the junction of the optic canal and the orbital apex (Figure 47). It may be found within the posterior ethmoid or sphenoid sinus, or at the junction between the two, depending on the degree of pneumatisation of the adjacent cells [5].

Optic strut: this was first defined as the pillar of bone which connects the body of the sphenoid to the medial inferior portion of the posterior projection of the lesser wing of the sphenoid, ie the medial inferior aspect of the anterior clinoid process (86). Thus it separates the optic canal from the internal carotid artery. It has recently been classified according to its position relative to the pre-chiasmatic sulcus into presulcal, sulcal, postsulcal and asymmetric [87]. Of these, sulcal and postsulcal are the commonest.

Surgical note: the ophthalmic artery usually runs inferolateral to the nerve in the optic canal but in 15% of cases it runs medial to the nerve, in the inferomedial quadrant, placing it at risk during optic nerve decompression [15]. Consequently it is recommended that incision of the optic nerve dural sheath be undertaken in the superomedial quadrant if required – it should be noted that such an incision will enter the CSF space.

Canals associated with the sphenoid:
A number of canals are associated with the basisphenoid (the floor of the sphenoid sinus/clivus): from lateral to medial and in order of importance these are:

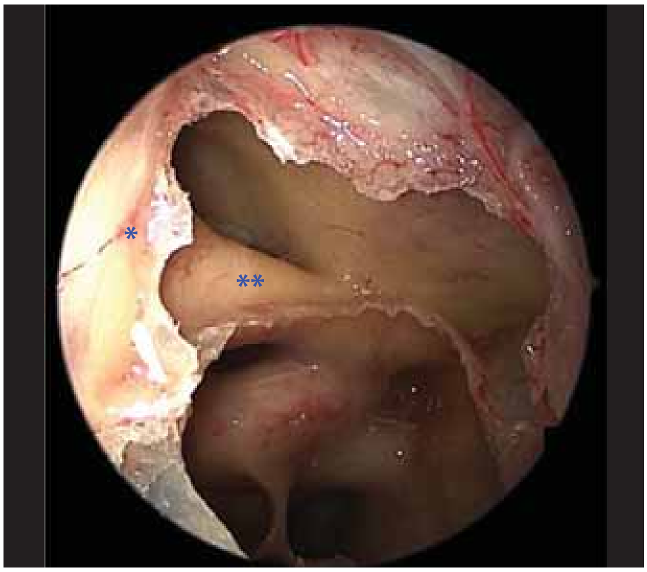

Figure 47. The optic nerve tubercle (*) is the bulge of thicker bone overlying the medial aspect of the optic canal (**), at the junction of the optic canal and the orbital apex.

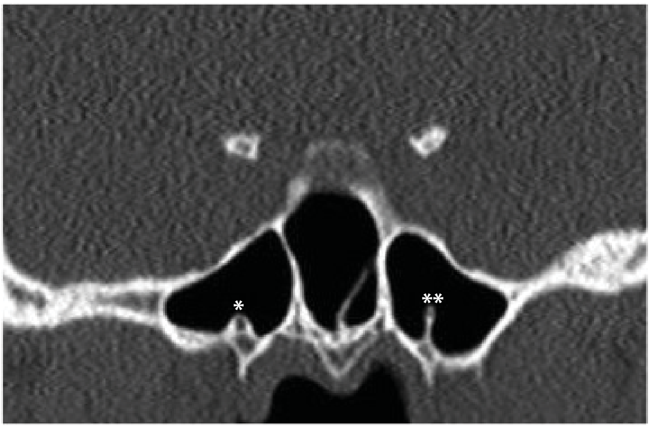

Figure 48. The pterygoid canal (*) runs anteriorly from the foramen lacerum through the sphenoid to open into the pterygopalatine fossa. The nerve may be encased in the basisphenoid bone (*), partially protruding into the sinus floor or occasionally exposed within the sinus cavity and connected to the floor by a bony mesentery (**).

1. **Pterygoid canal (formerly Vidian)** [12.6]: this runs anteriorly from the foramen lacerum through the sphenoid to open into the pterygopalatine fossa. It transmits the nerve of the pterygoid canal composed of the great petrosal nerve and the deep petrosal nerve together with autonomic fibres associated with the carotid artery, and its associated artery [88]. Its position relative to the sphenoid sinus is dependent on the pneumatisation of the sinus so that the

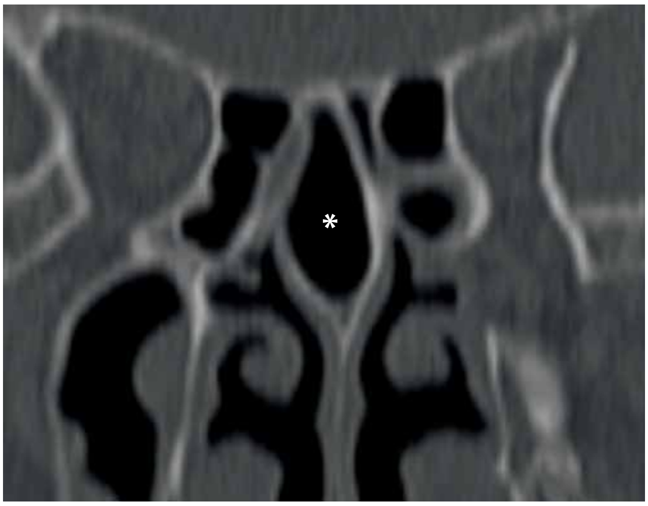

Figure 49. Sometimes sphenoid sinus pneumatisation can extend significantly into the posterior parts of the nasal septum, i.e. the vomer (*).

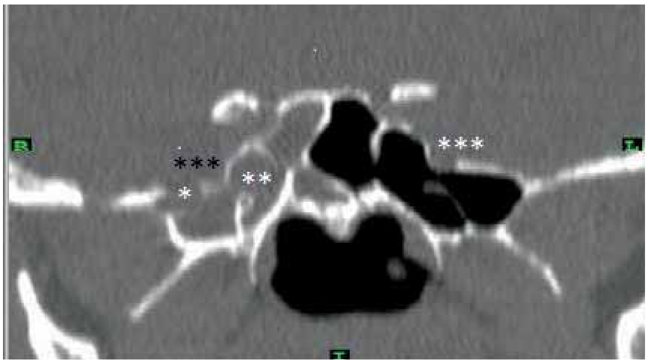

Figure 50. Lateral craniopharyngeal canal (formerly Sternberg's canal) is a congenital bony defect (*) in the lateral wall of the sphenoid sinus (**). This canal is located in the posterior part of the lateral sphenoid sinus wall, lateral to the maxillary nerve (V2) (***). Large meningo-encephalocele protruding through defect into right sphenoid sinus.

nerve may be encased in the basisphenoid bone, partially protruding into the sinus floor or occasionally exposed within the sinus cavity and connected to the floor by a bony stalk [89] (Figure 48).

2. **Palatovaginal canal** [15]: bony canal containing the pharyngeal branch of the maxillary nerve and the pharyngeal branches of the maxillary artery [90].
3. **Vomerovaginal canal** [14]: Small, inconsistent canal that may lie medial to the palatovaginal canal, and lead into the anterior end of the palatovaginal canal. When present, it may contain a branch of the sphenopalatine artery.

Surgical note: the pterygoid artery has an important anastomosis between the internal carotid artery and a branch of the sphenopalatine artery and therefore to the external carotid system. The pterygoid canal is an important marker for the horizontal part of the carotid artery.

Surgical note: 'recurrence' of juvenile angiofibroma is often related to persistence of angiofibroma in the body of the sphenoid especially in the region of the pterygoid canal which has not been explored surgically [91,92].

Lateral craniopharyngeal canal (formerly Sternberg's canal) [12.9.4]: a congenital bony defect in the lateral wall of the sphenoid sinus (Figure 50) has been described which may result from failure of fusion of the greater wing of the sphenoid and the presphenoid [25]. This canal is located in the posterior part of the lateral sphenoid sinus wall, lateral to the maxillary nerve (V2). This canal is said to be present in young children but only 4% of adults and is associated with extensive sphenoidal pneumatisation.

Surgical note: the canal has been suggested to be a site of weakness. A combination of this and (maybe more important) a raised intracranial pressure may lead to the extrusion of intracranial contents and/or 'spontaneous' cerebrospinal fluid rhinorrhoea [22, 26, 93, 94].

Clivus [19.1]: There was a discussion as to whether the clivus includes both the basisphenoid and the basiocciput with these two regions forming the lower and middle thirds of the clivus [95] or is simply that part of the basioccipital bone up to the junction with the basisphenoid. The sphenoid pneumatises into it to a variable degree (Figure 42).

Discussion: Clivus anatomically denotes the basiocciput only; the border with the sphenoid is the synchondrosis spheno-occipitalis. As the latter in adults is hardly ever discernible, clivus (which translates as a "slope") has been used for both the (intracranial) slope from the dorsum sellae down to the foramen magnum as well as for the bone of various thickness in front of this, i.e. the basisphenoid.

Sella region and pituitary gland [12.4,12.5,18.1-3]: The sella region is part of the middle cranial fossa and comprises the sphenoidal plane, the pituitary fossa (sella turcica) and the pituitary gland as well as the cavernous sinuses lateral to the sella on both sides [96]. The sella's topographic relationship to the sphenoid sinus depends on the degree of pneumatisation of the sinus (Figure 41). The sphenoidal plane constitutes the anterior part of the sphenoid sinus roof, which then passes into the saddle shaped pituitary fossa further posteriorly, at the level of the sellar tubercle. Anterior to this, a groove in the bone, the prechiasmatic sulcus, can be found, in which the optic chiasm is located in the majority of cases [96]. The pituitary fossa forms the sphenoid sinus roof posterior to the sphenoidal plane. The posterior wall is the sellar dorsum (dorsum sellae), which is a part of the clivus. Laterally, the pituitary fossa is bordered by the

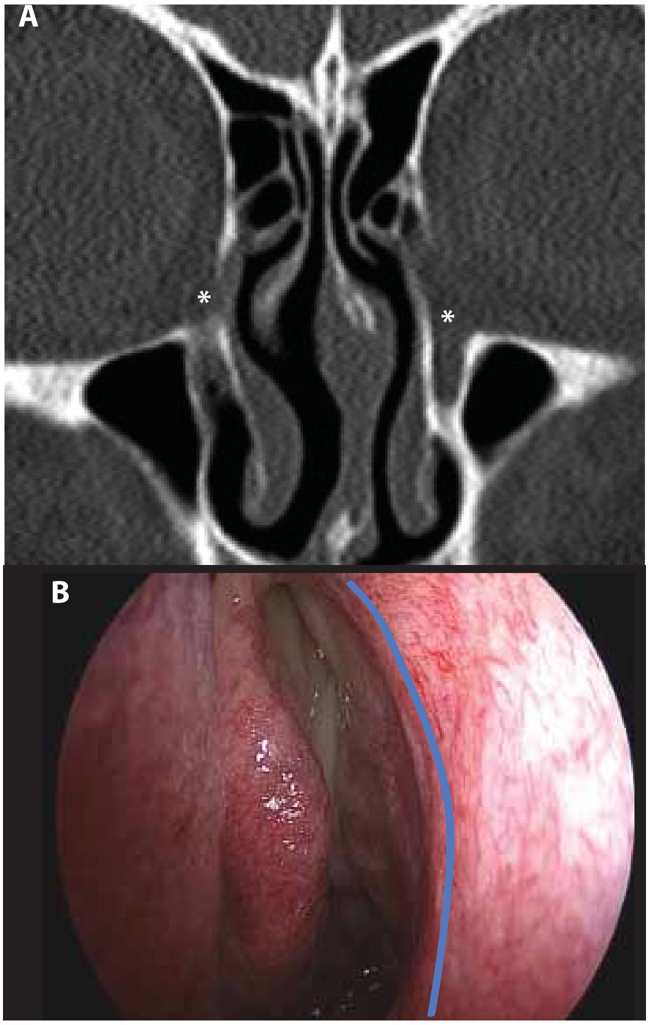

Figure 51. A) The nasolacrimal sac (*) lies within the lacrimal fossa of the medial orbital wall. B) In endoscopic dacryocystorhinostomy (DCR) surgery, identify the 'lacrimal bulge' (blue line) on the lateral nasal wall formed by the frontal process of the maxilla; the lacrimal sac/duct are lateral to this.

cavernous sinus, containing the internal carotid artery [97], which has various configurations (carotid siphon) in its course to the cerebral arterial circle (of Willis), together, with cranial nerve (CN) VI (abducens). CN III (oculomotor), IV (trochlear), V1 (ophthalmic) and V2 (maxillary) are not located in the free lumen but in the cavernous sinus wall. Of these, CN III is located most superiorly in the posterior aspect; anteriorly, on its way to the superior orbital fissure, CN IV crosses over CN III. The sphenoparietal sinus and ophthalmic vein open into the cavernous sinus, which drains via the superior and inferior petrosal sinuses [98].

Surgical note: both cavernous sinuses are interconnected by the superior and inferior intercavernous sinus (forming the 'circular sinus') which may be a source of bleeding during trans-sphenoidal pituitary surgery, when opening the sellar floor dura. This particularly occurs with microadenomas, which in contrast to macroadenomas, fail to compress the venous sinuses.

The pituitary gland consists of two phylogenetically and functionally different lobes, the anterior lobe (adenohypophysis) and the posterior lobe (neurohypophysis). The latter originates in the diencephalon whereas the anterior lobe stems from an ectodermal pouch (Rathke's pouch) in the roof of the pharynx, which ascends to the pituitary fossa via the medial craniopharyngeal canal. The posterior lobe is connected to the hypothalamus via the pituitary stalk (infundibulum). The anterior lobe is subdivided into the tuberal part and the intermediate part.
The pituitary gland is separated from the subarachnoid space by the sellar diaphragm that is part of the dura mater and stretches like a tent over the pituitary fossa from the sellar tubercle to the sellar dorsum. The diaphragm is penetrated by the pituitary stalk (infundibulum) that links the posterior pituitary lobe to the hypothalamus. The optic chiasm is located anterior to the pituitary stalk. The gland is suspended inside the pituitary fossa by areolar tissue bands (the 'pituitary ligaments') which attach to the medial cavernous sinus wall [99]. The pituitary gland is supplied by the superior and inferior hypophyseal arteries, which arise from the cavernous segment of the internal carotid artery. The blood flows in a circulation similar to the hepatic portal vein system and venous blood drains into the cavernous sinus. The anterior pituitary lobe produces adrenal gland stimulating hormones the posterior lobe (neuropituitary) anti-diuretic hormone and oxytocin are stored and released, after having been produced in the hypothalamus.

Pterygomaxillary fissure and pterygopalatine fossa: the pterygomaxillary fissure lies between the pterygopalatine fossa and the infratemporal fossa (Figure 49), and transmits the maxillary vessels. The pterygopalatine (or previously named pterygomaxillary) fossa is a pyramidal space below the orbital apex, wider superiorly and narrowing inferiorly. Its anterior boundary is the posterior wall of the maxilla, and posteriorly is the base of the pterygoid process and the greater wing of the sphenoid bone. Its roof is the body of the sphenoid bone with the orbital process of the palatine bone, and the floor comprises the pyramidal process of the palatine bone with the lateral pterygoid plate. Medially lies the perpendicular plate of the palatine bone; the sphenopalatine foramen connects the superomedial aspect of the fossa to the nasal cavity. The pterygopalatine fossa contains the maxillary branch of the trigeminal nerve, the nerve of the pterygoid canal, the sphenopalatine nerve and ganglion, the lesser and greater palatine nerves and the maxillary artery. Thus it communicates with the middle cranial fossa (through the foramen rotundum), orbit (through the inferior orbital fissure), infratemporal fossa, nasal and oral cavities.

Infratemporal fossa: this lies between the ramus of the mandible laterally and the superior constrictor muscles of the pharynx and the lateral pterygoid plate medially. The latter can

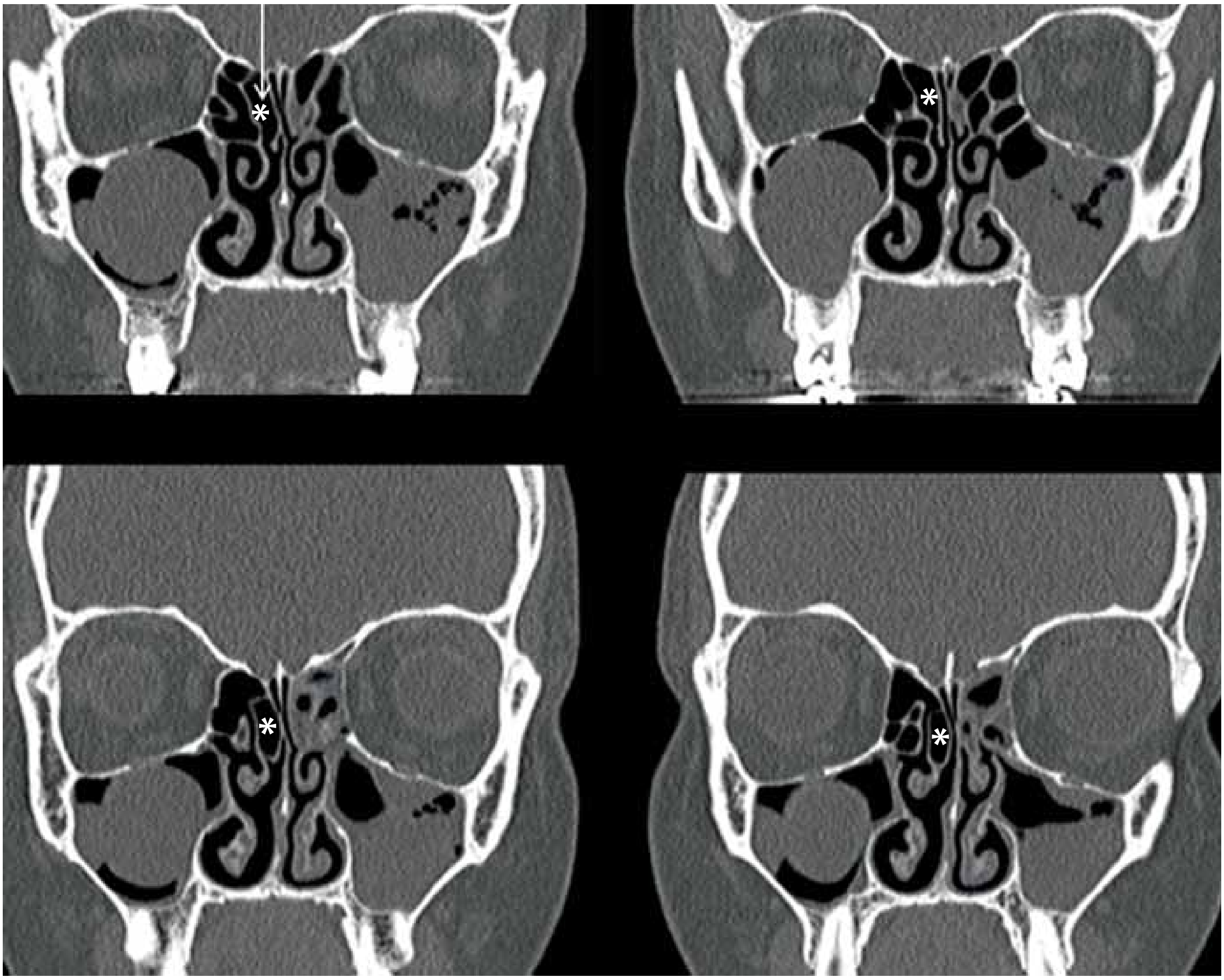

Figure 52. Here on the right side an interlamellar cell (*) (= anterior extension of the superior meatus) can be seen encroaching upon the vertical lamella of the middle turbinate, resulting in a concha bullosa of the latter.

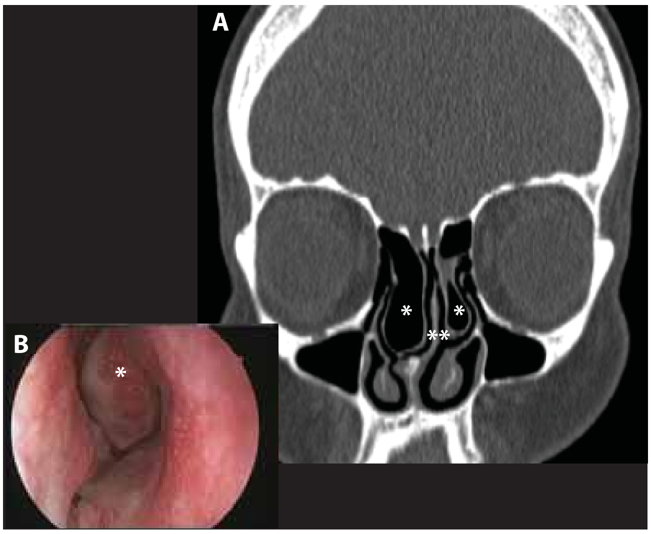

Figure 53. A) Concha bullosa both sides (*) and nasal septal deviation (**). B) Concha bullosa right (*).

therefore be seen as separating the pterygopalatine and infratemporal fossae. The anterior wall is the posterolateral aspect of the maxilla and the roof consists of the greater wing of the sphenoid bone; between the two lies the inferior orbital fissure. The posterior limit of the fossa is the carotid sheath and the styloid process of the temporal bone. The infratemporal fossa contains both the parapharyngeal and masticator spaces i.e. the pterygoid muscles, the maxillary artery and its branches, the pterygoid venous plexus and maxillary veins, and the mandibular nerve and its branches (Figure 49).

Nasolacrimal sac and duct: the lacrimal sac (Figure 51A) receives the common canaliculus of the lacrimal drainage system, formed from the union of the superior and inferior canaliculi. The sac lies within the lacrimal fossa of the medial orbital wall, an area approximately 12mm long, 4-8mm wide and 2mm deep [101]. The frontal process of the maxilla forms the anterior part of the fossa (anterior lacrimal crest) and the lacrimal bone forms the posterior part (with a posterior lacrimal crest). The sac lies between the anterior and posterior lacrimal crests to which the superficial and deep heads of the medial canthal ligament attach respectively. The lacrimal bone is very thin and has a close anatomical relationship to the uncinate process. An agger nasi cell has been found to overlie the upper parts of the lacrimal sac in 55% of patients. An anteriorly-attaching uncinate process covering at least 50% of the lacrimal fossa has been found in 63% of individuals [36]. The nasolacrimal duct leaves the inferior aspect of the lacrimal sac, runs inferiorly and enters the inferior meatus approximately 10-15mm from the anterior end of the inferior turbinate. Mucosal folds form Hasner's valve at its entry into the inferior meatus [1.4.1.1].

Discussion: There are two different interpretations of the term 'maxillary line'. It has been used to describe the half-moon shaped ridge seen on the mucosa of the lateral wall of the nose produced by the attachment between the lacrimal bone and the frontal process of the maxilla (lacrimomaxillary suture) [102]. The term has also been used clinically to describe the sulcus posterior to the lacrimal bulge. This is usually, though not exclusively, at the site of the attachment of the uncinate process to the maxilla. As the term has been applied to various anatomical situations in the literature, the group suggests that this term is abandoned and we refer instead to the attachment of the uncinate process.

Surgical/Diagnostic note: the lacrimal drainage system can be easily and non-invasively demonstrated with CT or MRI dacriocystography. 0.3-0.6 ml of contrast is directly applied to the eyeball and patient is asked to actively "blink". A coronal CT or MRI will then display the lacrimal sac and nasolacrimal duct [103].

Surgical note: in endoscopic dacryocystorhinostomy (DCR) surgery, identify the 'lacrimal bulge' (Figure 51B) on the lateral nasal wall formed by the frontal process of the maxilla; the lacrimal sac/duct are lateral to this. (The duct forms the lacrimal eminence on the medial wall of the maxillary sinus [6.6]). Thus the endoscopic location of the dome or top of the sac is between 8 to 10mm above the anterior insertion of the middle turbinate (the axilla) [104]. This may be facilitated by the use of an optical fibre inserted through the superior or inferior punctum into the common canaliculus and sac.

Surgical note: when incising the lacrimal sac, be aware that it can be in direct contact with the periorbita.

Structures of the medial orbit [11.3-6]: the orbit is a quadrilateral pyramid, surrounded on 3 sides by the paranasal sinuses. The medial wall is most frequently encountered in endoscopic sinus surgery as it separates the orbit from the ethmoid complex (Figure 33). This wall is composed primarily of the lamina papyracea of the ethmoid, with the frontal process of the maxilla and

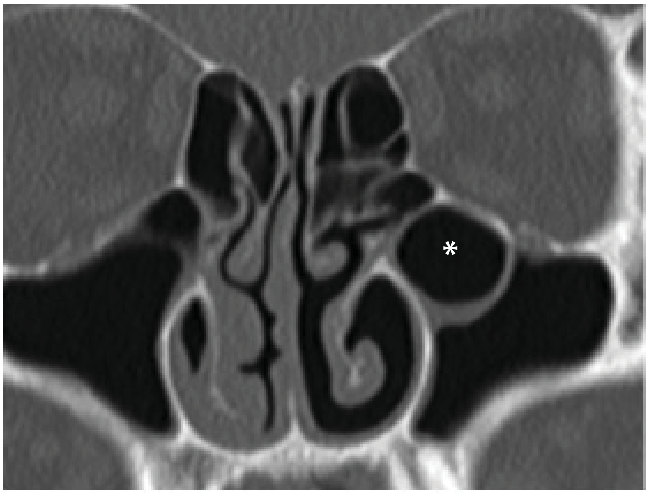

Figure 54. An infraorbital (Haller) cell (*) is an anterior or posterior ethmoidal cell that develops into the orbital floor, where it may narrow the adjacent maxillary sinus ostium or infundibulum.

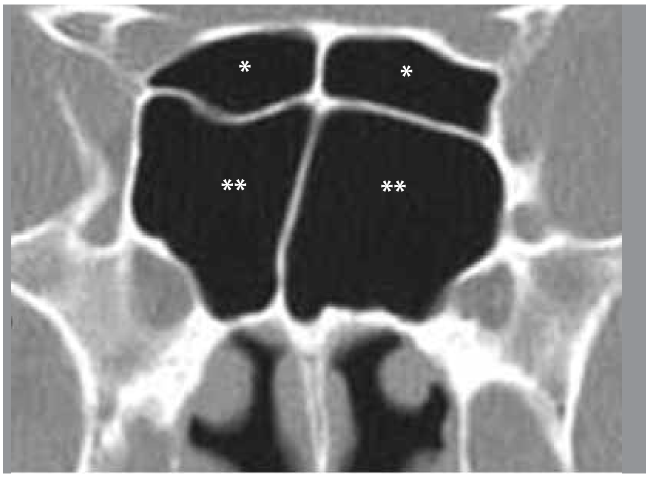

Figure 55. Sphenoethmoidal (Onodi) cell (*) and sphenoid sinus (**).

the lacrimal bone situated anterior to the lamina and the body of the sphenoid posterior to the lamina. The lamina papyracea is extremely thin (0.2-0.4 mm) [105], being thickest in its posterior part where it articulates with the sphenoid body. Here it forms the medial wall of the optic canal (see above). The orbital apex is a confluence of the body and greater and lesser wings of the sphenoid.

The lamina articulates with the frontal bone, the maxilla and the lacrimal bone. Superiorly, the lamina papyracea articulates with the roof of the orbit at the frontoethmoid suture where the ethmoidal foramina are found. Inferiorly the lamina attaches to the maxilla, where the bone is often thick. The lamina is perpendicular anteriorly but inclines medially as it progresses posteriorly [106].

Surgical note: in general, the lamina papyracea lies in the same plane as or lateral to the maxillary sinus ostium. It is more vulnera-

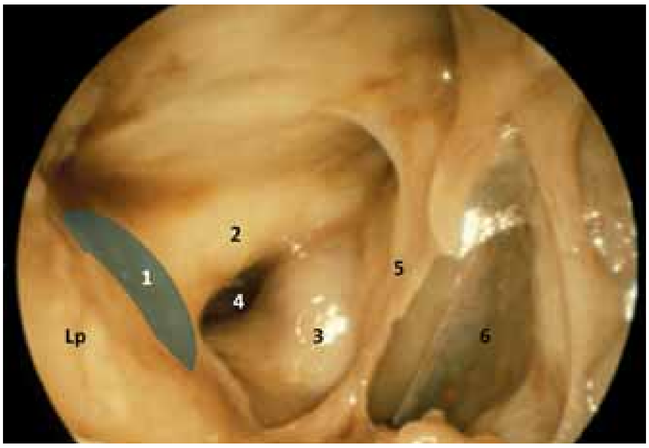

Figure 56. Endoscopic image of cadaveric dissection on the right: lp = lamina papyracea, 1 (shaded area) = optic nerve tubercle, 2 = bulge of optic nerve, 3 = internal carotid artery, 4 = optico-carotid recess, all exposed in a posterior sphenoethmoidal (Onodi) cell. The sphenoid sinus proper lies medially and below (6).

Figure 57. Uncinate process pneumatised (*) both sides. Nasolacrimal duct (**).

ble to accidental penetration when it lies medial to the ostium but caution should always be exercised in this region [107].

The orbital periosteum lines the socket and is adherent to the orbital margins, sutures, foramina, fissures and lacrimal fossa. It is continuous with dura through the optic canal and ethmoidal formina and the superior orbital fissure.

Within the periosteum, the orbit is a complex collection of fat, extraocular muscles, neurovascular structures, connective tissue and the globe. The contents are broadly divided into 3 spaces – extraconal, conal and intraconal, defined by the extraocular muscles which form the conal space. These comprise four recti (superior, inferior, medial and lateral) and two oblique (superior and inferior). The recti attach posteriorly to a fibrous ring (common annular tendon or annulus of Zinn), which surrounds the superior, medial and inferior margins of the optic canal and continues across the superior orbital fissure to attach to a tubercle on the greater wing of the sphenoid. The muscles pass forwards to attach by a tendinous expansion into the sclera.

The superior oblique muscle is related to the superomedial orbital wall. It arises from the body of the sphenoid, superomedial to the optic canal and passes forwards to form a round tendon passing in a synovial sheath through a fibro-cartilaginous structure, the trochlea, which is attached to the trochlear fossa of the frontal bone. The muscle then inserts into the lateral sclera behind the equator of the bulb.

Surgical note: the lamina papyracea is very thin and may be naturally dehiscent. It therefore provides a poor anatomical barrier to spread of disease and surgical transgression. However the periorbita is very resistant to spread of disease.

Surgical note: the medial rectus muscle has the closest relationship to the medial orbital wall particularly posteriorly where it may be easily damaged by surgery in the posterior ethmoid complex.

Surgical note: detachment of the trochlea during external sinus surgery can lead to superior oblique dysfunction and diplopia. Rarely it may also be damaged in extended endoscopic procedures such as Draf 3.

Anatomical variants: (Table 1)

Anatomical variants are common in the sinonasal region but there is no evidence that anatomical variants per se result in rhinosinusitis [11,12]. It is a matter of debate whether anatomical variants can contribute to severity or persistence of the disease [73,108,109].

- **Concha bullosa** [1.5.3,1.8.1]: aeration within the vertical part of the middle turbinate (or rarely superior turbinate), and is usually bilateral [11,12]. When unilateral, it is often associated with deviation of the nasal septum towards the contralateral side [110] (Figure 53).
- **Interlamellar cell (lamellar bulla)** [1.5.3.1]: arises from aeration of the vertical lamella of the middle turbinate from the superior meatus) (Figure 52) [5].
- **Infraorbital (Haller) cell** [9.5.6]: an anterior or posterior ethmoidal cell that develops into the orbital floor, where it may narrow the adjacent maxillary sinus ostium or infundibulum [11,12,111]. It may be defined as any ethmoidal cell which pneumatises inferior to the orbital floor and lateral to a line parallel with the lamina papyracea (Figure 54).
- **Sphenoethmoidal (Onodi) cell** [11.1]: a posterior ethmoidal cell (Figures 55 and 56) which develops lateral and/or superiorly to the sphenoid sinus [5,30,112]. The sphenoid sinus is then more medial and/or inferior than usual, and the optic nerve (and sometimes the internal carotid artery) may lie within the sphenoethmoidal cell rather than in the

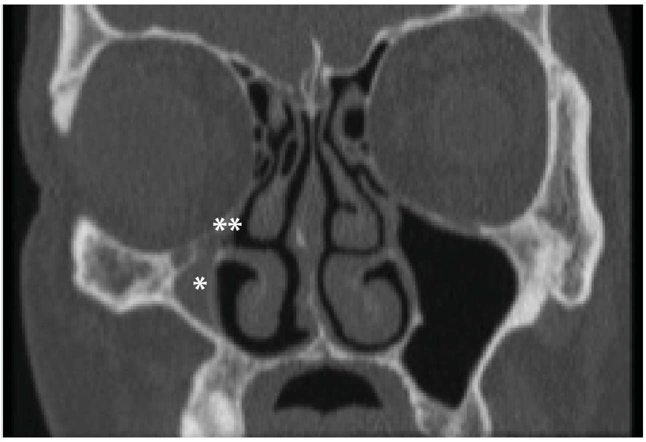

Figure 58. Maxillary sinus hypoplasia (*) or failure of development (arrested pneumatisation) can also occur in the absence of disease or surgery. This is often accompanied by hypoplasia of the uncinate process (**).

Figure 59. A silent sinus syndrome ('imploding antrum (*)' or chronic maxillary atelectasis) which may occur spontaneously and results in indrawing of the sinus walls (**) with resultant enophthalmos (***) and a lateralised middle turbinate.

lateral wall of the sphenoid sinus.
Surgical note: this cell renders the optic nerve and internal carotid artery at risk.

- **Everted (bent) uncinate process** [9.1]: curves medially towards the middle turbinate (Figure 5). Surgical note: this may be mistaken for a 'double' middle turbinate (17).
- **Aerated uncinate process** [9.2]: a rare variant in which the uncinate process contains an air-space (Figure 57).
- **Paradoxical middle turbinate** [1.5.2]: convex laterally, rather than the normal outward concavity (Figure 14); it can therefore obstruct the middle meatus.

Hypoplastic & aplastic sinuses: the frontal sinus is subject to greatest variation in pneumatisation, being aplastic (absent) (Figure 30) in 12-52% depending on ethnicity (12% in European races, 52% in Inuit people) (113). The aplasia may be unilateral or bilateral.

Surgical note: this is often seen in patients with cystic fibrosis and primary ciliary dyskinesia.

Maxillary sinus hypoplasia or failure of development (arrested pneumatisation) can also occur in the absence of disease or surgery (114). This is often accompanied by hypoplasia of the uncinate process (Figure 58). A prevalence of 10% has been described, with a proposed classification of the degree of hypoplasia based on CT appearances (16):

- Type 1 (7%) – a mild decrease in sinus volume with normal uncinate process and ethmoidal infundibulum.
- Type 2 (3%) – mild to moderate reduction associated with hypoplasic or absent uncinate process and/or ethmoidal infundibulum due to fusion of the uncinate process with the medial orbital wall.
- Type 3 (0.5%) – the maxillary sinus is only represented by a cleft and both the uncinate process and ethmoidal infundibulum are absent. The nasal cavity is correspondingly larger.

Surgical note: when a hypoplastic maxillary sinus occurs, the risk of inadvertent penetration of the orbit is increased (107).

Surgical note: this should be differentiated from the well-recognised 'silent sinus syndrome' ('imploding antrum' or chronic maxillary atelectasis) which may occur spontaneously and results in indrawing of the sinus walls with resultant enophthalmos and a lateralised middle turbinate (115,116) (Figure 59).

Enlarged sinuses (hypersinus; pneumocoele; pneumosinus dilatans): these processes can affect the frontal or more rarely the sphenoid, maxillary and ethmoid sinuses.

Hypersinus: a sinus that has developed beyond the upper limits of a normal sinus but does not extend beyond the bony boundaries so does not produce external deformity. The sinus is aerated and the bony walls normal.

Pneumosinus dilatans: defined as progressive air-containing expansion of a sinus cavity. It can affect one or more sinus cells on one or both sides, is commoner in men and may be idiopathic or may be associated with meningioma, fibro-osseous disease, arachnoid cysts and cerebral hemiatrophy. Extensive pneumatisation can result in cosmetic deformity and orbital damage (proptosis, diplopia, reduced vision) (117-121).

Pneumocoele: a pneumocoele, unlike pneumosinus dilatans, has walls with either generalised or focal thinning with total or partial loss of its integrity.

Table 1. Terminology.

	Present "Surgical" Terminology	Rhinologic & Anatomic Synonyms (Text Books, Literature)	Terminologia Anatomica [4] n.e. = non existant sing. = singular plur. = plural	Suggested English Terminology (Position Paper) t.b.a. = to be abandoned	Frequency of Variant in Literature**
1	**Nasal cavity**	Inner nose Cavum nasi	Cavitas nasi [9]	***Nasal cavity***	
1.1	Lateral nasal wall	Lateral nasal wall	n.e.	***Lateral nasal wall***	
1.2	Floor of nasal cavity	Nasal floor	n.e.	***Nasal floor***	
1.3	Nasal septum	Septum nasi	Septum nasi	***Nasal septum***	
1.3.1	Cartilaginous portion	Cartilaginous part of the nasal septum Cartilaginous segment Septal cartilage Lamina quadrangularis	Pars cartilaginea (septi nasi) Cartilago septi nasi	***Septal cartilage***	
1.3.2	Bony part	Bony / osseous septum Bony / osseous part of the nasal septum	Pars ossea septi nasi	***Bony septum***	
1.3.2.1	Lamina perpendicularis	Perpendicular plate of ethmoid	Lamina perpendicularis ossis ethmoidalis	***Perpendicular plate of ethmoid***	
1.3.2.2	Vomer	Vomer	Pars ossea septi nasi; Vomer	***Vomer***	
1.3.3	Membranous portion	Membranous portion	Pars membranacea septi nasi	***Membranous portion (of nasal septum)***	
1.3.4	Jacobson´s organ	Vomero-nasal organ	Organum vomeronasale	***Vomero-nasal organ***	
1.3.5	Septal tubercle	Tuberculum septi nasi Zuckerkandl´s tubercle Morgagni´s tubercle Septal swell body	n.e.	***Septal tubercle***	
1.4	Inferior turbinate	Inferior nasal turbinate Maxilloturbinal Concha inferior Lower turbinate	Concha nasi inferior	***Inferior turbinate***	
1.4.1	Inferior meatus	Inferior nasal meatus Lower nasal meatus	Meatus nasi inferior	***Inferior meatus***	
1.4.1.1	Naso-lacrimal duct opening	Hasner´s valve (Naso-) lacrimal duct ostium Ostium lacrimale	Apertura / ostium ductus nasolacrimalis	***Naso-lacrimal duct opening*** [10]	
1.5	Middle turbinate	Middle nasal turbinate First (persisting) ethmoturbinal First ethmoidal turbinate Middle concha Concha media	Concha nasi media	***Middle turbinate***	
1.5.1	Basal lamella of middle turbinate	Ground lamella of middle turbinate Third basal lamella	n.e.	***Basal lamella of middle turbinate***	
1.5.2	Paradoxically curved middle turbinate	Concave middle turbinate Inverse middle turbinate	n.e.	***Paradoxical middle turbinate***	3-26% [11,12]

1.5.3	Concha bullosa (of middle turbinate)	Bullous middle turbinate / concha	n.e.	***Concha bullosa (of middle turbinate)***	17-36% [11,12] ~50% in Turkish [13]
1.5.3.1	Interlamellar cell [1]	Interlamellar cell	n.e.	***Interlamellar cell***	
1.6	Middle meatus	Meatus medius Middle nasal meatus	Meatus nasi medius	***Middle meatus***	
1.7	Ostiomeatal complex	Ostiomeatal complex [14]	n.e.	***Ostiomeatal complex***	
1.8	Superior turbinate	Superior nasal turbinate Second (persisting) ethmoturbinal Second ethmoidal turbinate Superior concha Concha superior	Concha nasi superior	***Superior turbinate***	
1.8.1	Concha bullosa (of superior turbinate)	Concha bullosa (of superior turbinate)	n.e.	***Concha bullosa (of superior turbinate)***	1-2%
1.9	Superior meatus	Superior nasal meatus Upper nasal meatus	Meatus nasi superior	***Superior meatus***	
1.10	Supreme turbinate	Supreme nasal turbinate Third (persisting) ethmoturbinal Third ethmoidal turbinate Supreme concha Highest nasal concha Concha (nasalis) suprema (Morgagni)	Concha nasi suprema	***Supreme turbinate***	
1.11	Supreme meatus	Supreme nasal meatus	n.e.	***Supreme meatus***	
2	**Spheno-ethmoidal recess**	Recessus spheno-ethmoidalis	Recessus sphenoethmoidalis	***Spheno-ethmoidal recess***	
3	**Sphenopalatine foramen**	Foramen of sphenopalatine artery	Foramen sphenopalatinum	***Sphenopalatine foramen***	
4	**Olfactory cleft**	Olfactory ridge Olfactory groove Olfactory fissure Olfactory area	Sulcus olfactorius	***Olfactory cleft***	
4.1	Olfactory fibre(s)	Olfactory fibre(s) Fila olfactoria	Fila olfactoria (Sing.: filum olfactorium)	***Olfactory fibre(s)***	
5	**Choana** (plur.: choanae)	Posterior nasal aperture(s) Nares posteriores	Choana (Plur.: choanae); Apertura nasalis posterior	***Choana***	
6	**Maxillary sinus**	Maxillary antrum	Sinus maxillaris	***Maxillary sinus***	
6.1	Maxillary sinus ostium	Maxillary opening	n.e.	***Maxillary sinus ostium***	
6.1.1	Accessory maxillary ostium (plur: ostia)	Additional maxillary sinus ostium	n.e.	***Accessory ostium***	5% normal 25% CRS pts
6.1.2	Maxillary hiatus	Maxillary hiatus	Hiatus maxillaris	***Maxillary hiatus***	
6.2	Infraorbital nerve canal	Infraorbital canal	Canalis infraorbitalis	***Infraorbital canal***	
6.3	Zygomatic recess	Recessus zygomaticus	n.e.	***Zygomatic recess***	
6.4	Alveolar recess	Recessus alveolaris	n.e.	***Alveolar recess***	

6.5	Prelacrimal recess	Prelacrimal recess	n.e.	***Prelacrimal recess***	
6.6	Lacrimal eminence	Eminentia lacrimalis Bulging of nasolacrimal duct	n.e.	***Lacrimal eminence***	
6.7	Canine fossa	Canine fossa Fossa canina	Fossa canina	***Canine fossa***	
6.8	Anterior (nasal) fontanelle	Fontanella nasi anterior	n.e.	***Anterior fontanelle***	
6.9	Posterior (nasal) fontanelle	Fontanella nasi posterior	n.e.	***Posterior fontanelle***	
6.10	Maxillary artery	(Internal) maxillary artery	Arteria maxillaris	***Maxillary artery***	
7	**Ethmoidal complex**	Ethmoid Ethmoidal sinus(es) Ethmoidal labyrinth Labyrinthus ethmoidalis	Cellulae ethmoidales	***Ethmoidal complex***	
7.1	Anterior ethmoidal cells	Anterior Ethmoid Sinus ethmoidalis anterior Cells of anterior ethmoid Anterior ethmoid complex	Cellulae ethmoidales anteriores	***Anterior ethmoidal cells***	
7.2	Middle ethmoidal cells		Cellulae ethmoidales mediae	***t.b.a.***	
7.3	Posterior ethmoidal cells	Posterior Ethmoid Sinus ethmoidalis posterior Dorsal ethmoidal cells Cells of posterior ethmoid	Cellulae ethmoidales posteriores	***Posterior ethmoidal cells***	
7.4	Anterior ethmoidal artery	Anterior ethmoidal artery	Arteria ethmoidalis anterior	***Anterior ethmoidal artery***	
7.5	Middle ethmoidal artery	Third ethmoidal artery Accessory ethmoidal artery Intermediate ethmoidal artery Arteria ethmoidalis tertia (40% [15])	n.e.	***Accessory ethmoidal artery***	(Var) up to 45% if it equates to any situation where >2 arteries
7.6	Posterior ethmoidal artery	Posterior ethmoidal artery	Arteria ethmoidalis posterior	***Posterior ethmoidal artery***	
8	**Anterior ethmoidal complex**	Anterior ethmoidal cells	Cellulae ethmoidales anteriores	***Anterior ethmoidal complex***	
8.1	Agger nasi	Operculum conchae mediae [2]	Agger nasi	***Agger nasi***	
8.1.1	Agger nasi cell	Pneumatized agger nasi Agger cell	n.e. (cellula ethmoidalis anterior)	***Agger nasi cell***	>90% [16]
9	**Uncinate process**	Uncinate process	Processus uncinatus	***Uncinate process***	
9.1	Deflected uncinate process	Doubled middle turbinate[17] Anteriorly curved uncinate process Everted uncinate process	n.e.	***Everted uncinate process***	5-22% [11,12]
9.2	Aerated uncinate process	Bullous uncinate process Pneumatised uncinate process	n.e.	***Aerated uncinate process***	1-2%
9.3	Basal lamella of uncinate process	Ground lamella of uncinate process Uncinate lamella First basal lamella	n.e.	***Basal lamella of uncinate process***	

9.4	Hiatus semilunaris	Semilunar hiatus Hiatus semilunaris inferior [1] Semilunar gap	Hiatus semilunaris	***Inferior semilunar hiatus***	
9.4	Hiatus semilunaris (superior)	Hiatus semilunaris superior[1] Hiatus semilunaris posterior Superior semilunar hiatus	n.e.	***Superior semilunar hiatus***	(Var)
9.5	Ethmoidal bulla	Bulla ethmoidalis	Bulla ethmoidalis	***Ethmoidal bulla***	
9.5.1	Non pneumatized ethmoi-dal bulla	Torus bullaris [1,18]	n.e.	***t.b.a.***	8% [19]
9.5.2	Bulla lamella	Second ground lamella Basal lamella of ethmoidal bulla Second basal lamella	n.e.	***Basal lamella of ethmoidal bulla***	
9.5.3	Suprabullar recess	Sinus lateralis [1] Suprabullar cell Recessus bullaris	n.e.	***Suprabullar recess***	71% [16,20]
9.5.4	Retrobullar recess	Hiatus semilunaris superior	n.e.	***Retrobullar recess***	94% [16,20]
9.5.5	Supraorbital recess	Supraorbital cell Supraorbital ethmoid cell Cellula orbitalis	n.e.	***Supraorbital recess***	(Var) 17% [9]
9.5.6	Infraorbital cell	Haller cell Orbito-ethmoidal cell	n.e.	***Infraorbital cell***	4-15% [11,12]
9.6	Ethmoidal infundibulum	Ethmoidal infundibulum	Infundibulum ethmoidale	***Ethmoidal infundibulum***	
9.6.1	Terminal recess	Terminal recess of ethmoidal infundibulum Recessus terminalis	n.e.	***Terminal recess***	(Var) 49-85%[21]
9.7	Frontal recess	Recessus frontalis Frontal outflow tract	n.e.	***Frontal recess***	
9.7.1	Infundibular cells	Infundibular cells	n.e.	***Anterior ethmoidal cells***	(Var)
9.7.2	Lacrimal cells	Lacrimal cells	n.e.	***Anterior ethmoidal cells***	(Var) 33% [9]
9.7.3	Nasofrontal duct	Frontal outflow tract Frontal recess	Ductus nasofrontalis	***t.b.a.***	
9.7.4	Maxillary crest	Lacrimal crest Maxillary line	n.e.	***Lacrimal bulge***	
9.7.5	Ethmoidal crest	Crista ethmoidalis Ethmoidal crest of the pala-tine bone	Crista ethmoidalis	***Ethmoidal crest***	
9.7.6	Frontal sinus drainage pathway	Nasofrontal duct Frontal outflow tract Frontal recess	n.e.	***Frontal sinus drainage pathway***	
10	**Frontal sinus**	Frontal sinus	Sinus frontalis	***Frontal sinus***	
10.1	Interfrontal septum	Frontal sinus septum	Septum sinuum frontalium	***Frontal intersinus septum***	
10.2	Frontal sinus infundibulum	Frontal sinus infundibulum	n.e.	***Frontal sinus infundibulum***	
10.3	Intrafrontal cells	Frontal sinus cells Kuhn type 3/4 cells	Bullae frontales (sing.: bulla frontalis)	***Frontoethmoidal cells***	(Var)
10.4	Intersinus septal cell	Intersinus septal cell	n.e.	***Intersinus septal cell***	

10.5	Frontal bulla	Frontal bulla	n.e. (cellula ethmoidalis anterior)	***t.b.a.***	(Var)
10.6	Frontal sinus ostium	Frontal ostium Opening of frontal sinus	Apertura sinus frontalis	***Frontal sinus opening***	
10.7	Frontal beak	Nasal beak Superior nasal spine	Spina frontalis (ossis frontalis) Spina nasalis interna	***Frontal beak***	
11	**Posterior ethmoidal complex**	Posterior ethmoidal cells	Cellulae ethmoidales posteriores	***Posterior ethmoidal complex***	
11.1	Onodi cell	Spheno-ethmoidal cell Gruenwald cell [1]	n.e. (cellula ethmoidalis posterior)	***Sphenoethmoidal cell***	4-65% [22] 8-14% Caucasians, 26-29% Asians [23]
11.2	Basal lamella of superior turbinate	Fourth basal lamella	n.e.	***Basal lamella of superior turbinate***	
11.3	Lamina papyracea	Medial orbital wall Papyraceous lamina	Lamina orbitalis ossis ethmoidalis	***Lamina papyracea***	
11.4	Orbital apex	Orbital apex	n.e.	***Orbital apex***	
11.5	Annulus of Zinn	Common tendinous ring Common annular tendon	Annulus tendineus communis	***Annulus of Zinn***	
11.6	Ophthalmic artery	Ophthalmic artery	Arteria ophthalmica	***Ophthalmic artery***	
12	**Sphenoid sinus**	Sphenoid sinus	Sinus sphenoidalis	***Sphenoid sinus***	
12.1	Intersphenoidal septum	Intersphenoidal septum Sphenoid sinus septum	Septum sinuum sphenoidalium	***Sphenoid intersinus septum***	
12.2	Accessory sphenoidal septum (Plur.: septa)	Incomplete sphenoidal septations Partial sphenoidal septations Sphenoid sinus subseptations	n.e.	***Sphenoid septations***	(Var) 76% [24]
12.3	Sphenoid sinus ostium	Sphenoid (sinus) ostium Sphenoid (sinus) opening Natural sphenoid ostium	Ostium (apertura) sinus sphenoidalis (Plur.: ostia sinuum sphenoidalium)	***Sphenoid sinus ostium***	
12.4	Planum sphenoidale	Sphenoid sinus roof Jugum sphenoidale Sphenoidal yoke	Jugum sphenoidale	***Planum sphenoidale***	
12.5	Sellar floor	Floor of sella Sellar bulge	n.e.	***Sellar floor***	
12.6	Vidian canal	Pterygoid canal Canalis nervi pterygoidei	Canalis pterygoideus	***Pterygoid (Vidian) canal***	
12.7	Foramen rotundum	Canalis rotundus Round foramen	Foramen rotundum	***Foramen rotundum***	
12.8	Lateral recess of sphenoid sinus	Lateral recess of sphenoid sinus	n.e.	***Lateral recess of sphenoid sinus***	(Var)
12.9	Optic tubercle	Optic nerve tubercle [1,3] Prominentia nervi optici	Tuberculum nervi optici	***Optic nerve tubercle***	
12.9.1	Optic nerve canal	Eminentia nervi optici Optic nerve bulging Optic nerve canal contour	Canalis opticus	***Optic nerve canal***	(Var)
12.9.2	Carotid artery prominence	Prominentia canalis carotici	n.e.	***Carotid artery bulge***	(Var)

12.9.3	Optico-carotid recess	Carotid-optical recess Infraoptical recess	n.e.	***Optico-carotid recess***	(Var)
12.9.4	Sternberg´s canal	Canalis craniopharyngicus lateralis [22,25,26]	n.e.	***Lateral craniopharyngeal (Sternberg´s) canal***	4% adults
13	**Sphenoidal rostrum**	Rostrum	Rostrum sphenoidale	***Sphenoid rostrum***	
14	**Vomerovaginal canal**	Vomerovaginal canal	Canalis vomerovaginalis	***Vomerovaginal canal***	
15	**Palatovaginal canal**	Palatovaginal canal	Canalis palatovaginalis	***Palatovaginal canal***	
16	**Skull base**	Cranial base Basicranium	Basis cranii	***Skull base***	
16.1	Inner skull base	Internal surface of cranial base	Basis cranii interna	***Inner skull base***	
17	**Anterior cranial fossa**	Anterior cranial fossa	Fossa cranii anterior	***Anterior cranial fossa***	
17.1	Olfactory fossa	Ethmoidal notch [27] Fovea ethmoidalis	n.e.	***Olfactory fossa***	
17.2	Cribriform plate	Lamina cribrosa Roof of inner nose	Lamina cribrosa (ossis ethmoidalis)	***Cribriform plate***	
17.2.1	Cribriform foramina	Cribriform openings	Foramina cribrosa	***Cribriform foramina***	
17.2.2	Lateral lamella of cribriform plate	Lateral lamella of cribriform plate	n.e.	***Lateral lamella of cribri-form plate***	
17.3	Ethmoidal roof	Foveae ethmoidales (ossis frontalis)	n.e.	***Ethmoidal roof***	
17.4	Crista galli	Crista galli	Crista galli	***Crista galli***	
17.4.1	Pneumatized crista galli	Pneumatized crista galli	n.e.	***Pneumatized crista galli***	13% [28]
17.5	Foramen caecum	Foramen caecum	Foramen caecum	***Foramen caecum***	Open (Var: 1.4% [15])
18	**Middle cranial fossa**	Middle cranial fossa	Fossa cranii media	***Middle cranial fossa***	
18.1	Sella	Hypophysial fossa Pituitary fossa	Sella turcica	***Sella (turcica)***	
18.2	Sellar tubercle	Suprasellar notch	Tuberculum sellae	***Tuberculum sellae***	
18.3	Dorsum sellae	Dorsum sellae	Dorsum sellae	***Dorsum sellae***	
18.4	Anterior clinoid process	Anterior clinoid process	Processus clinoideus anterior (plur.: processus clinoidei anteriores)	***Anterior clinoid process***	Pneumatized (Var.: 16.5 %)
18.5	Posterior clinoid process	Posterior clinoid process	Processus clinoideus posterior (plur.: processus clinoidei posteriores)	***Posterior clinoid process***	
19	**Posterior cranial fossa**	Posterior cranial fossa	Fossa cranii posterior	***Posterior cranial fossa***	
19.1	Clivus	Clivus	Clivus	***Clivus***	

**The frequency of specific variations in the anatomy varies considerably in the literature which relates to the definitions used, the methodology utilised ie anatomical dissection or imaging, whether the study included normal controls and/or patients with chronic rhinosinusitis and the ethnicity of the subjects.

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Further Reading

In addition to the books included in the list of references, this is a selection of recent and seminal textbooks, which may be of interest to those wishing to delve into the deeper details of sinonasal anatomy.

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