ANATOMY OF THE PARANASAL SINUSES AND ANTERIOR SKULL BASE

Fundamentals of Endoscopic Endonasal Surgery

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First developed in the early 20th century, endonasal sinus surgery has been rediscovered and advanced in the past 50 years owing to the introduction of optical instruments (rigid endoscopes have become the standard, microscopes are less and less widely used) (overview: Hosemann et al. 2000; Weber 2015). Endonasal sinus surgery is currently the first-line standard in the operative treatment of sinusitis, particularly chronic rhinosinusitis. At the same time, endonasal and transnasal surgical procedures have increasingly gained in acceptance for additional indications, and specialized interdisciplinary rhino-neurosurgery centers have been established (Hosemann and Schroeder 2015). This monograph elucidates the microanatomical architecture forming the basis of sophisticated endonasal sinus surgery and extended transnasal surgery. It updates and expands an older brochure (Hosemann and Fanghanel 2004). The focus lies on surgical anatomy, i.e., the variation range of anatomic configurations, pathways, and hazard areas in relation to practical endonasal or transnasal endoscopic surgery. General anatomic descriptions have been omitted in favor of this perspective since it is assumed that readers are already familiar with the basics of anatomy.

Concerning the surgical technique itself, a comprehensive series of pertinent monographs and scientific publications of various surgical schools are available on both surgery for sinusitis and expanded indications. In the endnotes listed in the bibliography (see pp. 98), the reference numbers of these monographs are shown against a blue background without being consistently cited in the text.

What is the purpose of this manual?

In the field of nasal and paranasal sinus surgery, it is no longer acceptable for young surgeons to build their skills solely based on pertinent textbooks of surgery and a host of video clips, while otherwise relying on gaining the necessary experience through practical work in the operating room. The call for additional training modalities draws its justification from rising standards which reflect the wide range of potential surgical complications and increasingly differentiated approaches with regard to endonasal micromanipulation techniques. Repeated practice on a “real anatomic substrate” is therefore highly recommended during initial stages of the skills training (Hosemann 2013). The authors have responded to these developments by offering well-structured specialized anatomical dissection courses. (see www.fess-course.com; www.sinus-academy.de).

This booklet is intended as a “companion” to the aforementioned sinus and skull base dissection courses. It serves to illustrate the anatomy and to impart knowledge on the range of anatomic variations while providing a structured basis for step-by-step dissection training. In that sense, the booklet should be understood as an illustrative systematic guide to the variable paranasal sinus anatomy. Its content builds upon existing knowledge, with the presented facts having been specifically selected based on their clinical relevance or conciseness and, in some cases, is presented in a deliberately simplified manner. Some overlap, inconsistencies, and ambiguities, e.g., concerning the reported prevalence ratios and dimensions, were accepted since they reflect uncertainties in the available literature as well as the wide range of variability in terms of individual anatomic dimensions.

A similar approach was used regarding anatomic terminology – a complete list of consented anatomic terms for the paranasal sinuses and anterior skull base does not exist. Microanatomical diversity is presented in tabular overviews in an effort to show anatomic variations and prevalence ratios as they apply to daily practice. At the end of the booklet, space is provided for adding comments during the attended dissection course in the form of an individual “collection of notes.” The goal is to develop an overall picture that is based on key anatomic knowledge and practical insights obtained from each participant’s hands-on training session.

The individual microanatomy of the paranasal sinuses shows a wide range of variation. In clinical routine and in reports written from a hands-on perspective, there is still a tendency to address this variety by coining a pretentious, easily memorable “group-specific nomenclature.” However, precise and clear anatomic terminology is requisite to any cross-facility communication and to scientific progress in general – eponyms and cryptic acronyms, for instance, should be avoided wherever possible (Winkelmann 2012). In this publication, an effort is made to rationally present anatomic terms in compliance with an European Position Paper on Anatomical Terminology (Lund et al. 2014). In view of the availability of materials for self-study, this text and the references incorporated therein give preference to sources from the past 30 years – but whenever possible, older and still relevant publications should be read as well, e.g., from van Alyea, Hajek, Halle, Mosher, Onodi, Schaeffer or Zuckerkandl. The same applies to newer anatomical reviews, e.g., from Rhoton, or with regard to monographs, e.g. from Lang and Navarro.

W. Hosemann, Th. Kühnel, R. Weber.
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Teleology
We do not know why human beings have paranasal sinuses. Many theories have been advanced – reducing the weight of the skull, improving voice resonance, humidifying the inspired air, providing thermal insulation for the brain, absorbing traumatic shocks, – but none have been definitely confirmed. Conversely, to this day, the said theories are subject to teleological discussions and scientific analyses (z. B.: Gallup and Hack 2011; Irmak et al. 2004; Kellman and Schmidt 2009; Lee et al. 2014).

Embryogenesis
In the fetus, the lateral nasal wall bears a series of five or six separate ridges (ethmoturbinals), some of which have a curved shape resembling that of the free edge of the middle turbinate. The fetal ethmoturbinals fuse completely in their posterior portions, while mainly the apexes of the ridges become fused anteriorly. The persistence or partial fusion of the ridges, plus the ingrowth of ethmoid air cells (pneumatization), leads to the adult form of the lateral nasal wall. The ethmoid “labyrinth” in the adult still contains four or five, more or less intact remnants of the fetal ethmoturbinals called the basal lamellae (ground lamellae) (Fig. 1.1).

As stipulated in a position paper of the European Rhinological Society, use of the term “ground lamella” should be discontinued in favor of “basal lamella” (Lund et al. 2014).

Clinical Hints
- The degree of pneumatization may be disproportionately high in the anterior or posterior ethmoid, in which case the basal lamella may be deflected anteriorly or posteriorly by relatively large ethmoid cells (Figs. 2.18, 2.19). As a consequence, in approx. 14% of cases, the basal lamella is displaced anteriorly toward the ethmoid bulla, as mentioned above. This anatomical variation can have surgical implications because a thorough excision of the ethmoid bulla in these cases is bound to open the basal lamella, thereby entering the posterior ethmoid.
- In microanatomy of paranasal sinuses, bilateral asymmetry is often seen as a rule rather than an exception. A similar observation applies to gender- and ethnicity-related disparities.

The most important lamella is the third lamella / basal lamella of the middle turbinate. It separates the anterior and posterior ethmoid cells anatomically (forming a partition) and also functionally (creating separate mucociliary drainage pathways). The anterior ethmoid cells communicate through the ethmoid infundibulum and/or the retrobullar recess with the middle meatus, while the posterior ethmoid cells drain into the superior meatus and/or the supreme meatus, if present.

Fig. 1.1 Schematic diagram of the basal lamellae (ground lamellae) of the left-sided ethmoid (after Terrier 1991).
Basal lamella of the uncinate process (1); Basal lamella of the ethmoid bulla (2); Basal lamella of the middle turbinate (3); Basal lamella of the superior turbinate (4), (not shown: usually absent supreme turbinate); anterior sphenoid sinus wall (5); Space in continuity with the ethmoid infundibulum (variable) (6); anterior middle meatus (7); ethmoid bulla (8); retrobullar recess (9); posterior ethmoid (10,11).
Key Structural Features

Anatomically and pathophysiologically, the ethmoid is the centerpiece of the paranasal sinuses. The collection of ethmoid cells on one side is shaped like a truncated pyramid with its base directed posteriorly (Fig. 1.2). The system of air cells measures 4–5 cm anteroposteriorly and 2.5–3 cm from top to bottom. Its anterior width is approximately 0.7 cm, its posterior width approximately 1.5 cm. It is 1 cm broader inferiorly than superiorly.

Various classification systems have been proposed for the ethmoid cells. From an anatomical standpoint, the position of the ostium ("starting point" for pneumatization) in relation to the basal lamellae determines the classification of each cell. In individual cases it is not always a straightforward matter to distinguish between cells with ostia on the one hand and recesses (extensions ending blindly, niches) of defined cavities on the other (Thomas and Pallanch 2010). When disease is present, however, the ostia and, occasionally, the key elements of the basal lamellae cannot be seen exactly. This is why embryological-anatomical and surgical-anatomical classification systems differ considerably in detail. The latter are mainly referred to in this booklet (see, e.g., Frontoethmoidal cells, Chapter 2).

As a rule, a distinction is made only between anterior and posterior ethmoid cells. Both cell groups are separated by the basal lamella (see above) of the middle turbinate (Figs. 1.1, 1.3).

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**Fig. 1.2** Endoscopic view of the outer bounding surfaces of the left system of ethmoid air cells after removal of the cell septa (endonasal ethmoidectomy). The resulting space is shaped like a cuboid, i.e., a truncated pyramid. Nasal septum (1); vertical lamella of the middle turbinate (2); view onto the skull base (3); medial orbital wall (4); access to the maxillary sinus (5).

**Fig. 1.3** Basal lamella of the middle turbinate. 

a. Endoscopic view of the anterior aspect of the surgically exposed left basal lamella. Shown are the constituting anatomical segments of the exposed lamella (1). Access to the maxillary sinus (2); Access to the frontal sinus (3); Anterior ethmoid artery (4).

b. Lateral macroscopic view of a dissected right basal lamella. Anterior segment including the junction zone toward the median-sagittal lamella of the middle turbinate (a); Posterior-horizontal segment (p); Superior segment (s); Inferior segment (i); Lateral attachment to the Lamina papyracea (l).

**Fig. 1.4** Access to the left anterior ethmoid sinus through the middle meatus.

a. Endoscopic view of the anterior middle meatus. Nasal septum (1); Head of the middle turbinate (2); Uncinate process (3); Anterior lateral nasal wall with maxillary line (4).

b. The middle turbinate is medialized with an instrument (5) affording an expanded view of the anterior middle meatus; Anterior wall of the ethmoid bulla (6); Free edge of the uncinate process (7).
Access (entry) to the anterior ethmoid is gained through the middle meatus, which can be used for an endonasal approach while also serving as a natural drainage pathway of both the maxillary sinus and the frontal sinus (Figs. 1.4, 1.5). This anterior ethmoid compartment contains 2 – 10 anterior ethmoid cells. They are subdivided into defined cell groups which are categorized based on topographical position and on how they relate to the frontal sinus drainage pathway:

- **Agger nasi cell** and **supra agger cells**, adjoining directly above,
- **Ethmoid bulla** and overlying (supra bulla) cells, occasionally adjoined by **supraorbital cells**,
- **Cells of the interfrontal sinus septum** as well as
- **occasionally, an infraorbital cell**.

Surgical access to the posterior ethmoid can be obtained through the basal lamella of the middle turbinate or transnasally through the superior meatus (Fig. 1.6).

The posterior ethmoid compartment contains relatively few (2–6) ethmoid cells, of which only 2 have been specially named and require the rhinosurgeon’s particular attention:

- **Posterosuperior ethmoid cell** ("sphenoethmoid" cell, in the past also referred to as "Onodi cell"), which contacts the optic nerve.
- **Posterior infraorbital or retromaxillary ethmoid air cell**.

The anterior ethmoid artery runs obliquely, either within the roof of the anterior ethmoid or inferiorly, usually between the insertions of the second and third basal lamellae. The posterior ethmoid artery courses from lateral to medial through the roof of the posterior ethmoid, directly in front of the anterior sphenoid sinus wall. In some cases, a third ethmoid artery (middle ethmoid artery) is found between the anterior and posterior ethmoid arteries. The lamina papyracea (orbital lamina of the ethmoid) separates the ethmoid from the orbit laterally.
Embryology, Biological Benefit and Key Structural Features of the Paranasal Sinuses

Fig. 1.6 Alternative surgical approaches to the posterior ethmoid (5) through the middle (1) or superior (2) meatus (transethmoidal vs. transnasal approach).

a. Sagittal CT scan showing both approaches, (1) and (2).

b. Endoscopic view after perforation of the basal lamella of the middle turbinate; (4; left side, dotted line marks the perforation margin).

Anterior wall of the ethmoid bulla (3); orbit (6).

The frontal sinus is a pneumatized space in the frontal bone and develops from the anterior ethmoid (Fig. 1.7). Pneumatization varies greatly between individuals and can extend far dorsally and laterally over the orbit, far cranially into the frontal bone, and laterocranially into the temporal bone. Conversely, some individuals may exhibit aplasia. The posterior wall of the frontal sinus is in close proximity to the cribriform plate, the olfactory fibers as well as the anterior ethmoid artery and anterior nasal artery.

The position and size of the frontal sinus drainage pathway is determined by the shape and size of the nasal spine, by the frontal sinus “opening”, and by anterior ethmoid air cells, which in some cases extend into the frontal sinus. Caudally, it is continuous with the frontal recess of the anterior ethmoid.

The maxillary sinus – a pneumatized space of the maxilla – is shaped like a trilateral pyramid, composed of an anterolateral, posterior, and medial wall, with the maxillary sinus roof being formed by the orbital floor (Fig. 1.8). The tip of the pyramid points to the zygomatic recess, lying anterolaterally. The infraorbital nerve as the terminal branch of the maxillary nerve runs along the maxillary sinus roof to the anterior wall, where it exits through the infraorbital foramen into the cheek soft tissue. Along its course through the maxillary sinus, it gives off the superior alveolar nerves. The maxillary sinus floor is formed by the alveolar recess.

Fig. 1.7 CT scan of a frontal sinus in three planes: frontal (a), axial (b), and sagittal (c).

Frontal sinus (1); agger nasi cell (2); superior nasal spine (3); anterior ethmoid artery (4).

Fig. 1.8 CT scan of a maxillary sinus in three planes: frontal (a), axial (b), and sagittal (c).

Zygomatic recess (1); alveolar recess (2); palatine recess (3); infraorbital nerve (4); uncinate process (5).
in close proximity to the roots of the maxillary teeth and the palatine recess. The nasolacrimal duct runs in the anterior medial wall of the maxillary sinus and forms the dorsal boundary of a prelacrimal recess. The natural ostium of the maxillary sinus is found directly behind the nasolacrimal duct, in close proximity to the maxillary sinus roof.

Behind the posterior wall of the maxillary sinus is the pterygopatellar fossa containing, among others, the maxillary artery and its terminal branches (pterygopalatine artery, descending palatine artery, etc.), the maxillary nerve and its terminal branches (e.g., the infraorbital nerve), the sphenopalatine ganglion, and the nerve of the pterygoid canal (Vidian nerve). Lateral to a sagittal plane running through the infraorbital nerve, the pterygopatellar fossa opens into the infratemporal fossa.

The sphenoid sinus can variably pneumatize the body of the sphenoid bone, the greater or lesser sphenoid wings, the palatine bone, the vomer, the nasal septum, the pterygoid process, or the posterior ethmoid cells (Fig. 1.9). Individual variations particularly include different lateral recesses. The sphenoid sinus is in close proximity to the following structures:

- Superiorly, to the pituitary and middle cranial fossa;
- Dorsally, to the posterior cranial fossa, the clivus, brain stem and the basilar part of the occipital bone;
- Inferiorly, to the nasopharynx;
- Laterally, to the cavernous sinus with its internal structures;
- Inferolaterally, to the maxillary nerve and inferiorly, to the nerve of the pterygoid canal;
- Superolaterally, to the optic nerve;
- Posterolaterally, to the internal carotid artery.

The natural ostium of the sphenoid sinus is most commonly found medial to the attachment site of the superior turbinate above the choana.

In approximately 50% of cases, a so-called sphenoethmoidal recess is present; this is a laterally oriented, blind recess of the nasal cavity directly anterior to the anterior wall of sphenoid sinus and posterior to the superior (or supreme) turbinate.

The width of the contact area between the anterior sphenoid sinus wall and the nasal cavity and/or sphenoethmoidal recess on the one hand (nasal surface of the anterior sphenoid sinus wall) and the posterior ethmoid on the other (ethmoidal surface of the anterior sphenoid sinus wall) varies depending on the degree of pneumatization. Anterior to the sella, the roof is formed by the planum sphenoidale.

Many of the mentioned variable anatomic structural features can be analyzed and quantified during systematic endoscopy of the nasal cavity (Fig. 1.10).
Fig. 1.10 Illustrative example of a sequence of endoscopic images captured during systematic exploration of the right nasal cavity. Inspection of the anterior nasal cavity (a), inferior meatus (b), nasopharynx (c, d), middle meatus (e–i), and anterior sphenoid sinus wall (j–k). Inferior turbinate (1), middle turbinate (2), olfactory cleft (3), nasal septum (4), nasal floor (5), posterior part of the auditory tube (6), posterior wall of nasopharynx (7), choana (8), uncinate process (9), ethmoid bulla (10), inferior semilunar hiatus (11), posterior insertion of the middle turbinate (12), superior turbinate (13), sphenoid sinus ostium (14).
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

Structural Elements of the Paranasal Sinuses
Alphabetical Compilation of Key Anatomical Terms with Details of Practical / Clinical Relevance

Agger nasi

The agger nasi is an eminence of the osseous lateral nasal wall directly anterior to the anterior insertion of the middle turbinate. It is considered to be part of a remnant of the first ethmoturbinate or first basal lamella. The agger nasi is generally pneumatized (70–90%), and larger cells are found in 15% of cases (quite often, agger nasi cells are mistaken for lacrimal cells or a terminal recess). In typical cases, 1–5 (usually 2) anterior ethmoid cells are found in the region of the agger nasi (Figs. 2.1, 2.2). In 80% of cases, such agger nasi cells drain into the frontal recess, and in approximately 20% of cases, directly into the ethmoidal infundibulum. When planning surgical procedures, an agger nasi cell is considered an anatomic key reference point since it is the first cell seen in an anterior to posterior direction in a frontal CT scan. Accordingly, it serves as a landmark, for instance, when assessing frontoethmoidal cells (see: Frontoethmoidal cells). The natural drainage pathway of the frontal sinus may be displaced dorsally and also medially by large agger nasi cells (Fig. 2.3) – there is controversy as to whether large cells correlate with a large anteroposterior diameter of the most inferior frontal sinus (“frontal infundibulum”). In more than 50% of cases, agger nasi cells overlie medial portions of the lacrimal sac.

Fig. 2.1 Frontal (a) and sagittal (b) CT scans showing an agger nasi cell (⁎).

Fig. 2.2 Frontal (a) and sagittal (b) CT scans showing an agger nasi cell (⁎) and supra agger cells (†).

Fig. 2.3 Upward oblique view (30° scope) showing an opened agger nasi cell (dotted line) on the left side (same patient as in Fig. 2.1).

a. Vertical lamella of the middle turbinate (Cm); part of the frontal maxillary process (Pfm) superior to the lacrimal sac; frontal sinus drainage pathway (arrow).

b. A blunt elevator is inserted into the frontal sinus drainage pathway. Access to the frontal sinus is explored and expanded step by step by lateralizing the remaining medial wall of the agger nasi cell.

Special Literature

† see also: Concha media; Frontoethmoidal cells
Arteria carotis interna

Generally, the course of the *internal carotid artery* (ICA) is divided into *cervical*, *petrous*, *cavernous*, *clinoideal*, and *cisternal* segments. In detail, however, the definitions differ, particularly for the paranasal segments of the vessel (see Fig. 2.4 and Tab. 2.1). These segments are of special importance in endonasal surgery and exhibit morphological variants (Tab. 2.2).

The second genu (g2) of the ICA is located above the *foramen lacerum*. In this genu, the horizontal, petrous segment of the ICA becomes the paraclival, vertically oriented segment. Viewed from anterior, the *nerve of the pterygoid canal* (Vidian nerve) “points” to the anterolateral side of this genu; the vertical axis of the vessel segment is medial to the *nerve of the pterygoid canal*. Superior to the plane of the petrous bone, the ICA enters the *cavernous sinus*.

![Diagram of ICA segments](image)

**Tab. 2.1** Various classification schemes for mapping the ICA segments – as found in the literature (from: *Hosemann and Schroeder 2015*).

<table>
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<th>Tab. 2.1</th>
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<td>Bouthillier et al. 1996; DePowell et al. 2014</td>
<td>From the standpoint of transsphephoid surgery:</td>
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<td>From the standpoint of transnasal surgery:</td>
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<td>Cervical segment</td>
<td>Paracaval Segment</td>
<td>C1 Cervical segment (Pars cervicalis)</td>
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<td>Petrous segment</td>
<td>■ Segment at the foramen lacerum</td>
<td>C2a First genu (g1) with petrous segment (Pars petrosa)</td>
<td>■ Petrous segment (up to postero-medial foramen lacerum)</td>
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<tr>
<td>Lacerum segment</td>
<td>■ Segment at the trigeminal nerve / Gasserian ganglion</td>
<td>C2b Pterocaval segment at the foramen lacerum with second genu (g2)</td>
<td>■ Paracaval segment (up to superior petroclival fissure)</td>
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<tr>
<td>Cavernous segment</td>
<td>Paracaval Segment</td>
<td>C3 Cavernous segment (Pars cavernosa) with posterior vertical segment, posterior bend (&quot;P bend&quot;), horizontal segment, anterior bend (&quot;A bend&quot;) and anterior vertical segment</td>
<td>■ Parasellar segment (up to proximal dural ring)</td>
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<td>Clinoideal segment</td>
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<td>C4 Segment medial to the anterior clinoid process</td>
<td>■ Paracloidioid segment (up to distal dural ring)</td>
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<td>Ophthalmic segment</td>
<td>Paracaval Segment</td>
<td>C5 Intracranial (cisternal) segment (Pars cerebralis)</td>
<td>■ Intradural segment (up to the branching of the artery)</td>
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<td>Communicating segment</td>
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<td>Alfiery and Jho 2001</td>
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<tr>
<td>Labib et al. 2014</td>
<td>Paracaval segment (up to proximal dural ring)</td>
</tr>
</tbody>
</table>

---

*see also: Sphenoid sinus*
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

### Tab. 2.2 Variations of spatial arrangement patterns of ICA in the sphenoid sinus region.

<table>
<thead>
<tr>
<th>Structural Feature</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
<th>Type 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form of the dorsal bend at the junction of the (intracavernous)</td>
<td>Classic course – angle between 85° and 145° (70%).</td>
<td>Hidden, “U-shaped” course with the “U” opening anteriorly (30%).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>paracaval ICA to the inferior horizontal portion of the parasellar ICA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Course of the bilateral horizontal portion of the cavernous ICA segment in the</td>
<td>Type 1 “O-shape” in axial plane (8%).</td>
<td>Type 2 “X-shape” in axial plane (25%).</td>
<td>Type 3 Parallel, straight course in axial plane (40%).</td>
<td>Type 4 “V-shape” in axial plane (20%).</td>
<td>Type 5 Inverted “V-shape” in axial plane (7%).</td>
</tr>
<tr>
<td>horizontal plane (e.g., in axial CT) (Wang et al. 2013).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle between the posterior vertical and horizontal portions of the cavernous</td>
<td>Type “Z” Extremely small angle, 0° – 45° (22 %).</td>
<td>Type “A” Acute angle, 45° – 75° (18 %).</td>
<td>Type “S” Nearly right (perpendicular) angle, 75° – 105° (22 %).</td>
<td>Type “O” Obtuse angle larger than 105° (38 %).</td>
<td></td>
</tr>
<tr>
<td>segment of the ICA in the sagittal plane (Wang et al. 2013).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Course and bend of the ICA from the standpoint of transnasal surgery</td>
<td>Type 1 Sharp angle (&lt; 80°) in C4 region at the junction of the vertical</td>
<td>Type 2 Posterior ascending arterial segment is almost vertical; angle</td>
<td>Type 3 Rather gentle, curved course, angle at the junction of the</td>
<td>Type 4 Side-to-side asymmetry particularly in C4 region (25 %).</td>
<td></td>
</tr>
<tr>
<td>– the focus is on the junction of the vertical and horizontal portions of the</td>
<td>and horizontal portions (25%).</td>
<td>to the horizontal portion 80° – 100° (35 %).</td>
<td>posterior ascending portion (C4) and the horizontal portion is</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cavernous segment C4 (Cebula et al. 2014).</td>
<td></td>
<td></td>
<td>larger than 100° (15 %).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is followed by a highly variable bend in the cavernous sinus (*posterior bend*), which can appear as a prominence in the posterolateral wall of the sphenoid sinus – otherwise, the prominence remains hidden in transnasal endoscopy (*hidden loop*). The above bend marks the transition to the horizontal portion of the parasellar segment. The parasellar segment of the *internal carotid artery* (ICA) often appears as typical prominence in the lateral sphenoid sinus wall. Anteriorly, the artery bends cranially (*anterior bend*), giving rise to the anterior vertical segment (Fig. 2.5). Endoscopically, this area exhibits an anterolaterally convex prominence, located lateral to the sella. In elderly patients, the average wall thickness of the ICA in the parasellar segment (siphon) measures only 1 mm. More distally, the artery takes an almost horizontal course in a posterior direction again – both parts of this segment (clinoid and cisternal segment) are extracavernous in location. The clinoid segment passes between two dural rings around the artery. The superior ring is in the surface plane of the *anterior clinoid process*; the inferior ring originates from the inferior surface of the process. The following cisternal segment of the ICA courses posterosuperiorly and medially until its bifurcation where the artery divides into the anterior and middle cerebral arteries.

In the literature there is inconsistency concerning the bony covering of the ICA in the lateral sphenoid wall. Approx. 10% of cases reveal a partially uncovered course (i.e. exposed) of parts of the ICA in the sphenoid sinus, while focal dehiscence of the covering bone is observed in approximately 30% of cases.

**Clinical Hints**

- The *nerve of the pterygoid canal* serves as a landmark for locating the petroclival segment of the ICA (Kassam et al. 2008; see *Canalis pterygoideus*).
- The proximal mandibular nerve, as a landmark in expanded transpterygoid or transmaxillary approaches, is located directly anterior to the horizontal portion of the petrous ICA segment in the frontal plane (Mehta et al. 2018).

**Special Literature**


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**Fig. 2.5** Endoscopic straight-forward view into the right lateral sphenoid sinus. Anterior bend of the ICA in the cavernous segment (*A.c.i.*); Optic nerve (*N.o.*); Optico-carotid recess (*R.o.c.*); Secretion droplet (★).
**Arteria ethmoidalis anterior**

The *anterior ethmoid artery* (AEA) – a branch of the ophthalmic artery (the latter is given off by the *internal carotid artery*) – measures approximately 0.8 mm in diameter. Its origin from the ophthalmic artery exhibits morphological variants. The artery exits the intracranial space of the orbital cavity in a medial direction, in over 90% of cases between the *medial rectus* and *superior oblique muscles*, then passes through the *anterior ethmoidal foramen* toward the ethmoid cavity (Fig. 2.6). In the frontal plane, the medial *anterior ethmoid artery* is located behind the eyeball. At the foramen, the bone of the *lamina papyracea* forms a small, medially oriented, funnel.

At the roof of the anterior ethmoid, the artery, accompanied by an *ethmoidal nerve* and a small vein, then runs in a bony canal from posterolateral to anteromedial (Fig. 2.7). In this configuration, it forms an approximately 60° angle with the *lamina papyracea* and is most commonly (> 85%) located between the superior insertion of the second and third basal lamellae or in the *suprabullar recess*. The anteroposterior distance to the “frontal sinus opening” is approximately 11 mm (6–15 mm), and the distance to the anterior insertion of the middle turbinate, approximately 20 mm (17–25 mm). In front of the artery, the skull base first slopes gently upward (15°) and steepens further anteriorly as it joins with the posterior frontal sinus wall.

The bony canal is embedded to a variable degree in the skull base or may lie in a mesentery “suspended” from the skull base at a distance of up to 5 mm (Tab. 2.3, 2.4). The “suspended” variation is more common in men, in patients presenting extensive pneumatization, in cases of a deep olfactory fossa (Keros type 3), in those with a larger anteroposterior diameter of the frontal sinus, and particularly in the presence of supraorbital cells – in the latter case, the artery runs in the posterior wall of these cells. The anteroposterior location of the anterior ethmoid artery is, however, unrelated to the extent of pneumatization. Asymmetries are common, and in these cases the right side usually exhibits a larger distance between the artery and the skull base.

---

**Fig. 2.6** CT scan showing an “extension” of the superomedial orbital wall (↓) along the course of the AEA. *Superior oblique muscle* and *medial rectus muscle* highlighted in color; the AEA runs between the two structures in a medial direction.

**Fig. 2.7** Endoscopic view of the left anterior skull base after removal of cell septa. **Positional variation C** of the *anterior ethmoid artery* (♀) (according to: *Moon et al 2001*) in the posterior region of the frontal sinus “opening.” Frontal sinus drainage pathway (arrow); vertical lamella of the anterior middle turbinate (Co.m.); suction tip (♂ ♂).

---

**Table 2.3** Positional variation patterns of the *anterior ethmoid artery* (AEA) at the skull base in relation to the insertion of the basal lamellae (Moon et al. 2001).

<table>
<thead>
<tr>
<th>Variation</th>
<th>AEA course</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>coursing between 2nd und 3rd basal lamellae (87 %).</td>
</tr>
<tr>
<td>B</td>
<td>AEA in the 3rd basal lamella (11 %).</td>
</tr>
<tr>
<td>C</td>
<td>AEA in the 2nd basal lamella (2 %).</td>
</tr>
</tbody>
</table>
The bone along the medial portion of the anterior ethmoid artery is very thin at its junction with the olfactory fossa. In approximately 40% of cases, the arterial canal is focally absent, i.e., there are bony dehiscences. After entering the endocranium, the artery runs in a groove of the lateral olfactory fossa (anterior ethmoidal sulcus) (Fig. 2.8) for a distance of 3–16 mm; this groove is often visible in CT. One of its branches becomes the anterior nasal artery at the site where it re-enters the nose through the anterior cribriform plate (cribro-ethmoidal foramen). With other, peripheral extracranial branches (medial and lateral anterior nasal branches), it supplies the anterosuperior part of the nasal septum and the middle turbinate. Other branches continue endocranially, for instance between two dural sheets, then termed as anterior meningeal artery and anterior falcine artery (A. falcea anterior).

### Clinical Hints
- Generally, the anterior ethmoid artery is found by dissecting cautiously along the anterior wall of the ethmoid bulla toward the skull base. The artery most commonly lies approximately 1–2 mm behind this bulla lamella.
- The anterior ethmoid foramen forms a small, bony funnel which runs toward the ethmoidal infundibulum. This anatomical configuration is fraught with the risk of inadvertent transection of the anterior ethmoid artery at the lateral
In about \( \frac{2}{3} \) of cases, the individual positional and morphological variation patterns of the anterior ethmoid artery do not afford adequate space to apply a vascular clip in that position (Floareani et al. 2006).

In patients with craniofacial malformations, abnormal relative positions of the AEA have been observed (Wong et al. 2014). Arterial aplasia is found in about 3% of cases.

Peripheral branches of the AEA (anterior nasal artery) which re-enter the nasal cavity through the cribro-ethmoidal foramen (opening in the cribriform plate) may be located as landmarks in expanded frontal sinus procedures (first olfactory neuron lies approx. 3 mm further dorsally; for safety reasons, dorsal bone removal from the frontal sinus floor should be limited to tissue \( \geq 7 \text{ mm} \) anterior to the neuron or generally to tissue anterior to the artery). In alternative cases, the vessel is used to supply special mucosal flaps of the nasal septum. Less commonly, the peripheral septal branches are the source of spontaneous epistaxis (Gras-Cabrerizo et al. 2016; Turri-Zanoni et al. 2018; Upadhyay et al. 2016).

Using the anterior lacrimal crest as a reference point, the anterior ethmoid artery is located 24 mm posteriorly. The posterior ethmoid artery is located 12 mm further dorsally, and the optic canal, 6 mm behind it (“24 – 12 – 6 rule”). An alternative rule (“21 – 14 – 7 rule”) is cited for the posterior lacrimal crest. However, both rules are unreliable due to the considerable variability in the stated distances (particularly with regard to the distance between the posterior ethmoid artery and the optic canal).

### Special Literature


### Arteria ethmoidalis media („A. ethmoidalis accessoria“)

In approximately 30% of cases, a third ethmoid artery with a separate ethmoidal foramen is found at the skull base, often only on one side (usually on the right). This middle ethmoid artery is smaller in diameter than the anterior ethmoid artery and runs in a bony canal with relatively thick walls. Therefore, the middle ethmoid artery is rarely demonstrated in surgical routine. According to literature, it is most commonly found in the next-to-last quarter of a line drawn between the anterior ethmoid artery and the posterior ethmoid artery (Fig. 2.9). It follows a straight course from lateral to medial (Fig. 2.10).

![Fig. 2.9 Schematic drawing of the right anterior skull base (horizontal plane, view from top “through the skull base”) demonstrating the locations of the ethmoid arteries (from: Wang et al. 2014b). Shown are, among others, the anterior and posterior ethmoid arteries as well as the midpoint between the two vessels (M) and the point halfway between (M) and the posterior artery (M’). Any middle ethmoid artery, if present, is most commonly located between (M) and (M’). Other authors place the middle ethmoid artery closer to (M), with both the anterior ethmoid artery and posterior ethmoid artery lying at a distance of 11 mm (Mason et al. 2019).](image-url)
More than three or less than two ethmoid arteries are found in approximately 10% of cases (Tab. 2.5).

<table>
<thead>
<tr>
<th>Number of ethmoid arteries (Piagkou et al. 2014)</th>
<th>Type 1 One ethmoid artery (2%).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 2 Two ethmoid arteries (61%).</td>
<td></td>
</tr>
<tr>
<td>Type 3 Three ethmoid arteries (28%).</td>
<td></td>
</tr>
<tr>
<td>Type 4 Multiple ethmoid arteries (9%).</td>
<td></td>
</tr>
</tbody>
</table>

**Tab. 2.5** Anatomic classification scheme based on the number of ethmoid arteries.

---

**Arteria ethmoidalis posterior**

The *posterior ethmoid artery* is approximately 0.5 mm in diameter. Unlike the anterior ethmoid artery, within the orbit, it typically courses medially over the superior oblique muscle. This is followed by an almost horizontal course along the skull base near the anterior sphenoid sinus wall. In its course, it is virtually always (> 90%) embedded in the osseous skull base; side-to-side differences are common. In the coronal CT scan, a small extension of the cranial medial wall of the orbit as the proximal portion of the canal is seen in approximately 25–50% of cases (Fig. 2.11). In about 10% of cases, the artery is not identifiable in a routine CT scan and cannot be exposed by dissection.

**Special Literature**


**Fig. 2.11** Frontal CT scan of the posterior ethmoid. Shown is the proximal canal of a posterior ethmoid artery (arrow).

---

**Arteria ethmoidalis anterior**

The *posterior ethmoid artery* is approximately 0.5 mm in diameter. Unlike the anterior ethmoid artery, within the orbit, it typically courses medially over the superior oblique muscle. This is followed by an almost horizontal course along the skull base near the anterior sphenoid sinus wall. In its course, it is virtually always (> 90%) embedded in the osseous skull base; side-to-side differences are common. In the coronal CT scan, a small extension of the cranial medial wall of the orbit as the proximal portion of the canal is seen in approximately 25–50% of cases (Fig. 2.11). In about 10% of cases, the artery is not identifiable in a routine CT scan and cannot be exposed by dissection.

**Special Literature**


**Fig. 2.10** Endoscopic view of the left anterior skull base. Vertical lamella of the anterior middle turbinate (Co.m.); *Medial ethmoid artery* (arrows); maxillary sinus fenestration in the middle meatus (S.max.).
**Arteria maxillaris**

The maxillary artery is the terminal branch of the external carotid artery. Its diameter is approximately 2–3 mm. The course and branching of the maxillary artery are subject to considerable variation (Tab. 2.6, 2.7). Generally, the course of the vessel is divided into three portions:

1. **Mandibular portion** proximal to the inferior margin of the lateral pterygoid muscle.
2. **Pterygoid portion** running above or below the lateral pterygoid muscle up to the sphenomaxillary fissure.
3. **Pterygopalatine portion** in the pterygopalatine fossa.

For the topics discussed herein, portions 2 and 3 are relevant. In the pterygoid portion, the artery is surrounded by a venous plexus (pterygoid plexus) and runs above (laterally, superficially) and below (medially) in 30% of cases. These two portions contain the following main arterial branches:

1. **Anterior and posterior deep temporal artery.**
2. **Pterygoid artery.**
3. **Masseteric artery.**
4. **Buccal artery.**
5. **Posterior superior alveolar artery** (approx. 1.3 mm in diam.).
6. **Infraorbital artery** (approx. 1.3 mm in diam.).
7. **Descending palatine artery** (approx. 0.7 mm in diam.).
8. **Palatovaginal artery** (pharyngeal artery).
9. **Artery of the pterygoid canal** (approx. 0.7 mm in diam.).
10. **Sphenopalatine artery** (approx. 1.8 mm in diam.).

---

**Morphological variation patterns of the distal maxillary artery dividing into the sphenopalatine artery and descending palatine artery, viewed from anterior to posterior.** (Abuzayed et al. 2009; Choi and Park 2003; Morton and Khan 1991).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Y” Type</td>
<td>(20%)</td>
</tr>
<tr>
<td>“T” Type</td>
<td>(20%)</td>
</tr>
<tr>
<td>“M” Type</td>
<td>(30%)</td>
</tr>
<tr>
<td>“Intermediate” Type</td>
<td>(30%)</td>
</tr>
</tbody>
</table>

**Morphological variation patterns of the distal maxillary artery in the pterygopalatine fossa (Chiu 2009).**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single loop</td>
<td>(18%)</td>
</tr>
<tr>
<td>Double loop</td>
<td>in the shape of the letter “E” (51%)</td>
</tr>
<tr>
<td>Double loop</td>
<td>in the shape of the letter “M” (31%)</td>
</tr>
</tbody>
</table>

**Tab. 2.6** Morphological variation patterns of the distal maxillary artery when viewing at the right posterior wall of maxillary sinus (figures greatly simplified).

**Variations related to the branching of the distal maxillary artery.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td><em>Infraorbital artery and posterior superior alveolar artery</em> arise from a common branch of the maxillary artery (60 %).</td>
</tr>
<tr>
<td>Type 2</td>
<td>The branches (mentioned above) originate from the maxillary artery at different sites (40 %).</td>
</tr>
</tbody>
</table>

**Tab. 2.7** Variations related to the branching of the distal maxillary artery.

**Special Literature**


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*[a] see also: Fossa infratemporalis; Fossa pterygopalatina*
Arteria nasalis posterior septi (A. septi posterior)

In most cases, the posterior nasal septal artery (approx. 1.7 mm in diameter) passes through the sphenopalatine foramen independently from the sphenopalatine artery (Tab. 2.18). It courses over the anterior sphenoid sinus wall between the choana and sphenoid sinus ostium, where it divides (lateral to the ostium in approx. 65% of cases) into two branches (Figs. 2.12, 2.13). The inferior branch is dominant in 60% of cases. Proximal to the bifurcation, the artery often gives rise to a branch running toward the superior turbinate, the choana, and/or the mucosal surface of the anterior sphenoid sinus wall. On the nasal septum mucosa, the artery branches in a highly variable manner. Courting in a caudal direction, the inferior main branch remains more than 5 mm anterior to the posterior septal margin. Peripheral anastomoses to branches of the posterior ethmoid artery, to the anterior ethmoid artery, to the septal branch of the dorsal nasal artery, and to the greater palatine artery can be seen.

Clinical Hints
- On the one hand, the posterior nasal septal artery can be the source of troublesome bleeding during transnasal sphenoid sinusotomy. Electrocoagulation performed under endoscopic control is commonly a straightforward task.
- On the other hand, the artery is particularly relevant to the blood supply of any pedicled nasoseptal flap used for extensive coverage of skull base defects.

Special Literature
**Arteria nasalis posterior lateralis**

As a distal branch of the sphenopalatine artery, the posterior lateral nasal artery, in turn, divides into one artery to the inferior turbinate and one to the middle turbinate. In this regard, there are a series of variable branches, with further variations related to their course, as shown in Fig. 2.14. The proximal branch to the middle turbinate is found almost invariably (90%). In 40% of cases, the branch to the inferior turbinate runs in a frontal plane in front of the posterior maxillary sinus wall. Therefore, ample fenestration of the maxillary sinus in the middle meatus poses the risk of iatrogenic injury (Figs. 2.15, 2.16). Distally, the branch of the vessel terminates in the tissue of the inferior turbinate.

---

**Fig. 2.14** Arterial supply of fontanelles in the area of the dorsal middle meatus (note, the posterior portions of the middle turbinate have been removed). Variation pattern (a) is most commonly found; variation patterns (b–d) are listed in order of decreasing frequency. *Superior turbinate (sT); Middle turbinate (mT); Inferior turbinate (iT); Ethmoidal crest (Ce)* (from: Lee et al. 2002).

**Fig. 2.15** Schematic drawing of the right posterior middle meatus (a–d). Parts of the middle turbinate (mT) have been removed: Variation patterns related to the potential course of the posterior lateral nasal artery (ANPL). The yellow line corresponds to the frontal plane of the posterior maxillary sinus wall. Clearly, in case of far dorsal maxillary sinus fenestration, (controllable) bleeding should be anticipated in some cases. *Uncinate process (PU); Superior turbinate (sT); Middle turbinate (mT); Inferior turbinate (iT)* (from: Lee et al. 2002).

**Fig. 2.16** Endoscopic straight forward view of the right middle meatus. In case of ample fenestration of the maxillary sinus, bleeding in a posterior position is seen to arise from the posterior lateral nasal artery (or one of its branches). *Lacrimal sac (S.l.) (under mucosal covering, lacrimal bone or frontal process of maxilla); Middle turbinate (Co.m.), suction tip (♀).*

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*a* see also: Concha inferior; Fontanelles

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**Special Literature**

Lee et al. 2002; MacArthur and McGarry 2017.
Arteria ophthalmica

Arteria palatovaginalis

As a distal branch of the maxillary artery, the palatovaginal artery has a diameter of less than 1 mm. It is often also referred to as pharyngeal artery or pterygovaginal artery and runs alongside a peripheral nerve originating from the maxillary nerve or pterygopalatine ganglion in a separate bony canal (pharyngeal canal) from the pterygopalatine fossa toward the nasopharynx and its mucosa. The pharyngeal canal is located between the sphenoid bone and the often (nearly 70% of cases) very thin sphenoidal process of the palatine bone. In 10% of cases, the sphenoid bone exhibits only a groove instead of a pharyngeal canal, and in 5%, neither a canal nor a groove is present.

In about 70% of cases, the pharyngeal canal (or palatovaginal canal) can be identified in the posterior wall of the pterygopalatine fossa, either by radiological imaging and / or by dissection. In the frontal CT scan, it is found medial to the pterygoid canal. The distance between the two openings is usually 2–4 mm. If present, the canal is approximately 7 mm long (much shorter than the pterygoid canal) and runs dorsomedially (Fig. 2.17). Dorsal to the posterior opening, the pterygoid canal is continuous with a groove in the sphenoid bone. Further posteriorly, the palatovaginal canal and pterygoid canal diverge, thereby forming an angle of approximately 40° in the horizontal plane. Dorsally, the upward slant of the palatovaginal canal is a little more pronounced (9°).

Clinical Hints
- The palatovaginal artery can be the source of epistaxis or intraoperative bleeding.
- In the best possible circumstances, a coronal CT scan should allow to identify three canals at the junction of the palatine bone and sphenoid bone (from medial to lateral: palatovaginal canal, pterygoid canal, foramen rotundum). In juvenile angiofibroma, for instance, all three canals may harbor tumor extensions.
- Intraoperatively, the palatovaginal canal can be confused with the pterygoid canal. The former is therefore best to locate at the cranial end of the sphenoidal process of the palatine bone.

Arteria sphenopalatina

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a see: Canalis N. optici; Orbita
b see: Foramen sphenopalatinum
Structural Elements of the Paranasal Sinuses

Basal lamellae

The basal lamellae are remnants of 5–6 ridges which form in the lateral nasal wall during embryogenesis, some of which later undergo partial fusion (ethmoturbinals). The most important is the basal lamella of the middle turbinate (remnant of the third ridge = third basal lamella). It separates the anterior and posterior ethmoid cells and has a complex three-dimensional geometry: Its anterior segment has a sagittal, vertical orientation; its middle segment lies in an almost frontal plane, and its dorsal segment is almost horizontal (Figs. 1.3, 2.18). During embryonic pneumatization, large posterior ethmoid cells may cause an anterior bulge in the basal lamella of the middle turbinate, while expansive anterior ethmoid cells may indent the lamella posteriorly (“struggle of the ethmoid”, see Figs. 2.18c, 2.19). As a result, in 10% of cases, the presumed “posterior” ethmoid is formed partially by cells or recesses of the ethmoid bulla, while conversely, 14% of the posterior cells bulge forward into the region of the ethmoid bulla.

Besides the basal lamella of the middle turbinate / third lamella, the following basal lamellae exist (see Figs. 1.1, 1.5):

- First basal lamella – agger nasi and uncinate process.
- Second basal lamella – ethmoid bulla.
- Fourth basal lamella – basal lamella similar to the third lamella, but involving the superior turbinate.
- Moreover, a supreme turbinate is present in 15% of cases, adding a fifth basal lamella.

As mentioned above, the European Rhinological Society recommends using the term basal lamella rather than “ground lamella.”

Clinical Hints

- The “struggle of the ethmoid” can occasionally have implications, namely by intraoperatively interfering with a precise and complete appreciation of the topographic anatomy of the basal lamella. In patients with an anterior displacement of the basal lamella of the middle turbinate, the complete removal of the “anterior face” of the ethmoid bulla would formally correspond to an opening of the posterior ethmoid (Fig. 2.19).

- The described variability of the anatomy complicates a compelling standardization of surgical procedures.

Fig. 2.18 CT scan in three planes showing the basal lamella (––––––) of the middle turbinate.

a. Sagittal plane overview.
b. Frontal CT scan of an anterior sagittal segment.
c. Axial CT scan of the middle segment lying in an almost frontal plane.
d. Frontal CT scan of the horizontal dorsal segment.

---

8] see also: Concha media and Fig. 1.1
Bulla ethmoidalis

The *ethmoid bulla* is a remnant of the second ethmoturbinal (second basal lamella). During embryogenesis and later maturation, its pneumatization creates the typically largest and most nonvariant anterior ethmoid cell (alongside the often less noticeable *agger nasi cell*). In most cases, the ethmoid bulla contains 1–2 anterior ethmoidal air cells, which usually drain into the retrobullar recess with the *superior semilunar hiatus* (Figs. 1.5, 2.20, Tab. 2.8). Less commonly, the ostium of a bulla cell is found anteriorly or medially.

In some rare cases, the lamella is not pneumatized, and only a mucosal-bony *“torus bullaris”* remains. More commonly (8%), there is an existing, but distinctly underdeveloped bullar pneumatization. Based on other calculations, the ethmoid bulla appears, from an anterior aspect, typically disc-shaped or balloon-shaped in 45% of cases, as a bulla extending from superior to inferior in 34% of cases, and hypoplastic in 21% of cases. If the ethmoid bulla extends to the skull base (in the absence of a *suprabullar recess*), it forms the posterior boundary of the frontal recess.

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**Special Literature**

- Christmas et al. 2015
- Daniels et al. 2003
- Joe et al. 2000
- Lund et al. 2014
- Setliff et al. 2001
- Tan et al. 2017
- Thomas and Pallanch 2010
- Wormald et al. 2016

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**Clinical Hint**

In clinical practice, it is not always easy to differentiate a suprabullar recess from a suprabullar cell.

---

**Tab. 2.8** Variations related to pneumatization of the ethmoid bulla and suprabullar cells.

| Pneumatization patterns of the ethmoid bulla (Setliff et al. 2001). | Type 1 | “Simple type” – single cell (47 %). |
| Type 2 | “Compound type” – multiple cells, with an opening into / through the superior semilunar hiatus (26 %). |
| Type 3 | “Complex Type”: multiple cells with variable openings to surrounding structures (27 %). |

| Variations of suprabullar pneumatization (Tan et al. 2017). | Type 0 | No air cell between ethmoid bulla and skull base, bulla extends to skull base (13 %). |
| Type 1 | A single suprabullar cell (not extending into the frontal sinus) (24 %). |
| Type 2 | Multiple suprabullar cells (not extending into the frontal sinus) (40 %). |
| Type 3 | Single cell or multiple suprabullar cells extending into the frontal sinus (frontal bullar cell) (23 %). |

**Fig. 2.19** As part of the variable expansion of anterior or posterior ethmoid air cells (“struggle of the ethmoid”), the development and maturation of the ethmoid cell system may, in some cases, result in variable deformation of the middle third of the basal lamella of the *middle turbinate* (Daniels et al. 2003).

**Fig. 2.20** Endoscopic straightforward view into the left middle meatus after resection of the uncinate process and fenestration of the maxillary sinus. Anterior wall of ethmoid bulla (*Bu*); Access to retrobullar recess (*arrow*); Vertical lamella of middle turbinate (*Co.m.*); Nasal septum (*S.*); Frontal process of maxilla (*Proc.f.max.*); Access to maxillary sinus (*S.max.*).
**Bulla frontalis**

The frontal bulla is a particularly large anterior ethmoid cell which extends anteriorly along the skull base and superiorly along the posterior wall of frontal sinus (i.e., into the frontal sinus) (Fig. 2.21).

There has been no uniform classification and terminology for the frontal bulla, e.g., in terms of its classification as a “frontoethmoidal cell.” Based on a more recent classification, the term “supra bulla frontal cell” is used (see: Frontoethmoidal cells).

**Clinical Hint**

Identification of a posterior frontal bulla (i.e., a supra bulla frontal cell) is of key importance in ENT surgery (frontal sinus drainage pathway lies anteriorly in such cases). Mistaking the frontal bulla for an anterior “frontoethmoidal cell” – i.e., a supra agger frontal cell (SAFC) – can lead to destruction of the skull base in frontal sinusotomy (in the presence of an SAFC, the frontal sinus drainage pathway lies posteriorly).

**Special Literature**

Wormald et al. 2016.

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**Canalis craniopharyngealis**

**Canalis infraorbitalis**

**Canalis nasolacrimalis**

---

a] see also: Bulla ethmoidalis; Frontoethmoidal cells; Recessus frontalis
b] see: Sternberg canal
c] see: N. infraorbitalis
d] see: Lacrimal passages
Canalis N. optici

The optic nerve generally comprises four segments, the intracranial (approx. 10 mm), intracanalicular, intraorbital (25–30 mm), and intraocular (approx. 1 mm) segments. The second and third segments are enveloped by the dura and arachnoid mater, with a thin extension of the subarachnoid space.

The optic canal is about 9 mm (5–12 mm) in length, has an oval cross-section, and measures 4–7 mm in diameter (Fig. 2.22). The canal runs at a variable angle to the horizontal plane; its narrowest point is in its center, and its wall is 0.3–1 mm thick. In 80% of cases, however, the bone is only less than 0.5 mm thick in some locations (usually in the central medial part of the canal), and in approximately 5%, natural dehiscences are found (more commonly in case of extensive pneumatization of the posterior paranasal sinuses).

The literature provides highly inconsistent information on the canal's position in relation to the adjacent paranasal sinuses. For general orientation, the distal opening of the canal is found in the wall of a posterior sphenoethmoidal cell in 50% of cases, at the junction of the sphenoid sinus and ethmoid sinus in 25%, and in the sphenoid sinus itself in another 25% of cases (see: Sphenoethmoidal cell).

In 8–32% of cases, the optic canal forms a prominence in the lateral sphenoid sinus wall (Tab. 2.9). In sphenoethmoidal cells, this rate is about 40%. On average, about 100° of the canal circumference lies exposed. If the anterior clinoid process is pneumatized, then a distinct prominence and exposure of the canal is even more likely (Fig. 2.23). The bony optic tubercle corresponds to a thickened medial wall of the optic foramen, which is clearly visible in the sinuses in some cases.

The intracanalicular and intraorbital segments of the optic nerve are enveloped by dura mater and arachnoid. At the orbital apex, adjacent to the optic foramen and the superior orbital fissure, the dura and orbital periosteum fuse (periorbita) and form a connective tissue ring (annulus of Zinn, annular tendon, insertion of the eye muscles). The optic nerve passes through the medial part of the annulus of Zinn.

The ophthalmic artery has a diameter of approximately 1.7–2 mm. It originates from the supraclinoid segment of the carotid artery in variable locations (rostromedially in 52%, medially in 26%, and laterobasally in 22% of cases), each about 2.5 mm from the entrance of the optic canal. Within the canal, the proximal ophthalmic artery courses intradurally and medially in 15% of cases, and in its further course, inferiorly and medially in 23% of cases. When exiting the canal, the artery courses medially in 15% of cases and laterally in 85% of cases (Fig. 2.24).

In its canal, the blood supply of the optic nerve itself is largely provided by 1–4 thin branches (about 0.3 mm in diameter) from the region of the superior hypophyseal artery (A. hypophysialis superior), typically not by the ophthalmic artery itself.

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Fig. 2.22  Dimensions of the optic canal in a random case (axial CT scan).

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Fig. 2.23  Example of an extensively pneumatized anterior clinoid process (N.a.) within the sphenoid sinus (see: Processus clinoideus anterior).
Fig. 2.24 Schematic drawing showing variations in the course of the ophthalmic artery (red) in the right optic canal (axial slice; nerve in yellow). Note that the relative position of the artery often changes along the course of the optic canal (from: Slavin et al. 1994). Based on literature, the prevalence of morphological variation patterns are highly variable (see e.g.: Erdogmus and Govsa 2006b; Li et al. 2008; Locatelli et al. 2011).

Location of the optic canal in relation to the paranasal sinuses (DeLano et al. 1996).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Adjacent to the sphenoid sinus (76%).</td>
</tr>
<tr>
<td>Type 2</td>
<td>Prominence on the sphenoid sinus wall (15%).</td>
</tr>
<tr>
<td>Type 3</td>
<td>Courses through the sphenoid sinus (6%).</td>
</tr>
<tr>
<td>Type 4</td>
<td>Adjacent to the sphenoid sinus and posterior ethmoid cells (3%).</td>
</tr>
</tbody>
</table>

Location of the posteriormost ethmoidal cell relative to the optic canal (Chmielik and Chmielik 2017).

| Type A | No contact between the wall of the ethmoid cell and the optic canal (44%). |
| Type B | Minimal contact (< 2 mm) without optic canal prominence and without cell extensions superior or lateral to the nerve (16%). |
| Type C | Overt contact (> 2 mm) with cell extensions superior or lateral to the nerve, without any optic canal prominence (15%). |
| Type D | As Type C, but with optic canal prominence (25%). |

Prominence of the optic canal in the sphenoid sinus (Chen et al. 2006).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 0</td>
<td>No pneumatization of the sphenoid sinus near the optic canal (5%).</td>
</tr>
<tr>
<td>Type 1</td>
<td>Pneumatization extends to optic canal (26%).</td>
</tr>
<tr>
<td>Type 2</td>
<td>Optic canal presents as a minor prominence in the sphenoid sinus (40%).</td>
</tr>
<tr>
<td>Type 3</td>
<td>Optic canal projects by less than 50% of its circumference (14%).</td>
</tr>
<tr>
<td>Type 4</td>
<td>Optic canal projects by more than 50% of its circumference (15%).</td>
</tr>
</tbody>
</table>

Angle between optic canal and internal carotid artery when looking at the lateral sphenoid sinus wall (Yilmazlar et al. 2012).

| Type 1 | Obtuse angle (42%). |
| Type 2 | Acute angle (36%). |
| Type 3 | ~ Overlap of both structures (22%). |

Clinical Hints

- Endoscopic endonasal removal of the medial wall of the optic canal (optic nerve decompression) is generally feasible for a length of approx. 7 mm and approx. 100°–180° of its circumference. The circumferential exposure can be increased to a maximum degree of 270° in case of favorable anatomy, for instance by drilling and prying away the last bony lamella inferior to the clinoid process. The exposed surface area is typically approx. 0.66 (0.37–1.15) cm². Medial-inferior decompression or exposure of the optic nerve is in principle feasible beyond the course of the optic canal, i.e., from the optic tubercle to the chiasm. In such cases, bone ablation would extend over a length of 15 ± 2 mm (Di Somma et al. 2017; Hart et al. 2009; Locatelli et al. 2011).

- The special benefit (improved nerve decompression) or harm (impaired microvascularization) of slitting the optic nerve sheath following bone removal, with exposure of the optic nerve, is a subject of controversy in the literature (Kühnel and Reichert 2015; Slavin et al. 1994).

- In cases where the ophthalmic artery runs medial to the optic nerve through parts or all of the optic canal, the optic nerve may be at risk when performing decompression with slitting of the optic nerve sheath.

- Rare anatomic variations with optic nerve dystopia have been observed, e.g., in a patient with Turner syndrome.

Special Literature

Canalis palatovaginalis\textsuperscript{b} (Canalis pharyngealis)

Canalis pterygoideus\textsuperscript{c} (C. N. pterygoidei, C. N. Vidiani)

The pterygoid canal is a bony canal running from the anterolateral foramen lacerum to the pterygopalatine fossa. In view of its relationship to the internal carotid artery in the foramen lacerum region, the canal is of vital importance in surgical practice.

The greater petrosal nerve runs over the distal petrosal segment of the internal carotid artery into the pterygoid canal, the latter lying inferior to the plane of the artery. It joins with fibers from the sympathetic plexus around the carotid artery and continues as the nerve of the pterygoid canal (Vidian nerve). The nerve is accompanied by one or two small arteries approximately 0.1 mm in diameter. In nearly 50% of cases, this arterial connection is a true anastomosis of the internal carotid artery and maxillary artery.

At the foramen lacerum, the canal is embedded within chondral tissue, which is in contact with the content of the foramen lacerum. As it progresses forward, the canal is lined by periosteum, which distally fuses with the periosteal lining of the pterygopalatine fossa.

The canal is about 15 mm (10–23 mm) long, almost straight (dorsally following a slightly lateral course) and tilted toward the horizontal plane by only 3° (i.e., it minimally ascends dorsally). In the sphenoid sinus, it courses along the floor forming a “prominence” in about 65% of cases, while such a distinctive feature is absent in 35% of cases (Fig. 2.17). As a result, the canal has a diameter of approx. 2 mm anteriorly and approx. 1.8 mm posteriorly. In a well-pneumatized sphenoid sinus, the pterygoid canal tends to be narrower. Rarely (1%), the canal is split into two parts in its anterior segments.

The anterior ostium of the pterygoid canal can be localized in frontal CT scans by mentally projecting the letter “H” onto the image. The upper vertical leg of the letter matches the sagittal plane of the ascending paracervical carotid artery (in a deeper slice), while the lower vertical legs correspond to the medial plane of the palatine bone. The horizontal leg represents the sphenoid sinus floor. The pterygoid canal is located at the junction between the horizontal and vertical legs (Fig. 2.26).

Upon detailed analysis, the location of the canal does not fully comply with this rule: Relative to the medial lamella of the pterygoid, the canal runs medially in 31% of cases, laterally in 6%, and directly in the plane in only 63% of cases. The relationship between the dorsal canal segments and the genu of the internal carotid artery (“g2”: junction of the petrous segment and the petroclival segment; Fig. 2.17) is not fully clear either: in 89% of cases, the canal is inferior to the genu, in 7%, in the same plane, and in 4%, superior to the genu.

The distance between the anterior opening of the pterygoid canal and foramen rotundum is 6–8 mm in the horizontal plane and 5–6 mm vertically (the pterygoid canal is located inferiorly; Fig. 2.27). This distance is subject to great variability, however (1.5–10 mm). The distance to the sphenopalatine foramen is also approximately 6 mm. With the medial, often immediately adjacent (in other cases about 6 mm distant) palatovaginal canal, the pterygoid canal forms an approximately 40° angle.

Course of the pterygoid canal shown in an axial plane (from: Lang and Keller 1978).

| Type A | Straight course at an angle of approx. 14° (5°–45°) with the mid-sagittal plane (anteromedial, posteros medial; 44%). |
| Type B | Straight course parallel to the mid-sagittal plane (24%). |
| Type C | Crescent-shaped course in a medial direction (32%). The anterior segment forms an approx. 12° angle with the mid-sagittal plane (5°–24°, anterolateral, posteromedial). |

View onto the skull base (detail) with variations related to the course of the pterygoid canal (red).

Tab. 2.10 Variations related to the course of the pterygoid canal and morphology of surrounding bony structures (continued on next page).

\textsuperscript{a} see: Palatine bone
\textsuperscript{b} see: A. palatovaginalis; Canalis pterygoideus (Fig. 2.17)
\textsuperscript{c} see also: A. carotis interna; Fossa pterygopalatina
Structural Elements of the Paranasal Sinuses

Level of the sphenoid sinus floor in the region of the pterygoid canal and the palatovaginal canal (Cheng et al. 2015a).

| Type 1 | Convex elevation of sphenoid sinus floor (40%).
| Type 2 | Flat sphenoid sinus floor (60%).

Prominence of the pterygoid canal (Cheng et al. 2017).

| Type 1 | Canal protrudes into the sphenoid sinus (65%).
| Type 2 | Canal courses in the sphenoid sinus floor without direct relationship to the sphenoid sinus lumen (35%).

Pneumatization "around the pterygoid canal" (percentage of circumference) (Vescan et al. 2007).

| Type 1 | 0 % (29 %).
| Type 2 | 1 % – 33 % (10 %).
| Type 3 | 34 % – 66 % (44 %).
| Type 4 | 67 % – 100 % (17 %).

Variation patterns of the pterygoid canal on the sphenoid sinus floor (synthesized from: Acar et al. 2019; Lee et al. 2011a; Lee and Lin 2012; Yazar et al. 2007).

| Type 1 | Canal runs completely exposed in the sphenoid sinus (approx. 10 %).
| Type 2 | Canal runs partially exposed on the sphenoid sinus floor (approx. 50 %).
| Type 3 | Canal lies completely within the sphenoid bone (approx. 40 %).

Contour of the sphenoid sinus floor in relation to the pterygoid canal (Liu et al. 2010a).

| Type 1 | Flat sphenoid sinus floor, canal in the plane of the floor (53 %).
| Type 2 | Sphenoid sinus floor laterally upsloping, canal superior to the medial floor (26 %).
| Type 3 | Sphenoid sinus floor laterally downsloping, canal inferior to the medial floor (9 %).
| Type 4 | Sphenoid sinus floor contoured as an “inverse V”, canal inferior to the lateral floor (12 %).

Tab. 2.10 Variations related to the course of the pterygoid canal and morphology of surrounding bony structures.

Fig. 2.25 Exemplary course of a “Type 1” pterygoid canal (according to Lee and Lin 2012) with “free” course in the sphenoid sinus. In the frontal CT scan, “crab eyes” are visible (Lund et al. 2010).
Clinical Hints

- If the need arises to remove tissue at the junction of the petrous bone and sphenoid bone, the pterygoid canal serves as an important “guide rail” to identify the carotid artery near the foramen lacerum. When drilling away bone “around the pterygoid canal”, firm rules should be adopted: On the left side, the bone is first removed counterclockwise from 9 o’clock to 3 o’clock (beneath the nerve). Only after drilling away the medial and inferior portions of bone toward the petrous apex, the superior portion of bone is removed, now proceeding clockwise from 9 o’clock to 3 o’clock (Kassam et al. 2008). Limitations to this rule regarding the relative location of the carotid artery and pterygoid canal are given above (Adin et al. 2018).

- The paracaval internal carotid artery is commonly found medial to the pterygoid canal. The horizontal petrous part of the artery is located superiorly and laterally (Dallan et al. 2010a).

- According to the literature, techniques have been proposed for sparing the nerve of the pterygoid canal in transpterygoid approaches: Following complete removal of the posterior maxillary sinus wall and the vertical portions of the palate bone, first the vascular and neural elements of the pterygopalatine fossa are exposed. After transecting the sphenopalatine and palatovaginal arteries, followed by a stepwise removal of the bone overlying the nerve of the pterygoid canal, the nerve may then be transposed laterally together with the soft tissue contained in the fossa. This reportedly leads to unobstructed access to the medial portions of the pterygoid process (Vidian nerve transposition, pterygopalatine fossa transposition) (Araujo Filho et al. 2006; Pinheiro-Neto et al. 2013).

Special Literature


Canalis rotundus

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*see: Foramen rotundum*
**Canalis vomerovaginalis**

This inconstant canal lies between the vaginal process of the sphenoid bone and the ala of vomer and is 4–7 mm long. It contains pharyngeal nerve branches with one or two small arteries arising from the sphenopalatine artery, and it courses from the medial pterygopalatine fossa toward the nasopharynx.

In most cases, the canal originates together with the palatovaginal canal in the vicinity of the anterior pterygoid canal; in other cases, the canal has a separate origin from the medial posterior wall of the pterygopalatine fossa. The canal runs in a medial direction.

In about 70% of cases, a vomerovaginal canal and a palatovaginal canal can be radiologically distinguished and defined. Anteriorly, the two canals exhibit a bony separation in only about 25% of cases, which is why the two canals often cannot be told apart radiologically. In the horizontal plane, the angle between the vomerovaginal canal and pterygoid canal is even larger (approx. 50°) than the angle between the pterygoid canal and palatovaginal canal (approx. 40°). The angle between the mid-sagittal plane and the anterior vomerovaginal canal is much larger anteriorly than posteriorly and is subject to great variation.

**Special Literature**

Lang and Keller 1978; Meng et al. 2015.

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**Cavum Meckeli**

**Clivus**

Since the synchondrosis between the occipital bone and sphenoid bone is difficult to locate as a landmark in adults, the anatomic term “clivus” is usually understood to be the bony downslope from the dorsum sellae to the foramen magnum.

For general orientation, the clivus is subdivided into three segments:

- The upper third of the clivus extends from the dorsum sellae to the plane of the trigeminal nerve or the plane where the abducens nerve enters the dura. The sphenoid sinus floor often corresponds to the inferior boundary of this segment.

- The middle third extends caudally to the level of the glossopharyngeal nerve roots or to the inferior end of the petroclival fissure. When viewed from anteriorly, the middle third is bounded inferiorly by a small bony elevation (pharyngeal tubercle) to which the superior pharyngeal constrictor muscle is attached.

- The lower third ends at the foramen magnum.

In total, the clivus is about 45 mm in length. To estimate its width, the distance between the two carotids may be used — in the region of the dorsum sellae, it measures only approx. 15 mm, while it is approx. 40 mm in the plane of the pharyngeal tubercle. The inferior clivus often contains emissary veins which connect the basilar venous plexus to the retropharyngeal plexus.

Another major anatomic structure in close proximity to the clivus is the abducens nerve (CN VI). Over its entire course, it can be divided into 5 segments, namely the cisternal segment, Dorello’s canal, cavernous segment, fissural segment, and intracranial segment:

- After exiting the brain stem at the pontomedullary sulcus, the nerve travels first through the cisternal segment until it enters the dura about 17 mm inferior to the posterior clinoid process, 6–12 mm away from the entry point of the trigeminal nerve (CN V).

- The second nerve segment lies between the dura mater and the clival periosteum, in a space between these layers, named Dorello’s canal, measuring about 9.5 mm in length.

- Furthermore, between dura and clival periosteum, there is a thick venous plexus which communicates with the cavernous sinus.

- The petrosphenoidal ligament (Gruber’s ligament) is found superior to the entry of Dorello’s canal. The dural entry point of the nerve is located approx. in the plane of the superior boundary of the carotid artery in the foramen lacerum region.

- At the end of the canal, the nerve is in close proximity to the sympathetic plexus, superior to the lateral wall of the cavernous internal carotid artery and to the medial wall of Meckel’s cave.

The distance between the two abducens nerves at the pontomedullary sulcus is approx. 10 mm. This distance increases to approx. 18 mm at the dural entry point (in the plane of Gruber’s ligament).

**Special Literature**


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[4] see: Sinus cavernosus
Concha bullosa

A concha bullosa media develops due to the pneumatization of an anterior middle turbinate, which can be present in various forms and degrees (Tab. 2.11, Fig. 2.28). Pneumatization can be restricted to the inferior, bulky part of the middle turbinate or to the vertical lamella (appearing as interlamellar cell), or may otherwise involve both parts. Accordingly, a concha bullosa is divided systematically into a bulbous, lamellar, and extensive type. In some cases, several chambers are found in the concha bullosa.

Pneumatization of the concha bullosa may originate from the anterior or posterior ethmoid (or superior meatus in the case of interlamellar cells). Variations of anterior pneumatization are slightly more common, at 55%, and they present different points of origin (frontal recess, suprabullar or retrobullar recess, middle meatus). If, in frontal section, the structure forms a “half shell” with a wider opening into the middle meatus, it is also known as “conchal sinus” (Fig. 2.29).

The prevalence of a concha bullosa ranges from 15% to 50%, depending on the patient population and on how narrowly it is defined. Women tend to have a larger concha bullosa, that is, they are more likely to exhibit a non-lamellar type of pneumatization. A positive correlation has been found between the extent of pneumatization of a concha bullosa and that of other parts of the paranasal sinuses. The presence of a unilateral, bulky concha bullosa is typically associated with a contralateral septal deviation.

<table>
<thead>
<tr>
<th>Variations related to shape and extent of pneumatization in the anterior middle turbinate (Bolger et al. 1991; Hatipoglu et al. 2005).</th>
<th>Bulbous Type (a)</th>
<th>Pneumatization limited to the thickened margin of the vertical lamella (~ 30 %).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamellar Type (b)</td>
<td>Pneumatization is localized to the slender vertical lamella (~40 %).</td>
<td></td>
</tr>
<tr>
<td>Extensive Type (c)</td>
<td>Combination of variation types (a) and (b) (~30 %).</td>
<td></td>
</tr>
</tbody>
</table>

![Variations of interlamellar cell of the middle turbinate (Calvo-Henriquez et al. 2018).](image)

**Variation types of a Concha bullosa.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 0</td>
<td>No cell (60 %).</td>
</tr>
<tr>
<td>Type 1</td>
<td>Pneumatization extends over the vertical half of the anterior middle turbinate (24 %).</td>
</tr>
<tr>
<td>Type 2</td>
<td>Pneumatization extends over the vertical half of the posterior middle turbinate (4 %).</td>
</tr>
<tr>
<td>Type 3</td>
<td>Combination of Type 1 and Type 2 (8 %).</td>
</tr>
<tr>
<td>Type 4</td>
<td>Type 3 with coexisting concha bullosa forming in the inferior half of the turbinate (4 %).</td>
</tr>
</tbody>
</table>

Fig. 2.28 Frontal CT scan showing a bilateral, extensive type of Cocha bullosa (†).
**Structural Elements of the Paranasal Sinuses**

### Concha inferior

This independent bone (of the inferior turbinate) is lined with mucosa and lies in the inferior part of the maxillary hiatus. The turbinate bone is in contact with the maxilla, lacrimal bone, ethmoid bone, and palatine bone; it forms the roof of the inferior meatus. Its mucosal lining is 8–11 mm thick, while the bone has a thickness of 1–2.5 mm.

Among the major morphological variations of the inferior turbinate are those with variably extensive or paradoxical curvatures, the latter often corresponding to a concavity or spur emerging from the adjacent nasal septum. The turbinate bone can be quite variable in size. Bony hypertrophies are more commonly seen in cases of contralateral septal deviation in the anterior aspect of the turbinate. Rarely (2%), there is a “true pneumatization” (concha bullosa) of the inferior turbinate establishing communication with the inferior meatus or the maxillary sinus. A “double” inferior turbinate, whether false (uncinate process displacement) or true, is considered a rare finding. Far more common are variations in size, which are clinically classified into 4 grades (see Tab. 2.11, Calvo-Henriquez et al. 2018).

The blood supply of the inferior turbinate is largely provided by the posterior lateral nasal artery and its variable branches. Usually, there is only one relevant supplying vessel, a branch of the sphenopalatine artery coursing caudally beneath the posterior attachment of the middle turbinate. In 15% of cases, a second artery originates from the descending palatine artery. The distal vessels enter the inferior turbinate at a distance of approximately 7–15 mm from its posterior portion and, in their anterior course, branch in proximity to or in the turbinate bone.

### Variations of the inferior turbinate bone (Uzun et al. 2004b).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Lamellar Type (thin bony lamella) (62 %).</td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>Compact Type (solid bone) (9 %).</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>Composite Type (compact and cancellous bone) (29 %).</td>
<td></td>
</tr>
<tr>
<td>Type 4</td>
<td>Bullous Type (Pneumatization) (&lt; 1 %).</td>
<td></td>
</tr>
</tbody>
</table>

### Size of the inferior turbinate, classified in grades (Camacho et al. 2015).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Proportion of space taken up by width of the anterior inferior turbinate, measured from the attachment site to the nasal septum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td>0 % – 25 %</td>
</tr>
<tr>
<td>Grade 2</td>
<td>26 % – 50 %</td>
</tr>
<tr>
<td>Grade 3</td>
<td>51 % – 75 %</td>
</tr>
<tr>
<td>Grade 4</td>
<td>76 % – 100 %</td>
</tr>
</tbody>
</table>

---

**Clinical Hints**

- A large concha bullosa media can be associated with a lateralized uncinate process, reduction in size and laterodorsal displacement of the ethmoidal bulla as well as dorsal deviation of the basal lamella of the middle turbinate. These changes in relative topographic positions must be taken into account in surgical procedures.

- A pneumatized middle turbinate of Type 3 or Type 4 (see Tab. 2.11, Calvo-Henriquez et al. 2018) has been found to be associated with a higher risk of fracture and ensuing instability of the vertical lamella, which may occur in cases of undue surgical manipulation.

**Special Literature**


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### Tab. 2.12 Anatomic variations of the inferior turbinate bone.

*See also: A. nasalis posterior lateralis*
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

Fig. 2.30a Microanatomic variation patterns of the inferior turbinate (shown is a right inferior turbinate in frontal section). Attachment of the turbinate at the lateral nasal wall (★); turbinate bone (black). Examples in the diagram: Paradoxically curved in a lateral direction (a1); sturdy turbinate bone (a2); delicate turbinate bone (a3); medially deflected turbinate (a4); “double” turbinate (a5); bifid turbinate (a6); “conchal sinus” (a7); Concha bullosa (a8); pneumatization from the maxillary sinus (a9).

Special Literature
Balbach et al. 2011; Braun and Stammberger 2003; Camacho et al. 2015; Dawlaty 1999; Dogru et al. 1999; Maru et al. 2015; Orhan et al. 2010b, 2014; Ozcan et al. 2002, 2008b; Ozturk et al. 2005; Padgham and Vaughan-Jones 1991; Pittore et al. 2011; Rusu et al. 2018; Spear et al. 2003; Uzun et al. 2004a,b.

Concha media

The major constituting element of the middle turbinate is the third basal lamella. The basal lamella of the middle turbinate consists of three segments (Fig. 2.18):

1. A vertical, sagitally oriented lamella of the anterior middle turbinate, attaching to the lateral wall of the olfactory fossa. This segment is best visualized in axial (and frontal) CT.

2. A lamella in the frontal plane, attaching to the ethmoid roof. This segment separates the anterior and the posterior ethmoid cell system. It is best visualized in sagittal or axial CT.

3. A horizontal, posteriorly oriented segment, in contact with the ethmoidal crest of the palatine bone, in proximity to the sphenopalatine foramen. It is best visualized in frontal CT.

Viewed from medially, the middle turbinate clearly presents its variable morphological characteristics (Tab. 2.13). Anterosuperiorly, its free portion is formed by a common surface area of the medial wall of the middle and superior turbinates (and supreme turbinate, if present) (conchal lamina, “turbinal wall of the ethmoidal labyrinth”). The sagitally oriented, common turbinate surface extends over a total area of 6–11 cm², is approx. 1 cm high and approx. 3.5 cm deep (Fig. 2.31). Anterosuperiorly, in the axilla region, the middle turbinate is continuous with the agger nasi region. Cranio-caudally, the anterior vertical lamella is approx. 26 mm high (up to the cribriform plate). The vertical dimension extends superiorly to become the lateral wall of the olfactory cleft.

In approx. one-third of cases, the middle turbinate presents with specific alterations. It can have an expanded appearance, as with a concha bullosa (15%); a sagittal niche (6%), it can appear laterally displaced (4%), present an “L”-shaped frontal section (3%), it can be shaped convexly toward the nasal cavity or can be curved laterally (3% each), and it can have a transversal cleft (Fig. 2.32).

In rare cases (approx. 2–7%), endoscopy of the middle meatus reveals a middle turbinate which appears to be “doubled” (Fig. 2.33). This alteration can be caused by an anteromedially oriented kinking of the uncinate process, by buckling of cell septa out of the ethmoid bulla (incomplete anterior bulla wall), by formation of a bulge at the insertion of the inferior turbinate or a sagittal cleft of the inferior middle turbinate. Often, but not always, this finding is associated with impaired ventilation and drainage properties of the dependent paranasal sinuses.

see also: Concha bullosa; Basal lamellae
Tab. 2.13 Anatomical variations of the contour line of the middle turbinate.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>From the axilla, the anterior margin immediately takes a dorso-inferior course.</td>
<td>45%</td>
</tr>
<tr>
<td>Type 2</td>
<td>From the axilla, the anterior margin initially courses inferiorly, then turns in a dorsal direction</td>
<td>44%</td>
</tr>
<tr>
<td>Type 3</td>
<td>Anterior margin bulges ventrally below the axilla</td>
<td>11%</td>
</tr>
</tbody>
</table>

Type A: Tail of the middle turbinate extends beyond the dorsal end of the inferior turbinate (40%).
Type B: Tail of the middle turbinate and that of the inferior turbinate lie in the same frontal plane (34%).
Type C: Tail of the inferior turbinate extends beyond the dorsal end of the middle turbinate (26%).

Fig. 2.31 Shown is the common sagittal bony lamella (conchal lamina) of the middle and superior turbinates (and supreme turbinate, if present), (Bodino et al. 2004).

Fig. 2.32 Shown are morphological variation patterns of the middle turbinate ("accessory, double, and/or secondary middle turbinates") (red). Accessory middle turbinate in the narrow sense (a); formation of a sagittal cleft in the inferior middle turbinate (b); kinking of the uncinate process (c); paradoxical curvature (d) (from: El-Shazly et al. 2012; Khanabthamchhai et al. 1991b; Ozcan et al. 2008b).
Clinical Hints

- The morphological variability of the anterior portion of the middle turbinate can give reason, in some cases, to partially “reduce” (resect) the head of the middle turbinate. Generally, complete resection of the middle turbinate (not indicated routinely) is bound to reduce the surface area of the medial wall of the middle and superior turbinate by one half.

- In some cases, the form or shape of the basal lamella of the middle turbinate can be altered to such an extent by expanding posterior ethmoid cells, that they encroach on the ethmoidal bulla region – such changes in microanatomy hamper a consistent classification of surgical procedures (complete removal of a tentatively identified “bulla” in those cases formally corresponds to an opening of the posterior ethmoid) (Fig. 2.19).

- In case of an “accessory middle turbinate”, an individualized morphological analysis is sensible and useful to enable a targeted microsurgical removal of tissue (Fig. 2.32).

Special Literature


Concha superior a

The superior turbinate is very rarely the source of relevant anatomic variations. Pneumatization of its vertical lamella is observed in approx. 12% of cases (this, in turn, is associated with a concha bullosa media in 60% of cases) (Fig. 2.34).

Due attention should be paid to the site where the superior turbinate inserts into the anterior sphenoid sinus wall – the position of the insertion determines the absolute and relative width of the ethmoidal portion (pars ethmoidalis) and nasal portion (pars nasalis) of the anterior wall (Tab. 2.14, Fig. 2.55).

Another anatomical reference structure of major practical importance is the sphenethmoidal recess (Figs. 2.35, 2.36). Largely variable in nature (prevalence of 50%), it appears as a laterally oriented blind pouch in the nasal cavity, measures approx. 5 mm in depth (sagittal dimension) and approx. 4 mm in width (transversal dimension); it lies directly in front of the anterior sphenoid sinus wall and posterior to the superior turbinate (or supreme turbinate, if present). The distance from the lateral recess to the nasal septum is 2 – 12 mm. The roof of the recess is formed by the planum sphenoidale.

a see also: Concha media; Sphenoid sinus
Structural Elements of the Paranasal Sinuses

**Tab. 2.14** Variation patterns of the insertion of the superior turbinate into the anterior sphenoid sinus wall (Type D according to Sunkaraneni et al. 2012 is not shown.

**Type A** Superior turbinate inserts in the medial third of the anterior wall.
**Type B** Superior turbinate inserts in the middle third of the anterior wall. **Types A + B = 81 %**.
**Type C** Superior turbinate inserts in the lateral third of the anterior wall.
**Type D** Superior turbinate inserts in the orbit. **Types C + D = 19 %**.

**Fig. 2.34** Coronal CT scan showing a bilateral concha bullosa superior (red) (secondary findings: maxillary sinusitis and septal deviation).

**Fig. 2.35** Axial CT scan (a) of a left sphenoid recess (C.e.p.). Alongside, note the corresponding schematic drawing (b).

**Fig. 2.36** Endoscopic view (45° direction of view) of the nasal part of the right anterior sphenoid sinus wall. Sphenoid sinus ostium ①; Superior turbinate inserting into the anterior sphenoid sinus wall ② (Type A acc. to Sunkaraneni et al. 2012) – note, there is no sphenoid recess, see (direct insertion of the dorsal portion of the superior turbinate into the anterior sphenoid sinus wall – see Fig. 2.35; Middle turbinate ③, Nasal septum ④ (from: Weber et al. 2017a).
Clinical Hints

- According to literature, the sphenoethmoidal recess may in some cases “obscure” the sphenoid sinus ostium when the latter is searched for endoscopically from anterior.

- In an intraoperative transethmoidal-transnasal view of the anterior sphenoid sinus wall along with the sphenoid ostium, the vertical lamella of the superior turbinate may occasionally have a somewhat “bulky” appearance. Irrespective of this finding, the lamella should be spared to the extent possible, especially with regard to the olfactory region. While observing this rule, removing at most 2 mm in height at the inferior margin is considered to be unproblematic in duly justified cases.

- In the presence of an anterior wall of sphenoid sinus type “A” and “B” in accordance with Tab. 2.14, transethmoidal sphenoethmoidotomy is recommended, whereas for types “C” and “D”, transnasal or transethmoidal-transnasal sphenoethmoidotomy is preferred.

- To expose the nasal portion of the anterior wall, the superior turbinate can be lateralized in a transnasal approach. As an alternative option, the medial anterior sphenoid sinus wall can be located via the superior meatus by passing through the partly cleared ethmoid cell system. In some cases, the insertion of the superior turbinate needs to be detached from the anterior sphenoid sinus wall. In either case, a look along the created pathway reveals the sphenoethmoidal recess, and in best cases, also the sphenoid ostium (Parsons et al. 1994).

Special Literature


Concha suprema

Most authors consider the presence of a supreme turbinate to be relatively rare (20%). Upon a detailed analysis addressing the formation of grooves in the lateral nasal wall, however, a supreme turbinate can reportedly be defined with some degree of certainty in 60% of cases (Tab. 2.15). The accompanying supreme meatus often contains only a single ostium of a posterior ethmoidal cell. The vertical lamella of a supreme turbinate is seen to be pneumatized in 10% of cases.

<table>
<thead>
<tr>
<th>Variations in terms of the relative size of the superior and supreme turbinates (concha superior /. concha suprema) (Orhan et al. 2010a).</th>
<th>Type A</th>
<th>The supreme turbinate is the shortest and shallowest turbinate (58 %).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variations in terms of structure and location of the supreme turbinate (Gotlib et al. 2018b).</td>
<td>Type B</td>
<td>The supreme turbinate is nearly of the same size as the superior turbinate (25 %).</td>
</tr>
<tr>
<td>Type C</td>
<td>The supreme turbinate is larger than the superior turbinate (17 %).</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variations in terms of relative size, structure and location of the superior and supreme turbinates.</th>
<th>Type 1</th>
<th>The supreme turbinate contains a posterior ethmoidal cell located at the skull base and/or the orbit (67 %).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 2</td>
<td>The supreme turbinate contains a small cavity without contact to the skull base; it appears as a “fold” of the superior mediol nasal wall (33 %).</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 2.15 Variations in terms of relative size, structure and location of the superior and supreme turbinates.

Clinical Hint

- Based on the literature, the sphenoid sinus ostium is commonly found medial to the posteroinferior boundary of any supreme turbinate.

Special Literature


Crista ethmoidalis

- See: Palatine bone, Foramen sphenopalatinum
Crista galli
The crista galli resembles a pyramid in shape, with a height and depth of approx. 13 mm each and a width of approx. 3.5 mm (variability: height 5–21 mm; width 1–9 mm). Side-to-side asymmetry is relatively common (40%), and the relative anatomic locations are variable in detail (Tab. 2.16). Of significance is the site where the *falx cerebri* attaches to the crista galli. Anteroinferiorly, the crista galli is in close proximity to the first segment of the *superior sagittal sinus*.

Variations in terms of relative anatomic location (type) and prevalence of a pneumatized crista galli (Hajiioannou et al. 2010).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Base of the <em>Crista galli</em> is located in the plane of the <em>cribriform plate</em> (23%).</td>
</tr>
<tr>
<td>Type 2</td>
<td>Less than 50% of the height of the <em>Crista galli</em> lies in a plane inferior to the <em>cribriform plate</em> (61%).</td>
</tr>
<tr>
<td>Type 3</td>
<td>More than 50% of the height of the <em>Crista galli</em> lies in a plane inferior to the <em>cribriform plate</em> (2%).</td>
</tr>
</tbody>
</table>

Differences in the bony architecture of the pneumatized crista galli (Mladina et al. 2017).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Pneumatized <em>Crista galli</em> encased by compact walls (46%).</td>
</tr>
<tr>
<td>Type B</td>
<td>Pneumatized <em>Crista galli</em> encased by spongy and compact bone (54%).</td>
</tr>
</tbody>
</table>

Tab. 2.16 Variations in terms of relative location, pneumatization, and bone structure of the *crista galli*.

Clinical Hint
- As part of resection of the anterior skull base (ethmoid roof of both sides together with the nasal septum), at an early point in time, the diamond burr should be “passed around” the *crista galli* from its caudal aspect to detach the crest from its “dural pocket” in a caudal direction.

Special Literature

Ductus nasolacrimalis<sup>a</sup>

Petrous apex<sup>b</sup>
The petrous apex is located between the cavernous sinus, the canal of the *abducens nerve* (Dorello’s canal) and Meckel’s cave. In 40% of cases, the lateral sphenoid sinus is in contact with the petrous apex, and as a rule, the extent of pneumatization of the sphenoid sinus and petrous bone are correlated.

Clinical Hint
- A well-pneumatized sphenoid sinus and petrous apex enables good access via the transsphenoidal route and facilitates the surgical treatment of pathological lesions of the petrous apex (e.g., cholesterol cysts, cholesteatomas).

Special Literature

Tab. 2.17 Variations of topographic anatomy in the area of the petrous apex.

Variations of the relative location of the *porus trigeminus* (PT) and superior petrosal sinus (SPS) (Tubbs et al. 2013).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>SPS superior to PT (68%).</td>
</tr>
<tr>
<td>Type 2</td>
<td>SPS inferior PT (18%).</td>
</tr>
<tr>
<td>Type 3</td>
<td>SPS hugs the circumference of the PT (16%).</td>
</tr>
</tbody>
</table>

- see also: *Lacrimal passages*
- see: *Sphenoid sinus*
**Fissura orbitalis superior**

The superior orbital fissure is where the cranial nerves (CN III, CN IV, CN VI, CN V1) and vessels (orbital branch of the middle meningeal artery, meningeal branch of the lacrimal artery, ophthalmic veins) are transmitted to and from the orbital cavity. The contour of its boundaries varies considerably – and is mostly shaped like a club. From the optic canal located superomedially, it is separated by a special bony strut (optic strut), and from the canalis rotundus inferomedially, by the maxillary strut, the latter measuring approx. 4 mm in diameter.

**Special Literature**

**Fissura pterygomaxillaris**

**Fontanelles**

Fontanelles are areas of the medial maxillary wall which lie above the inferior turbinate. They consist of only two mucosal layers and a thin intermediate layer of connective tissue without additional osseous support. Fontanelles are predilection sites for the development of secondary ostia. The latter become more common with increasing age. The anterior fontanelle lies anteroinferior to the bony uncinate process, while the posterior fontanelle is typically found posterosuperior to the dorsal extension of the process (Fig. 2.37).

The prevalence of accessory ostia reported in the literature varies widely (0–43%). They are typically found in the posterior fontanelle. The ostia have an inner diameter of 1–10 mm and are usually located 5–10 mm superior to the insertion of the inferior turbinate.

**Clinical Hints**

- With increasing age, accessory maxillary sinus ostia are seen more frequently, particularly in the posterior fontanelle. They should not be confused with the natural ostium – enlarging an accessory ostium while ignoring the blocked, adjacent natural ostium, a “missed ostium sequence” can develop leading to chronic or recurrent sinus disease (especially in the form of persistent secretions) (Parsons et al. 1996).

- The presence of accessory maxillary sinus ostia in the middle meatus is often associated with mucosal alterations (swelling, formation of cysts) in the adjacent maxillary sinus (Yenigun et al. 2016a).

**Special Literature**
Structural Elements of the Paranasal Sinuses

Foramen ovale\textsuperscript{a}

Foramen rotundum\textsuperscript{b}

The foramen rotundum is constituted by the anterior opening of the canalis rotundus at the posterior wall of the pterygopalatine fossa. The maxillary nerve runs through the canal and foramen. The foramen lies approx. 7 mm superolateral to the spheno-palatine foramen and approx. 4–8 mm superolateral to the opening of the pterygoid canal (Figs. 2.27, 2.38).

The dimension (diameter) of the foramen rotundum correlates with both the diameter of the optic canal and the diameter of the pterygoid canal. The distance between the foramen rotundum and the paraclival internal carotid artery is approx. 35 mm. The canalis rotundus has a length of 4–12 mm. Posteroanteriorly, it usually (in 94%) runs in a slightly lateral direction (at a 16° angle to the mid-sagittal plane). In addition to the maxillary nerve, two small arteries, each approx. 0.1 mm in diameter, pass through the canal. Very rarely, a duplicated maxillary nerve and doubled canal are found near the foramen.

Fig. 2.38
a. Frontal CT scan of the sphenoid sinus region showing the left canalis rotundus (1) and the pterygoid canal (2).
b. Endoscopic inspection of the left pterygopalatine fossa in the same anatomic specimen as in (a). Dissection reveals the foramen rotundum (3, dotted line) with the maxillary nerve (4). The latter becomes the infraorbital nerve at the maxillary sinus roof. Adipose tissue in the area of the pterygopalatine fossa (5); Maxillary artery (6); Lateral posterior wall of maxillary sinus (Sin.m.); Elevator (E).

Special Literature
Amin et al. 2010; Bertelli and Regoli 2014; Cheng et al. 2015b; Inal et al. 2015; Lang and Keller 1978; Rusu 2011.
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

Tab. 2.18

Foramen sphenopalatinum

Typically, the sphenopalatine foramen is located in the superior meatus adjacent to the posterior end of the middle turbinate (Tab. 2.18, Fig. 2.39). Its distance to the nasal floor is approx. 27 (±3) mm. Anteroinferior to the foramen, in over 80% of cases, a distinct ethmoidal crest is formed by the sagittally oriented perpendicular plate of the palatine bone. Medially, the ethmoidal crest is continuous with the almost horizontal dorsal extension of the basal lamella of the middle turbinate (Fig. 2.39, 2.50). This bony prominence is a key landmark to identify the foramen. In some cases, the crest is “interrupted” by the foramen, however, with the sphenopalatine foramen opening into both the superior and middle meatus. In other cases, two separate sphenopalatine foramina are found in the middle meatus and the superior meatus. The relative distribution of morphological variation patterns of the foramen differs widely in the literature.

The foramen measures approximately 5 mm (4–8 mm) in diameter and exhibits a highly variable contour (hourglass-shaped, oval, square, triangular, pear-shaped). The distance between the foramen and the posterior fontanelle of the middle meatus is approximately 14 mm.

In a more proximal (lateral) part of the foramen, the maxillary artery already divides into numerous small arterial branches and, near the sphenopalatine ostium, becomes the sphenopalatine artery with a caliber of approximately 1.8 mm (Fig. 2.40). At the plane of the ostium, there is a single sphenopalatine artery in 63% of cases, two branches in 32% of cases, and three branches in 5%. Based on other reports in the literature, 2 arteries were identified in the plane of the foramen in most cases (80%) and up to 5 or even a maximum of 10 arteries in isolated cases. Accessory foramina typically contain only one artery. Main branches of the sphenopalatine artery are the posterior septal artery (1.7 mm diam.) and the lateral posterior nasal artery (approx. 1.8 mm in diam.), in some cases accompanied by one or two collateral branches (Tab 2.18). The foramen transmits the arterial vessels together with accompanying veins and the nasopalatine nerve.

| Variation patterns of the bony sphenopalatine foramen (Wareing and Padgham 1998). |
| Type 1 | Foramen lies exclusively in the superior meatus (35 %). |
| Type 2 | Foramen interrupts the ethmoidal crest of the palatine bone, opening faces toward the superior and middle meatus (56 %). |
| Type 3 | Two separate foramina, one each in the superior and middle meatus (9 %). |

| Variation patterns related to the branching of the sphenopalatine artery (Wang et al. 2015). |
| Type 1 | The sphenopalatine artery bifurcates into the posterior septal artery and the lateral posterior nasal artery medial to the sphenopalatine foramen (17 %). |
| Type 2 | Lateral to the sphenopalatine foramen, the sphenopalatine artery bifurcates into the above mentioned branches – both branches pass the foramen together (23 %). |
| Type 3 | Bifurcation of sphenopalatine artery as in Type 2, but branches pass through two separate foramina (27 %). |
| Type 4 | Same as in Type 3, but division of the posterior septal artery into two branches before they pass through the separate foramina (33 %). |

Tab. 2.18 Anatomic variation patterns of the sphenopalatine foramen and the sphenopalatine artery.

| see also: Palatine bone; Fossa pterygopalatina |
Fig. 2.39 Shown in detail is the dorsal extension of the middle turbinate with the ethmoidal crest of the palatine bone relative to the sphenopalatine foramen.

Note that the foramen is interrupted by the extension of the middle turbinate (Type 2 acc. to Wareing and Padgham 1998; Tab. 2.18).

Fig. 2.40 Schematic drawing showing the distribution of nerve and arterial branches medial and lateral to the sphenopalatine foramen.

Note, that the depth of “section planes” in lateral (3) and medial sites (1) is different.

Maxillary artery (1); Sphenopalatine artery (2); Foramen rotundum (3); Maxillary nerve (4); Inferior alveolar artery and nerve (5); Sphenoid sinus ostium (6); Pterygopalatine ganglion (7); Mandibular nerve (8); Middle meningeal artery (9); Pharyngeal branch of artery (10); Optic chiasm (11); Inferior turbinate (12); Sphenomandibular ligament (13); Medial pterygoid muscle (14); Parotid gland (15); Oculomotor nerve (16); Pterygoid canal with nerve of the pterygoid canal (Vidian nerve, from the greater superficial petrosal nerve) and artery (17); Posterior septal artery (medial branch of the sphenopalatine artery) (18); Superior and inferior posterolateral branches of the sphenopalatine artery (19); Descending palatine artery (20); Posterior superior alveolar artery (21); Infraorbital artery (22) (after: Janfaza et al. 2001; Lee et al. 2002; Pearson et al. 1969).

Clinical Hints

- The *ethmoidal crest*, as a key landmark, allows the *sphenopalatine artery* to be located in a precise and minimally invasive way (at submucosal level), and in turn, to be sealed, e.g., by electrocoagulation.

- Using the *sphenopalatine foramen* and *inferior turbinate* as landmarks, any peripheral parasympathetic nerve fibers (superior and inferior posterior nasal branches) over the vertical portion of the palatine bone can be transected (therapeutic attempt in vasomotor rhinitis; Kikawada 2007, Eren et al. 2015).

- The *posterior septal artery* (going to the nasal septum) is located at the upper edge of the *sphenopalatine foramen*.

- During anteroposterior ethmoidectomy in a patient with a medially expanded maxillary sinus (Tab. 2.30) a triangular bony formation may be found in the frontal plane directly anterior to the *sphenopalatine foramen* (superiorly: posterior ethmoid air cells, sphenoid sinus or orbit; inferolaterally: maxillary sinus or pterygopalatine fossa; medially: middle meatus). Special attention must be given to the elevated risk of arterial injury if this bony formation is taken out (Eordogh et al. 2018).

Special Literature

**Fossa infratemporalis**

The *infratemporal fossa* is found below the greater wing of the sphenoid bone, dorsolateral to the maxillary sinus, lateral to the lateral pterygoid process, medial to the mandible, and anterior to the styloid process with its muscle insertions as well as the carotid artery and the deep lobe of the parotid gland. The infratemporal fossa is continuous medially with the pterygopalatine fossa and posteromedially with the parapharyngeal space. It contains, among others, the proximal two segments of the maxillary artery (retromandibular and intramuscular segment), the mandibular nerve (CN V₃), the pterygoid muscles, the temporal muscle, the otic ganglion and a rich venous plexus.

The foramen ovale is located in the infratemporal fossa, near the posterior edge of the lateral pterygoid process, lateral to the foramen lacerum, and anteromedial to the foramen spinosum. It is approx. 7 x 5 mm in size – the eponymous oval shape is present in only 57% of cases. In isolated cases, small bony prominences or incomplete septa are seen at the foramen.

The following figures may provide an initial spatial orientation:

- **Distance between the anterior nasal spine and the foramen ovale:** approx. 8 cm.
- **Distance between the posterior maxillary sinus wall and the foramen ovale:** approx. 19 mm.
- **Distance between the posterior edge of the lateral pterygoid process and the foramen ovale:** approx. 6 mm (distance from the anterior margin approx. 17 mm). Distance between the posterior edge of the lateral pterygoid process and the parapharyngeal internal carotid artery at the level of the nasal floor: approx. 24 mm.
- **Distance between the foramen ovale and the foramen spinosum:** approx. 4 mm.
- **Distance between the foramen ovale and the internal carotid artery in the petrous segment:** approx. 5 mm.

In its course directly below the foramen ovale, the mandibular nerve runs on the tensor veli palatini muscle, directly anterior to the tubal protuberance and medial to the superior part of the lateral pterygoid muscle. The buccal nerve runs in an anterior direction between the superior and inferior parts of the lateral pterygoid muscle. A key landmark is the lateral pterygoid process: An imaginary line dorsally extending the posterior edge of the lateral pterygoid process hits the foramen ovale; at a short postero-lateral distance lies the foramen spinosum. The lingual nerve and inferior alveolar nerve are found in the angle between the inferior edge of the lateral pterygoid muscle and the medial pterygoid muscle, dorsal to the plane of the buccal nerve.

The maxillary artery typically runs in an almost horizontal plane above the inferior part of the lateral pterygoid muscle toward the pterygopalatine fossa, where it gives rise to a series of branches. Viewed from an anterior aspect, the artery lies below the buccal nerve and above the lingual nerve, i.e., inferior alveolar nerve. In detail, microanatomy is subject to a wide range of individual and ethnic variations (Tabs. 2.6, 2.7; Fig. 2.41).

In a posterior and medial aspect, the cranial “parapharyngeal space” is continuous with the retropharyngeal space. Medially, it is bounded by the superior pharyngeal constrictor muscle, and laterally, by the pterygoid muscles and parotid gland (infratemporal fossa). Superiorly, the parapharyngeal space leads to the skull base; caudally, it is bounded by the styloidal muscles, the submandibular gland, and the mandibulo-stylohyoid ligament. With reference to the styloid muscular “diaphragm” (posterior digastric muscle, stylooid muscle, stylopharyngeus muscle) and stylopharyngeal aponeurosis, a pre-styloid compartment can be differentiated. The latter contains the carotid artery, the internal jugular vein as well as the inferior cranial nerves CN IX to XII. The major landmark for dissection of the post-styloid compartment is the Eustachian tube. The following are key landmarks for the parapharyngeal carotid artery: the foramen ovale directly anteriorly to the post-styloid compartment, the styloid process, and the junction of the cartilaginous and osseous part of the Eustachian tube with the superior insertion of the levator veli palatini muscle.

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**Fig. 2.41** Schematic drawing showing the various relative locations of the *maxillary artery* and the *lateral pterygoid muscle* (left side, viewed from anterior) – location “on” (a) or partially “below” (b) the muscle (from: Otake et al. 2011).

Maxillary artery (1); Middle meningeal artery (2); Posterior deep temporal artery (3); Anterior deep temporal artery (4); Posterior superior alveolar artery (5); Buccal artery (6); Inferior alveolar artery (7).

Not shown are additional distinct variations in the topographic relationship between maxillary artery and mandibular nerve with its branches.
Structural Elements of the Paranasal Sinuses

Clinical Hints

- Dissection of the foramen ovale: the key landmark is the lateral pterygoid process and, occasionally, the lingual nerve. In a first step, the posterior maxillary sinus wall is removed, the pterygopalatine fossa is opened, the pterygoid canal and the foramen rotundum are exposed. Next, the maxillary artery and, occasionally, the venous plexus between the temporal muscle and lateral pterygoid muscle (recognizable by the horizontal orientation of its muscle fibers) are identified. The lingual nerve and inferior alveolar nerve are located at the inferior border of the lateral pterygoid muscle (on the medial pterygoid muscle) and followed proximally for approx. 2 cm. In the course of dissection, it helps to regularly secure and remove local vessels as well as adipose tissue. When dissecting along the lateral pterygoid plate, the inferomedial parts of the lateral pterygoid muscle must be released from the pterygoid process or resected (Abuzayed et al. 2010b; Dallan et al. 2010a; Falcon et al. 2011; Kantola et al. 2013; Lee et al. 2012; van Rompaey and Solares 2013).

- For extended dissection of parapharyngeal structures lying in a plane dorsal to the styloid process, key landmarks are the foramen ovale, Eustachian tube, both pterygoid plates, and the styloid process. The tubal protuberance is directly posterior to the medial pterygoid process; posterior to the tubal protuberance, in turn, lies the parapharyngeal segment of the carotid artery (Falcon et al. 2011; Fortes et al. 2012; Hosseini et al. 2013).

Special Literature


Fossa lacrimalis

The lacrimal fossa is a vertically oriented, bony depression in the anterior medial orbital wall. It has a length of about 16 mm, a width of 7–10 mm (a.-p.) and a depth of approx. 2–4 mm (Fig. 2.42). This depression is made up of the frontal process of maxilla (anterior portion, sturdy bone) and the lacrimal bone (posterior portion, fragile bone < 1 mm thick; Fig. 2.43). The lacrimal bone and frontal process of maxilla cover the large lacrimal passages from medially at an equal share in 25% of cases, the maxilla covers more than half in about 30% of cases, and in a further 45% of cases, the surface of the lacrimal bone predominantly occupies the passages – albeit with some inter-ethnic differences. The above described ratio of bony covering is subject to the height of the lacrimal fossa – the frontal process is particularly dominant in the superior parts of the fossa.

Fig. 2.42 Lateral view onto a skull specimen with the right lacrimal fossa showing the adjacent osseous structures. Frontoethmoidal suture (1); Frontal bone (2); Frontal process of maxilla (3); Lacrimomaxillary suture (4); Lacrimal bone (5); Anterior lacrimal crest (6); Posterior lacrimal crest (7); Lacrimal fossa (8, dashed line); Nasal bone (9) (from: Weber et al. 2017b).

| see also: Lacrimal passages |
Clinical Hints

- In endonasal dacryocystorhinostomy, the bony medial wall of the lacrimal fossa is removed from a medial direction. In its inferior aspects, this is accomplished in a fairly straightforward manner with a KERRISON punch, e.g., by advancing the instrument and engaging the distal jaw from behind the free edge of the frontal process of maxilla (thus, the membranous lacrimal passages are mobilized laterally and spared, see Fig. 2.43). Using a punch to remove considerable amounts of bone in superior aspects can be technically quite demanding (other instruments, such as a chisel or a diamond burr may be needed).

- Complete exposure of the lacrimal sac fundus from medi ally requires opening an agger nasi cell in 40–90% of cases.

Fossa olfactoria

The olfactory fossa contains the olfactory bulb and olfactory tract. It is bounded inferiorly by the cribiform plate, laterally by a “lateral lamella” at the junction of the cribiform plate and the plane of the ethmoid roof (frontoethmoidal crest), and medially, by the crista galli with its extensions. The lateral wall of the olfactory fossa is very vulnerable, frequently exhibiting a bone thickness of only 0.05 mm. In 15–60% of cases, bone is focally absent (natural dehiscences, more common in the presence of a relatively deep olfactory fossa, not age-related). A special predilection site for such bony dehiscences is where the fossa is pierced by the anterior ethmoid artery.

The average depth of the olfactory fossa is 5 mm. In some populations, a more shallow olfactory fossa and a steeper lateral wall are seen in women; there is considerable ethnic variation. The overall distribution of variation patterns is shown in Tab. 2.19. Considerable differences in depth (≥ 2 mm) are seen between the left and right side in approx. 10% of cases (more so in men) (Fig. 2.44a). The lower the level of the cribiform plate, the higher the nasal cavity, as measured from the nasal floor to the ethmoid roof (foveae ethmoidales). The depth of the olfactory fossa is negatively correlated with its width and positively correlated with the steepness of the lateral wall of the fossa and the width of the adjacent ethmoid roof.

Anteriorly, the olfactory fossa can approach the frontal sinus – resulting in a “dangerous frontal bone” if the fossa projects from behind into the frontal sinus – and thus, the posterior frontal sinus wall endoscopically presents an olfactory torus (the removal of which must be strictly avoided!) (Fig. 2.44b). In the posterior junction, the skull base ascends to the planum sphenoidale. Aside from rare cases, e.g., those with a “dangerous frontal bone”, the first olfactory fiber in the nasal cavity lies approx. 4 mm dorsal to the frontal plane through the posterior frontal sinus wall.

Special Literature

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| see also: Lamina cribrosa; Ethmoid roof (fovea ethmoidalis) |
### Tab. 2.19 Variation patterns of the olfactory fossa in terms of depth and length as well as regarding the angle between cribriform plate and lateral wall of the olfactory fossa, with prevalence ratios (in parentheses) (see also: Ethmoid roof).

<table>
<thead>
<tr>
<th>Structural Element</th>
<th>Type 1 Description</th>
<th>Prevalence Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of the olfactory fossa (Keros 1962).</td>
<td>Depth of 1 – 3 mm</td>
<td>(12 %).</td>
</tr>
<tr>
<td></td>
<td>Depth of 4 – 7 mm</td>
<td>(70 %).</td>
</tr>
<tr>
<td></td>
<td>Depth of 8 – 16 mm</td>
<td>(18 %).</td>
</tr>
<tr>
<td>Length of the lateral lamella of the olfactory fossa (Yenigun et al. 2016b).</td>
<td>Length of 6 – 10 mm</td>
<td>(42 %).</td>
</tr>
<tr>
<td></td>
<td>Length of 11 – 15 mm</td>
<td>(53 %).</td>
</tr>
<tr>
<td></td>
<td>Length of 16 – 20 mm</td>
<td>(5 %).</td>
</tr>
<tr>
<td>Angle between horizontal plane through the cribriform plate and the lateral wall of the olfactory fossa (Gera et al. 2018).</td>
<td>Angle of more than 80°</td>
<td>(32 %).</td>
</tr>
<tr>
<td></td>
<td>Angle of 45° – 80°</td>
<td>(63 %).</td>
</tr>
<tr>
<td></td>
<td>Angle of less than 45°</td>
<td>(5 %).</td>
</tr>
</tbody>
</table>

**Clinical Hints**

- In endonasal paranasal sinus surgery, the focus of interest is not so much determined by the absolute depth of the olfactory fossa, but rather by the angle formed by the lateral wall of the fossa with the vertical plane: In view of the commonly highly vulnerable lateral wall, any inclination of the wall toward the horizontal plane (i.e., in the “working trajectory” of the endoscopic surgeon) should serve as a red flag (see Type 3 according to Gera et al. 2018 in Tab. 2.19 as well as Tab. 2.44).

- In a Draf type III frontal sinus drainage procedure, some authors recommend that the first olfactory fibre be used as a landmark prior to proceeding with the frontal sinusotomy. A distance of 4–6 mm between the fiber and the area of anticipated bone removal is recommended (for the same purpose, other authors refer to the distal nasal branch of the anterior ethmoidal artery as a landmark).

**Special Literature**

**Fossa pterygopalatina**

The pterygopalatine fossa lies between the pterygoid processes with their basis (dorsally), the palatine bone (anteromedially), and the maxilla (anterolaterally). Its shape resembles an inverted pyramid. Accordingly, its anteroposterior diameter is larger cranially, at approx. 8 mm (5–20 mm). The width is up to 9 mm. The course of the infraorbital nerve demarcates the sagittal plane, in which the pterygopalatine fossa is laterally continuous with the infratemporal fossa via the pterygomaxillary fissure.

The pterygopalatine fossa generally communicates with seven different spaces:
- The infratemporal fossa via the pterygomaxillary fissure.
- The middle cranial fossa via the foramen rotundum/canalis rotundus.
- The foramen lacerum via the pterygoid canal.
- The nasopharynx via the palatovaginal canal.
- The oral cavity via the greater palatine canal.
- The nasal cavity via the sphenopalatine foramen.
- The orbit via the inferior orbital fissure.

The anterior wall of the pterygopalatine fossa is formed by the maxillary sinus alone (41%), by the maxillary sinus and ethmoid bone (46%), or by the maxillary sinus and sphenoid sinus (13%). Within the pterygopalatine fossa, an anterior and a posterior compartment are distinguished. The former principally contains vascular structures; the latter, neural elements.

In approx. 20% of cases, the site of the maxillary artery in the pterygopalatine fossa can be recognized as a bulge arising from the posterior maxillary sinus wall, medial and inferior to the infraorbital nerve. Embedded in adipose tissue, the artery in the anterior compartment of the pterygopalatine fossa leads to the following branches, among others: posterior superior alveolar artery, infraorbital artery, descending palatine artery, artery of the pterygoid canal (“Vidian artery”), small artery in the canalis rotundus, pharyngeal artery (in the vomerovaginal canal), posterior ophthalmic artery, sphenopalatine artery.

In the posterior compartment, neural elements include the maxillary nerve (CN V2), nerve of the pterygoid canal, greater palatine nerve, and the pterygopalatine ganglion with numerous connections.

The opening of the pterygoid canal is found at the bony posterior wall of the fossa, approx. 2 mm (1–4 mm) superolaterally to the sphenopalatine foramen. In the horizontal plane, the pterygoid canal is located above the inferior boundary of the sphenopalatine foramen in 56% of cases, below the inferior boundary in 8%, and in the same plane in 36%. In the sagittal plane, the canal is found lateral to the posterior margin of the sphenopalatine foramen in 70% of cases, medially in 2%, and in the same plane in 28%. The diameter of the pterygoid canal is approx. 2 mm, and that of the foramen rotundum, nearly 3 mm.

The foramen rotundum is found superolateral to the pterygoid canal (horizontal distance 6–8 mm, vertical distance 5–6 mm; a positive correlation exists between these values, see: V-R-Line). Between the foramen rotundum and the anterior opening of the pterygoid canal, a longitudinal bony prominence (pterygoid ridge) may emanate from the anterior surface of the pterygoid process; this prominence is useful for local orientation.

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**Macroscopic morphological variation patterns of the pterygopalatine ganglion (Rusu et al. 2009).**

| Type A Bipartitioned ganglion, upper partition receives the nerve of the pterygoid canal (10%). |
| Type B Single ganglion, upper part receives the nerve of the pterygoid canal (55%). |
| Type C Single ganglion, lower part receives the nerve of the pterygoid canal (15%). |
| Type D Bipartitioned ganglion, lower partition receives the nerve of the pterygoid canal (20%). |

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**Tab. 2.20** Morphological variation patterns of the pterygopalatine ganglion.

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\* see also: *A. maxillaris; A. palatovaginalis; Canalis pterygoideus; Canalis vomerovaginalis; Foramen rotundum; Foramen sphenopalatinum; N. infraorbitalis*
The maxillary nerve runs from the foramen rotundum into the pterygopalatine fossa and onward to the infraorbital fissure (Fig. 2.45). Before it becomes the infraorbital nerve, it gives rise to the posterior alveolar nerve. The infraorbital canal is lateral to the foramen rotundum – and therefore, the maxillary nerve turns laterally after passing through the foramen rotundum. The infraorbital canal is at the same level or slightly inferior to the foramen; in 80% of cases, the nerve is “somewhat suspended” along its course between the two canals. The distance between the foramen rotundum and the canal entrance is approx. 19 mm.

As the largest peripheral parasympathetic ganglion, the pterygopalatine ganglion lies posteroinferiorly in the posterior pterygopalatine fossa, between the pterygoid canal and foramen rotundum. The distance between the ganglion and the foramen rotundum is reported to measure approx. 6 mm, and between the ganglion and the pterygoid canal, approx. 5 mm. The ganglion is variable in shape, measures approx. 4 x 2 mm, and is commonly divided into two sections (Tab. 2.20). When seen together with the nerve of the pterygoid canal, the branches to the maxillary nerve, and the greater palatine nerve, the ganglion often forms an “Y-shaped structure.”

The pterygopalatine ganglion contains three roots:

1. Parasympathetic nerve fibers through the greater petrosal nerve in the pterygoid canal.
2. Sympathetic nerve fibers through the deep petrosal nerve via the pterygoid canal.
3. Sensory nerve fibers from the maxillary nerve via the pterygopalatine nerve.

From the ganglion, parasympathetic fibers run to the nasal mucosa. These fibers give off variable branches, which among others, travel through separate small ostia in the palatine bone.

Clinical Hints

- Using a transnasal approach, the pterygopalatine fossa is opened in its mediusuperior aspect and the peripheral branches of the maxillary artery are transected (sphenopalatine artery, pharyngeal artery, posterior nasal artery). In this way, the soft tissue in the region of the posterior wall of the pterygopalatine fossa can be mobilized in the subperiostal plane from medial to inferolateral. Doing so considerably facilitates exposure of the nerve of the pterygoid canal (Vidian nerve) along with its opening at the posterior wall of the fossa.

- Following mobilization of the soft tissue, bone may be removed at the posterior wall of the pterygopalatine fossa in the area between the nerve of the pterygoid canal and the maxillary nerve to create a corridor to the lateral wall of a well-pneumatized sphenoid sinus (transpterygoid expanded sphenoidotomy).

- In-depth knowledge of the regional anatomy further permits a step-by-step removal of tissue with a transpterygoid expanded approach, for instance, to Meckel’s cave.

Special Literature

Foveolae ethmoidales

Frontal septal cell ("intersinus septal cell", "interfrontal sinus septal cell")

In the presence of any frontoethmoidal cells medially in the interfrontal septum, a frontal intersinus septal cell is formed (also referred to as intersinus septal cell, medial frontoethmoidal cell or interfrontal sinus septal cell) (Fig. 2.46). Alternatively, the interfrontal septum can be pneumatized from the frontal sinus. Pneumatized crista galli is worthy of special, extra consideration (Tab. 2.16, Fig. 2.86). The literature provides highly variable data on the relative prevalence of the two potential origins of frontal intersinus septal cells (pneumatization from the frontal sinus, anterior ethmoid, or frontal recess). The general prevalence of pneumatization is reported to range from 5–35%. A frontal intersinus septal cell can extend into the cranial interfrontal septum, caudally into the region of the naso-frontal junction, or between the two (Tab. 2.21).

<table>
<thead>
<tr>
<th>Forms of frontal intersinus septal cells (Merritt et al. 1996).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type 1</strong></td>
</tr>
<tr>
<td>Cell completely enclosed within the thin intersinus septum; bridges all of the inferior-superior extent (42 %).</td>
</tr>
<tr>
<td><strong>Type 2</strong></td>
</tr>
<tr>
<td>Cell bordered partially by the thin intersinus septum and partially by the thick septal base formed by the nasofrontal bone (hybrid form of Type 1 and Type 3; 20 %).</td>
</tr>
<tr>
<td><strong>Type 3</strong></td>
</tr>
<tr>
<td>Cell completely enclosed within the nasofrontal bone (superior nasal spine) (38 %).</td>
</tr>
</tbody>
</table>

**Tab. 2.21 Anatomic classification of frontal intersinus septal cells.**

Fig. 2.46 Frontal CT scans (a, b) accompanied by an endoscopic image (c) (45° direction of view) of the frontal sinus drainage pathway (2) and a frontal intersinus septal cell (1) on the right side.

**Clinical Hint**

- Given a type 3 frontal intersinus septal cell (according to Merritt et al. 1996), the osseous boundary of the lateral drainage pathway of the frontal sinus commonly presents with a sturdy bone while the drainage pathway itself is relatively narrow. These circumstances must be considered when developing an individualized surgical strategy to prevent the postoperative formation of scar tissue and subsequent stenosis.

**Special Literature**


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a see: Ethmoid roof  
b see also: Frontoethmoidal cells; Frontal sinus
**Frontoethmoidal cells**

The use of anatomical terminology for *frontoethmoidal cells* is inconsistent. For instance, in special cases, the exact classification of cells and differentiation between parts of the cell versus a recess can be challenging. Often, “frontoethmoidal cells” are considered to include only those anterior ethmoid cells which are in close topographic proximity to the *frontal process of maxilla* – if so, the term does not necessarily refer to cells directly in the frontal sinus drainage pathway or to any *frontal bulla* located dorsally. Three classification systems, which vary in detail, are presented in Tab. 2.22 and Fig. 2.47. Another, current classification scheme with respect to the “drainage pathway” or “opening” of the frontal sinus (junction between the frontal recess and frontal sinus) is presented in Tab. 2.23a with a diagram in Fig. 2.48, and recently proposed amendments in Tab. 2.23b.

Together with the variable anterosuperior attachment of the uncinate process, the ensemble of frontoethmoidal cells encases and forms substantial parts of the frontal sinus drainage pathway (Fig. 2.49). This drainage pathway does not always follow a straight line; it may meander and run around individual frontoethmoidal cells or parts of the anterosuperior uncinate process.

The *agner nasi cell* serves as the reference point for a patient-specific analysis of the anterior cells; this is done for practical reasons since this cell is rarely absent and can be identified as the first anterior ethmoidal cell in the frontal anterior CT scan (upon a more detailed review, however, it is commonly mistaken for a lacrimal cell which lies further dorsally at the lacrimal bone, or a *terminal recess* of the ethmoidal infundibulum).

A second reference point is the *frontal sinus opening*; strictly speaking, the term “frontoethmoidal” or “frontal” cell only applies to cells that extend beyond the frontal sinus opening in a cranial direction. If a cell penetrates the interfrontal septum, a frontal septal cell forms (intersinus septal cell, frontal septal cell, see Fig. 2.46, 2.86). Further cell forms lying immediately adjacent or in proximity to the frontal sinus include suprabullar and suprorbital ethmoid cells.

The presented classification schemes, with cell-type prevalence ratio and geometry, are subject to controversy in current literature. The prevalence of agger nasi cells is reported as approx. 90%, of supra agger cells as 30–80%, and of supra agger frontal cells, as 5–20%. The prevalence of suprabullar cells is reported to range from 10–80%, for suprorbital ethmoid cells, from 5–60%, and for suprabullar frontal cells (frontal bulla), from 5–20%. There is controversy about the actual existence of isolated cells in the frontal sinus (*Type-4-cell* according to *Bent et al.* and *Kuhn*, see below) (prevalence of 0–0.1%). A cell in the interfrontal septum is reportedly present in approx. 5–35% of cases. The same cell types are typically present on both sides, however, considerable inter-ethnic variations have been found.

The size of an agger nasi cell is considered to correlate with the anteroposterior dimension of the inferior frontal sinus (“opening” of the frontal sinus), but not with the depth (i.e., “thickness”) of a *superior nasal spine*. Only relatively large frontal sinuses can contain frontoethmoidal cells. The extent of supraorbital cells or the anteroposterior diameter of the inferior frontal sinus correlates with a distinct displacement of the anterior ethmoid artery below the skull base (see: *Anterior ethmoid artery*). Anteriorly, supraorbital cells can extend more than 4 cm laterally, while posteriorly, this distance typically equals only 15 mm.

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**Fig. 2.47** Schematic representation of *frontoethmoidal cells Types 1–2* (a); *Types 3–4* (b) (from: *Bent et al. 1994*). *Agger nasi* (*AN*); *Frontal sinus* (*FS*).
Suprabullar cells. Suprabullar cell lies above the ethmoid bulla.

Posterior cells (cells in the vicinity of the frontal process of maxilla).

Type 1 Single cell above the agger nasi cell. Type 1 cell above the agger nasi cell.

Type 2 Group of cells above the agger nasi cell. Type 2 Group of cells above the agger nasi cell.

Type 3 Single, bulky cell projecting into the frontal sinus. Type 3 Frontoethmoidal cell extending into the frontal sinus, but does not reach up to half of the height of the frontal sinus.

Type 4 Single, isolated cell within the frontal sinus. Type 4 Frontoethmoidal cell occupying ≥ 50% of the height of the frontal sinus.

Frontal bulla. Frontal bulla is a cell which originates in the suprabullar region and extends along the skull base into the frontal sinus, along the posterior frontal sinus wall.

Suprabullar cells. Suprabullar cell lies above the ethmoid bulla without projecting into the frontal sinus.

Interfrontal sinus septal cell. Intersinus septal cells are those lying in the interfrontal septum.

Tab. 2.22 Classification schemes of frontal frontoethmoidal cells.

<table>
<thead>
<tr>
<th>Cell group</th>
<th>Cell name</th>
<th>Definition</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior cells</td>
<td>Agger nasi cell</td>
<td>Cell which sits either anterior to or directly above the insertion of the middle turbinate into the lateral nasal wall.</td>
<td>Agger nasi cell (ANC), (approx. 92%).</td>
</tr>
<tr>
<td></td>
<td>Supra agger cell</td>
<td>Anterior-lateral ethmoidal cell located above an agger nasi cell (not pneumatizing into the frontal sinus).</td>
<td>Supra agger cell (SAC), (approx. 36%).</td>
</tr>
<tr>
<td></td>
<td>Supra agger frontal cell</td>
<td>Anterior-lateral ethmoidal cell pneumatizing into the frontal sinus. A small SAFC displaces only the frontal sinus floor, whereas a large SAFC may extend well into the frontal sinus (rarely, it may even reach up to the frontal sinus roof).</td>
<td>Supra agger frontal cell (SAFC), (approx. 12%).</td>
</tr>
<tr>
<td>Posterior cells</td>
<td>Supra bulla cell</td>
<td>Cell above the ethmoid bulla, not extending into the frontal sinus.</td>
<td>Supra bulla cell (SBC), (approx. 43%).</td>
</tr>
<tr>
<td></td>
<td>Supra bulla frontal cell</td>
<td>Cell which originates from the supra-bulla region and pneumatizes anteriorly along the skull base into the posterior region of the frontal sinus. The skull base or part of the posterior wall of frontal sinus forms the posterior wall of the cell.</td>
<td>Supra bulla frontal cell (SBFC), (approx. 6%).</td>
</tr>
<tr>
<td></td>
<td>Supraorbital ethmoid cell</td>
<td>An anterior ethmoidal cell which pneumatizes around (or anterior to or posterior to) the anterior ethmoid artery over the ethmoid roof. It often forms part of the posterior wall, particularly of an extensively pneumatized frontal sinus, and if so, is separated from the frontal sinus by only a bony septation.</td>
<td>Supraorbital ethmoid cell (SOEC), (approx. 29%).</td>
</tr>
<tr>
<td>Medial cells</td>
<td>Frontal septal cell</td>
<td>Medially based cell of the anterior ethmoid or the inferior frontal sinus, attached to or located in the interfrontal septum. Close anatomical relationship with the medial aspect of the frontal sinus outflow tract, causing the drainage pathway to be displaced laterally, and often, posteriorly.</td>
<td>Frontal septal cell (FSC), (approx. 16%).</td>
</tr>
</tbody>
</table>

Tab. 2.23a Current classification scheme of frontal and frontoethmoidal cells (according to Wormald et al. 2016) with summarized prevalence data from the literature (from: Tran et al. 2019).
### Structural Elements of the Paranasal Sinuses

#### Variation patterns related to pneumatization of the frontal process of maxilla, lacrimal bone, and uncinate process

| Variation patterns related to pneumatization related to the anterior lateral nasal wall (Rusu et al. 2019). |
|------------------|---------------------------------|---------------------------------|
| **Type 1**       | Single lacrimal cell without agger nasi cell (47 %). | **Abbreviation** |
| **Type 2**       | Distinctive lacrimal cell adjacent to agger nasi cell (8 %). | |
| **Type 3**       | Lacrimal cell which is fused with a pneumatized uncinate process (6 %). | |
| **Type 4**       | Agger nasi cell adjacent to a lacrimal cell which is fused with a pneumatized uncinate process (1 %). | |
| **Type 5**       | Agger nasi cell which is fused with a lacrimal cell (27 %). | |
| **Type 6**       | Agger nasi cell which is fused with a lacrimal cell and further with a pneumatized uncinate process (11 %). | |

**Tab. 2.23c** Variation patterns related to pneumatization of the frontal process of maxilla, lacrimal bone, and uncinate process (according to Rusu et al. 2019). Agger nasi cells lie in the region of the frontal process of maxilla immediately adjacent to the anterior insertion of the middle turbinate.

Lacrimal cells are seen at a more posterior site, and they are laterally bounded mainly by the lacrimal bone.

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**Fig. 2.48** Schematic representation of frontal and frontoethmoidal cells (Wormald et al. 2016) in a sagittal (a) and frontal (b, c) view (see Tab. 2.23).
Fig. 2.49 Schematic drawings demonstrating the variation range of the frontoethmoidal cell ensemble and the anterosuperior insertion of the uncinate process (right side).

a. Shown are various insertions of the cranial anterior uncinate process (three variations in one diagram – marked with different colors).

b. Anatomical relationship between the anterior agger nasi cell (turquoise) and/or the frontal sinus or the frontal sinus drainage pathway (Rot). They are separated by sectioned extensions of the superior nasal spine and the frontal sinus floor.

c. The coronal section, dorsal to (b), shows another variation of the relationship between uncinate process and agger nasi cell. The frontal sinus is pneumatized from medially, and the ethmoidal infundibulum terminates in a blind pouch (terminal recess).

d. A different case: A large agger nasi cell has displaced the uncinate process causing it to insert in the area of the middle turbinate.

e. A frontoethmoidal cell above the agger nasi cell leads the insertion of the uncinate process to the skull base.

f. Frontoethmoidal cell above the agger nasi cell, with insertion of the uncinate process on the lamina papyracea.

g. Similar to (f), but with multiple frontoethmoid cells (Type 2 according to: Bent, Kuhn et al. 1994).

h. The approach to the frontal sinus (red oval) is displaced laterally and narrowed by multiple frontoethmoid cells.

i. Same as (h), but with medial displacement of the frontal sinus drainage pathway (red oval) (from: Wormald 2003).

<table>
<thead>
<tr>
<th>Frontoethmoidal cells inferior to “frontal sinus ostium” (e.g., ANC, SAC, SBC).</th>
<th>“Frontal sinus ostium” a.-p. diam. ≥ 10 mm</th>
<th>“Frontal sinus ostium” a.-p. diam. 5 – 9 mm</th>
<th>“Frontal sinus ostium” a.-p. diam. ≤ 5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cells encroaching into the “frontal sinus ostium” (e.g., SAFC, SBFC, SOEC, FSC).</td>
<td>Grade 1</td>
<td>Grade 2</td>
<td>Grade 3</td>
</tr>
<tr>
<td>Cells extending well into the frontal sinus (e.g., SAFC, SBFC, SOEC, FSC).</td>
<td>Grade 2</td>
<td>Grade 3</td>
<td>Grade 4</td>
</tr>
</tbody>
</table>

Tab. 2.24 Complexity of endonasal frontal sinus surgery is determined by anatomic parameters (according to: Wormald et al. 2017). The presented rating distinguishes between 4 degrees of complexity assessed on the basis of preoperative CT scans. Abbreviations: see Tab. 2.23.

Clinical Hints

- The variable topography of frontoethmoidal cells and their impact on the frontal sinus drainage pathway can be graphically demonstrated on the basis of CT scans (in 3 planes) using a special software (“building blocks”) (Wormald 2006).

- A supra bulla frontal cell (frontal bulla) has been reported to be frequently associated with frontal sinusitis (Kubota et al. 2015). Similarly, intraoperatively missed supra bulla frontal cells reportedly increase the rate of postoperative frontal sinusitis (Nakayama et al. 2018). Other authors, however, argue that there is no conclusive correlation between certain cell types and frontal sinusitis (Eweiss and Khalil 2013).

- Specific features of the local anatomy in the frontal sinus drainage pathway can serve as an orientation to roughly define the anticipated level of difficulty in endonasal frontal sinus procedures. Relevant factors are an antero-posterior
Ganglion pterygopalatinum

The basal part of the palatine bone is made up of the horizontal plate and, at a nearly right angle to it, of the perpendicular plate. Cranially, the latter terminates in two processes, the (anterior) orbital process and the (posterior) sphenoidal process; caudally between these two processes lies the sphenopalatine foramen. In the vicinity of the foramen and always medial to the sagittally oriented perpendicular plate lies a small bony crest (ethmoidal crest), which contributes to the insertion of the posterior middle turbinate (3rd basal lamella) into the lateral nasal wall (Fig. 2.50).

Located between the palatine bone and the maxilla, the greater palatine canal, approx. 10 mm in length, stretches from the pterygopalatine fossa to the greater palatine foramen at the hard palate. The canal transmits the greater palatine nerve, the lesser palatine nerve, and the descending palatine artery (the greater palatine nerve is always found medially and usually anterior to the artery); in the sagittal plane, the canal runs anteriorly at an approx. 30° angle with the vertical axis. At the junction to the hard palate, the maxillary sinus extends approximately 7 mm (3–12 mm) further dorsally than the anterior margin of the greater palatine canal. The palatine bone is about 3 mm thick in the region of the canal. In about 40% of cases, dehiscences are found medial to the canal, particularly near the inferior turbinate and in the plane of the nasal floor.

Special Literature
Ayoub et al. 2017; Campbell et al. 2018; Daniels et al. 1998; Hafeez et al. 2015; Karci et al. 2018; Mellema and Tami 2004; Padua and Voegels 2008.

Ground lamellae

- The ethmoidal crest (crista ethmoidalis) of the palatine bone serves as a major landmark for exposure of the sphenopalatine foramen.
- The sphenoid process contributes to the palatovaginal canal. Removing parts of the orbital process facilitates exposure of the pterygopalatine fossa.

Clinical Hints
- The dorsal part of the maxillary sinus which is frequently seen to extend beyond the plane of the greater palatine canal, is a predilection area for iatrogenic injury to the canal in cases where a maximum maxillary antrostomy or medial maxillectomy is undertaken.

Special Literature
Ayoub et al. 2017; Campbell et al. 2018; Daniels et al. 1998; Hafeez et al. 2015; Karci et al. 2018; Mellema and Tami 2004; Padua and Voegels 2008.

Structural Elements of the Paranasal Sinuses

Special Literature

a see also: Fossa pterygopalatina
b see: Basal lamellae
“Haller cell”\(^a\)

**Hasner valve (Plica lacrimalis)\(^b\)**

**Hiatus maxillaris**

This term refers to the osseology of the isolated maxilla (without ethmoid bone, lacrimal bone, palatine bone, and inferior turbinate). Under these conditions, a large opening (hiatus) is found in the medial wall of the maxillary sinus.

**Hiatus semilunaris inferior\(^c\)**

Mainly two-dimensional, sagittally oriented, crescent-shaped cleft formed by the shortest line between the free posterior margin of the *uncinate process* and the *anterior face of the ethmoidal bulla* (Tab. 2.25). The *ethmoidal infundibulum* is reached through this cleft (Fig. 1.5, 2.51).

**Course (contour) of the inferior semilunar hiatus (Dahlstrom and Olinger 2014).**

- **Type 1** Classic type, gently curved (55 %).
- **Type 2** Shaped like the letter “J” (17 %).
- **Type 3** Shaped like the letter “L” (6 %).
- **Type 4** Shaped like the letter “U” (9 %).
- **Type 5a** Straight course, vertical (7 %).
- **Type 5b** Straight course, oblique (6 %).

Tab. 2.25 Anatomical variations defined by the shape of the course of the inferior semilunar hiatus.

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**Hiatus semilunaris superior\(^d\)**

Cleft between the posterior *ethmoid bulla* and the basal lamella of the middle turbinate. The *suprabullar and retrobullar recesses* are accessed via this cleft.

---

\(^a\) see: *Infraorbital ethmoid cell*

\(^b\) see: *Lacrimal passages*

\(^c\) see also: *Processus uncinatus; Infundibulum ethmoidale*

\(^d\) see also: *Rcessus supra- et retrobullaris*
### Structural Elements of the Paranasal Sinuses

#### Hypersinus, pneumosinus dilatans, pneumocele – enlarged sinuses

An enlarged sinus is a paranasal sinus which has been exposed to disproportionate pneumatization (particularly applies to the frontal sinus). As a result of this “hyperpneumatization”, the sinus is above the 99th percentile in size for the respective sinus. There is no evidence of pathologically altered bony walls nor are there seen any focal bulges; the affected paranasal sinus does not transgress into the cranium. The variation is asymptomatic.

The term hypersinus is to be distinguished from pneumosinus dilatans and pneumocele (Tab. 2.26).

<table>
<thead>
<tr>
<th>Hypersinus</th>
<th>Enlarged sinus above the 99th percentile for size. Stable finding, no specific symptoms and no condition of illness.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumosinus dilatans</td>
<td>Progressive expansion of a pneumatized paranasal sinus without affecting the integrity of bony walls; it may result in cosmetic deformity, diplopia, etc. Occasionally associated with other diseases (meningioma, arachnoidal cysts, etc.). Treatment is geared toward improving ventilation.</td>
</tr>
<tr>
<td>Pneumocele</td>
<td>Progressive and excessive pneumatization of a paranasal sinus with atrophy or partial absence of the bony wall of the paranasal sinus. Treatment is geared toward improving ventilation.</td>
</tr>
</tbody>
</table>

**Tab. 2.26** Definitions of hypersinus, pneumosinus dilatans and pneumocele (from: Acar et al. 2004; Juhl et al. 2001; Lund et al. 2014; Song et al. 2015; Urken et al. 1987a,b).

#### Infraorbital ethmoid cell (formerly: “Haller cell”)

*Infraorbital ethmoid cells* develop as extensions of the anterior or posterior ethmoid into the orbital floor. Anterior cells (formerly named “Haller cells”) have a prevalence of 4–20% and are more common in women (Fig. 2.52). The cells vary widely in size, with a maximum of 2.5 cm³, and are commonly associated with local dehiscences of the bony orbital floor. Anterior infraorbital cells drain into the posteroinferior part of the middle meatus and rarely into the ethmoidal infundibulum. In isolated cases, drainage into the maxillary sinus has been observed as well.

In up to 80% of cases, posterior ethmoid cells extend laterally beyond the sagittal plane of the medial maxillary sinus wall (Fig. 2.53, Tab. 2.27). In this area, terminological and morphological overlap exists for posterior infraorbital ethmoid cells versus retromaxillary cells versus lateral deviation of the superior meatus versus a divided maxillary sinus (the posterior segment of the maxillary sinus then drains into the superior meatus). The prevalence of these cells is unrelated to age and sex.

**Fig. 2.52** Bilateral appearance of anterior *infraorbital ethmoidal cells* (1) in close proximity to the uncinate process (2).

**Fig. 2.53** Schematic drawing of a frontal section through the posterior ethmoid bone. The posterior ethmoid cells extend laterally beyond the sagittal plane of the medial maxillary sinus wall (>). These cells should be distinguished from “Haller’s cells”, which originate from the anterior ethmoid (from: Herzallah et al. 2016).

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*a* see also: Maxillary sinus
Clinical Hint

The presence of an *infraorbital ethmoidal cell* and its size are not intrinsically associated with an elevated risk of maxillary sinusitis (Mathew et al. 2013). In some cases, however, it can become the source of infection or predispose to stenosis of the natural maxillary ostium.

**Infundibulum ethmoidale**

The *ethmoidal infundibulum* is a three-dimensional space. Medially, it is bordered by the *uncinate process*, laterally, by the *lamina papyracea* (lamina orbitalis) of the ethmoid, and occasionally, the *frontal process of maxilla* as well as the *lacrimal bone* (in isolated cases also a cellular process, see Tabs. 2.36, 2.37; Fig. 2.70). The ethmoid bulla lies dorsally. The *ethmoidal infundibulum* is reached via the *inferior semilunar hiatus*. The cleft of the infundibulum is 0.5–10 mm deep. The *natural ostium of the maxillary sinus* opens into the infundibulum. If the infundibulum is divided into 4 sections from anterosuperior to posteroinferior, the ostium is commonly (in approx. 50% of cases) in the next-to-last quarter.

Clinical Hint

The width of the *ethmoidal infundibulum* correlates inversely with a susceptibility to recurrent acute rhinosinusitis (Alkire and Bhattacharyya 2010).

**Infundibulum frontale**

Funnel-shaped structure in the frontal sinus floor at its junction to the anterior ethmoid.

**Infundibulum maxillare**

Funnel-shaped structure in the maxillary sinus region directly anterior to the *natural maxillary ostium*; found in some cases.

**Interlamellar cell**

Special form of pneumatization of a middle turbinate (see *Concha bullosa*). From the direction of the superior meatus, the vertical lamella of the middle turbinate is “split” and pneumatized by a flat cell (Tab. 2.11).

**Intersinus septal cell ("interfrontal sinus septal cell")**

**Sphenoid sinus** (anterior sphenoid sinus wall, posterior sphenoid sinus wall, lateral sphenoid sinus wall)

Above the choana, the anterior sphenoid sinus wall exhibits a height of approx. 20 mm (13–31 mm). For the *ethmoidal part* (lateral anterior wall), similar averages are reported. The sphenoid sinus ostium lies on average 10 mm (6–22 mm) superior to the choana, i.e., at half of the height of the anterior wall (other reports indicate that it is located in the upper third in ¾ of cases). In case of minor pneumatization, the relative position of the point is further cranially. In two-thirds of cases, the ostia of both sides are offset in height by more than 2 mm (Fig. 2.54).

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Special Literature


Special Literature

Alkire and Bhattacharyya 2010; Lang 1988; May et al. 1990.
Symmetry is seen in about 50% of cases and equally provided with lateral side-to-side differences are common. Considerable ethnic differences exist; age reportedly plays no role (but sex does, with the sphenoid sinus being slightly smaller in women). In general, peripheral pneumatization with lateral side-to-side asymmetry is seen in about 50% of cases, slightly lateral to this surface, about 4 mm (0.2–5 mm) paramedian (Fig. 2.55, cf. Fig. 2.36). Owing to deflection of the superior turbinates from the sagittal plane and the individual formation of a sphenoid recess, however, individual topographic relationships to the superior turbinate (or supreme turbinate) are seen in isolated cases (Fig. 2.56, cf. Tab. 2.14).

The ostium can be round (50%), aligned in various planes, assume an oval (30%) or ovoid or slit-like shape – the literature provides very divergent data on the prevalence of the seen variations. The diameter is approx. 3 (1–9) mm.

The average volume of a sphenoid sinus is about 7 cm³ (0–14 cm³); side-to-side differences are common. Considerable ethnic differences exist; age reportedly plays no role (but sex does, with the sphenoid sinus being slightly smaller in women). In general, peripheral pneumatization with lateral side-to-side symmetry is seen in about 50% of cases and equally pronounced in the sagittal and frontal planes, particularly in patients with a straight nasal septum. Extensive pneumatization causes individual structural elements of the lateral sphenoid sinus wall to become deviated in a lateroinferior direction, e.g., resulting in an increase in the distance between the nerve of pterygoid canal and maxillary nerve (frontal plane), with concomitant accentuation of the prominence of the pterygoid canal and canalis rotundus. Pneumatization of the sphenoid sinus may, among others, occur in the greater or lesser wing of sphenoid, palatine bone, vomer, pterygoid process, nasal septum, and the posterior ethmoid air cells, etc. (Fig. 2.57, Tab. 2.28). An anteroinferiorly oriented maxillary process, which jointly forms a “sphenomaxillary plate” with the maxillary sinus is rarely seen (cf. Fig. 2.78). Similarly rarely, a recess forms in the lateral sphenoid sinus wall between the trigeminal branches V1 and V2 or between V2 and V3.

Conversely, a posterior ethmoidal cell can expand along the sphenoid sinus roof into a space otherwise typically occupied by the sphenoid sinus (“overriding ethmoidal cell”) and, given a lateral location, it may come to a variable extent, in contact with the optic nerve (see: Sphenoid ethmoidal cell). Rarely (3%), the entire optic canal lies, as a result, in a sphenoid recess. Posterior ethmoidal cells in the sphenoid sinus roof are reportedly much more common in Asia than in Europe.

In the older literature, the degree of sphenoid sinus pneumatization is classified solely by the anatomical relationship between the posterior wall and the sella – accordingly, the classification provides for a rudimentary “conchal type” (approx. 2%), a “pre-sellar type” (pneumatization ends in the sagittal plane in the region of the anterior sellar wall, approx. 15%), and a “sellar type” (pneumatization extends further posteriorly toward the clivus, approx. 80%). Later, a “postsellar type” was added (40–60%). Alternative, more recent classification schemes are presented in Tab. 2.28. Sphenoid sinus agenesis is found in approx. 0.5% of cases – particularly in patients with craniofacial malformations or in those with primary ciliary dyskinesia and the like.

Fig. 2.55 Shown is the dorsal ethmoid (different cadaver specimens) in frontal section, directly anterior to the anterior sphenoid sinus wall. Average condition (a); Narrow “ethmoidal part” of the anterior sphenoid sinus wall (b); Wide “ethmoidal part” of the anterior sphenoid sinus wall (c). The space available for a transethmoidal approach to the sphenoid sinus differs considerably in width (marked by a red-and-white line on the right side of each specimen). Sectioned dorsal nasal septum (S). Sectioned optic nerve (✱) (from: Hosemann et al. 1995).

Fig. 2.56

a. Axial CT scan through the sphenoid sinus. Both sphenoid sinus ostia are lateral to a sagittal plane through the medial edge of the superior turbinate (or the lamina conchalis).

b. Nasal part of the right anterior sphenoid sinus wall as viewed from the front. In this case, the sphenoid sinus ostium (✱) faces toward the nasal cavity, medial to the superior turbinate (✱) with its dorsal insertion. Dorsolateral insertion of the middle turbinate (✱); Choana (✱).
### Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

**Pneumatization of the sphenoid sinus in the sagittal plane (in a posterior direction) from the standpoint of pituitary surgery (Hammer and Radberg 1961).**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conchal Type</td>
<td>Rudimentary pneumatization (2.5%).</td>
</tr>
<tr>
<td>Presellar Type</td>
<td>Pneumatization ends in a frontal plane through the sellar tubercle (bilateral in 11% of cases).</td>
</tr>
<tr>
<td>Sellar Type</td>
<td>Pneumatization extends dorsally beyond a frontal plane in the region of the sellar tubercle (bilateral in 59%).</td>
</tr>
<tr>
<td>Mixed Type</td>
<td>Pneumatization patterns variable on the left and right side (27%).</td>
</tr>
</tbody>
</table>

**Pneumatization of the sphenoid sinus in the sagittal plane (in a posterior direction) (Guldner et al. 2012).**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Absent or minimal pneumatization (0.3%).</td>
</tr>
<tr>
<td>Type 2</td>
<td>Pneumatization up to the anterior face of the sella (7%).</td>
</tr>
<tr>
<td>Type 3</td>
<td>Pneumatization up to the plane between the anterior and the posterior sellar wall (57%).</td>
</tr>
<tr>
<td>Type 4a</td>
<td>Pneumatization extends behind the plane of the posterior sellar wall, but not into the dorsum sellae (18%).</td>
</tr>
<tr>
<td>Type 4b</td>
<td>Pneumatization as in Type 4a, but also involving the dorsum sellae (18%).</td>
</tr>
</tbody>
</table>

**Pneumatization of the sphenoid sinus in the sagittal plane (in a posterior and anterior direction) (Wang et al. 2010).**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Absent or minimal pneumatization (0.3%).</td>
</tr>
<tr>
<td>Type 2</td>
<td>Pneumatization up to the anterior face of the sella (7%).</td>
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<td>Type 3</td>
<td>Pneumatization up to the plane between the anterior and the posterior sellar wall (57%).</td>
</tr>
<tr>
<td>Type 4a</td>
<td>Pneumatization extends behind the plane of the posterior sellar wall, but not into the dorsum sellae (18%).</td>
</tr>
<tr>
<td>Type 4b</td>
<td>Pneumatization as in Type 4a, but also involving the dorsum sellae (18%).</td>
</tr>
</tbody>
</table>

**Pneumatization of the sphenoid sinus in the frontal plane (in a lateral direction) (Wang et al. 2010).**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Pneumatization limited to the sphenoid body without lateral pneumatization.</td>
</tr>
<tr>
<td>Laterally extended pneumatization (46%)</td>
<td>Pneumatization of the lesser wing of sphenoid.</td>
</tr>
<tr>
<td>Type B</td>
<td>Pneumatization of the greater wing of sphenoid (12%).</td>
</tr>
<tr>
<td>Type C</td>
<td>Pneumatization of the pterygoid process (10%).</td>
</tr>
<tr>
<td>Type D</td>
<td>Combination of C + D (77%).</td>
</tr>
</tbody>
</table>

**Lateroinferior pneumatization of the sphenoid sinus from the standpoint of transpterygoidal surgery (Vaezi et al. 2015).**

| Type 1 | “Previdian type” – Pneumatization to the Vidian nerve (25%). |
| Type 2 | “Prerotundum type” – Pneumatization up to the foramen rotundum (39%). |
| Type 3 | “Postrotundum type” – Pneumatization extends also lateral to the foramen rotundum (37%). |

**Exposure of the retrosellar internal carotid artery in the lateral wall of the sphenoid sinus (Batra et al. 2004a).**

| Type 0 | No exposure (12%). |
| Type 1 | Exposure of less than 90° of circumference (33%). |
| Type 2 | Exposure of 90°–180° of circumference (50%). |
| Type 3 | Exposure of more than 180° of circumference (5%). |

**Exposure of the canalis rotundus in the lateral wall of the sphenoid sinus (Cheng et al. 2015b).**

| Type 1 | Significant bulging (20%). |
| Type 2 | On the surface of the lateral sphenoid sinus wall without bulging (77%). |
| Type 3 | Course without direct contact to the lumen of the sphenoid sinus. |

### Fig. 2.57 Frontal CT scan of a sphenoid sinus. Note, that there is lateral pneumatization extending toward the lesser wing of the sphenoid (1) and also toward the greater wing of the sphenoid (3) with the pterygoid process (4). The latter pneumatization pattern is assessed in relation to the “VR line” (2, ← as an imaginary line between the Vidian/pterygoid canal (C.N.p.) and the foramen rotundum (F.r.). Note that the intersphenoid septum inserts into the bony cover of the internal carotid artery, Optic nerve (N.o.).
The total width of both sphenoid sinuses, when measuring the distance between the two carotid arteries, is approx. 21 mm in the anterior pituitary region and only approx. 16–18 mm at the inferior border of the sella. In rare cases, however, the shortest distance between the mid-sagittal line and the carotid artery is as small as 3 mm.

In the lateral sphenoid sinus wall, variable recesses are found (e.g., superior and inferior lateral recess, optico-carotid recess, pterygoid recess, posterior and posterolateral recess). They encase prominences of the bony lateral wall which contain the optic nerve (prevalence: 5–60%), the petroclival internal carotid artery (30%), the anterior genu of the internal carotid artery (40–65%), the maxillary nerve (10–40%) and the nerve of the pterygoid canal (20–50%) (Fig. 2.58, 2.59). While the general degree of sphenoid sinus pneumatization correlates with the prominence degree of the carotid artery, this does not apply to the optic nerve. The pterygoid process is pneumatized in 10–40% of cases, the clinoid process in about 17%, and the vomer in 0.5%.

The intersphenoid septum remains in the mid-sagittal plane in only about 10–30% of cases. In case of a transverse course, points of insertion are seen in the region of the paraseptal or paracarotid carotid artery (approx. 30%; Fig. 2.57) or, e.g., of the optic nerve (approx. 20%). Furthermore, in approx. 50–80% of cases, additional, incomplete bony septa are observed in the sphenoid sinus. These septa usually abut the wall of the internal carotid artery, and much less commonly, the optic canal. They are frequently associated with a well-pneumatized pterygoid process and anterior clinoid process, for example.

In an anterior aspect, the roof of the sphenoid sinus consists of the planum sphenoidale and posteriorly, of the sella. In the area of the planum sphenoidale, the bone is about 0.6 mm (0.2–1.4 mm) thick; in a sellar pneumatization type, bone thickness in the region of the sella is approx. 0.4 mm. The pituitary itself is enveloped by two connective tissue membranes (lamina propria and pituitary capsule), which locally vary in thickness.
Clinical Hints

- According to an old rule published by Mosher (Mosher 1929), the superior turbinate’s insertion into the anterior sphenoid wall is divided into thirds (in width): the lateral two thirds (pars ethmoidalis) lie in the extension of the posterior ethmoid, while the medial third (pars nasalis) is oriented toward the nasal cavity. This rule is of very limited utility, but it does help to mentally plan sphenoidotomies (cf. Fig. 2.55).

- Once the sphenoid sinus ostium is localized, it serves as the starting point for opening the anterior wall, initially in a caudal direction. If the ostium cannot be found, according to Wigand a relatively safe puncture site lies 10 mm above the choana. Below this level, the osseous anterior wall is sturdier, and there is an elevated risk of bleeding from the posterior septal artery. Conversely, above this level, the risk of injury to the skull base increases (Hosemann et al. 1995; 2000).

- In 2.5% of cases, a single dorsal ethmoid cell (rarely multiple cells) cranially expands markedly over and into the sphenoid sinus (“overriding ethmoidal cell”; spheno-ethmoidal cell) (Christmas et al. 2004; Edelstein et al. 1995) – a key finding since it is often a source of anatomic disorientation. Inferior (and medial) to these cells, in that case, the actual sphenoid sinus lumen should be located and exposed.

- In the presence of a transversely oriented intersphenoid septum which is attached to the prominence of the internal carotid artery, due care must be taken with regard to the forces transmitted while operating on the nasal/ intersphenoid septum (risk of injury to the artery).

- Given sufficient pneumatization of the sphenoid sinuses, the petrous apex posterior to the petroclival segment of the carotid artery is also amenable to a surgical approach (using a navigation system) (Chatrath et al. 2007).

- The sphenoid sinus roof is considered a key landmark for dissection along the skull base from posterior to anterior – this holds true even though the roof is at a slightly higher level in absolute terms than the ethmoid sinus roof located anteriorly (van Alyea 1941).

- A maxillary recess of the sphenoid sinus with a “spheno-maxillary plate” can cause anatomic disorientation because of the close proximity of maxillary and sphenoid sinuses (Fig. 2.78).

Special Literature

Maxillary sinus, natural maxillary sinus ostium

The maxillary sinus is of pyramidal shape, with its apex formed by the zygomatic recess; its average volume is 16 cm³ (5 – 22 cm³) (Tab. 2.29).

The maxillary sinus ostium measures approx. 2.5–5 mm (in diameter); in approx. 80% of cases, the ostium to some extent appears like a small canal approx. 3 mm in length. Near the ostium, the maxillary sinus often features a mucosal fold as an “infraostial ridge.” In relation to the middle meatus, the ostium is found, in 70% of cases, in the inferior-posterior third of the ethmoidal infundibulum (or in the inferior-posterior next-to-last quarter) and it does not exactly lie in the sagittal plane (Fig. 2.60). In only about 10% of cases, the ostium is partially visible during routine transnasal endoscopy (0° telescope). When viewed from laterally, the ostium is located about halfway between the anterior and the posterior maxillary sinus wall, frequently near a mucosal fold of the maxillary sinus. Anteriorly, the ostium is located at an average of 4 mm from the lacrimal passages – but in isolated cases, this distance may be as small as 1.5 mm. Cranially, the orbital floor is often only 2 mm away and slopes laterally at an angle of 30° in the frontal plane. In 10% of cases, the orbit craniomedially arches over the ostium; in 4% of cases, the lateral nasal wall is distinctly “set beneath the orbit” in the middle meatus owing to a hypoplastic maxillary sinus (grade 1 maxillary sinus atelectasis), and the uncinate process is displaced accordingly (Figs. 2.61, 2.66).

Fontanelles are parts of the medial maxillary sinus wall above the inferior turbinate, which intrinsically have no bony support. Regarding the bony, inferior-posterior extension of the uncinate process, an anterior and a posterior fontanelle are distinguished (Fig. 1.5). Near such a fontanelle, two mucosal layers lie on top of each other, separated only by periosteal extensions from the adjacent area. Particularly the posterior fontanelle is a predilection site for perforations in the form of secondary (accessory) maxillary sinus ostia. Such secondary ostia are more common with age; the reported prevalence is 5–50%.

Major recesses of the maxillary sinus are the zygomatic recess, prelacrimal recess, alveolar recess, and the palate recess. In about 15% of cases, a “sphenomaxillary plate” forms a junction between the posterosal maxillary sinus and the sphenoid sinus (Fig. 2.62, Tab. 2.30). The osseous roof of the maxillary sinus is often only 0.5 mm thick. The infraorbital canal runs anteroposteriorly along the roof. This canal shows bony dehiscences in 15% of cases. The maxillary sinus floor is in very close proximity to the roots of the first and, particularly, the second molar; focal bone dehiscences are seen in approx. 2% of cases.

In the region of the lateral maxillary sinus wall, in about 25% of cases, the superior alveolar artery (approx. 1.6 mm in diameter) does not follow an intraosseous course, but runs in the mucosa approx. 10 mm superior to the maxillary sinus floor. Anastomoses connect the artery with the infraorbital artery (approx. 1.6 mm in diameter).

Two prominences are commonly found in the posterior maxillary sinus wall:

- In the superior region, the infraorbital canal or sulcus forms a first, almost vertical prominence in 40% of cases.
- In the middle region of the posterior wall, an almost horizontal prominence can be seen, resulting from the maxillary artery which lies dorsally.

In adults, the floor of the maxillary sinus is approx. 1.25 cm inferior to the nasal floor.

In about 25–50% of cases, the maxillary sinus floor presents with variably shaped, incomplete bony septa. Primary (incomplete) septa develop in the course of regular tooth eruption, while secondary septa arise later in life, after tooth loss. Septa are observed in 25% of cases in the premolar region, in 55%, in the molar region, and in 20%, in the retromolar region. They are seen frontally in approx. 50% of cases, sagittally in approx. 25%, and horizontally in approx. 20%, and they exhibit an average height of 9 mm (2–11 mm). Rarely (in 4% of cases), a maxillary sinus contains multiple septa. Anteromedially, septation can give rise to an “infraorbital maxillary sinus cell” seen close to the lacrimal passages; this cell must be distinguished from infraorbital ethmoidal cells in the strict sense. Very rarely (0.3%), a septum completely divides the maxillary sinus – dorsally, such septation must be distinguished from retromaxillary ethmoid cells or an ethmomaxillary sinus (Tab. 2.30, Fig. 2.78). True “doubling of regular maxillary sinuses”, with two separate ostia in the middle meatus, is rare.

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*Fig. 2.60 Schematic drawing showing the maxillary sinus in frontal section. Commonly, the maxillary ostium (●●●●) is tilted toward the sagittal plane and points, to a minor extent, in a posterior direction (from: Landsberg and Friedman 2001).*

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65

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*See also: Fontanelles; Infraorbital ethmoid cell (formerly: “Haller cell”); Lamina papyracea; Middle meatus – lateralization; N. infraorbitals, N. maxillaris; Anatomy of Paranasal Sinuses in Children*
Degree of maxillary sinus hypoplasia with consecutive changes in the uncinate process / ethmoidal infundibulum in CT imaging (Bolger et al. 1990).

<table>
<thead>
<tr>
<th>Stage of chronic maxillary atelectasis (Kass et al. 1997).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type 1</strong></td>
</tr>
<tr>
<td><strong>Type 2</strong></td>
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<td><strong>Type 3</strong></td>
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Forms of extensive maxillary sinus pneumatization (Kalavagunta and Reddy 2003).

<table>
<thead>
<tr>
<th>Forms of extensive maxillary sinus pneumatization</th>
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<tbody>
<tr>
<td><strong>Type 1</strong></td>
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<td><strong>Type 2</strong></td>
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<td><strong>Type 3</strong></td>
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</table>

Variation patterns related to the course of the nerve fibers (particularly of the anterior superior alveolar nerves) in the region of the anterior maxillary sinus wall (Robinson and Wormald 2005).

<table>
<thead>
<tr>
<th>Variation patterns related to the course of the nerve fibers</th>
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<tbody>
<tr>
<td><strong>Type A</strong></td>
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<td><strong>Type B</strong></td>
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<td><strong>Type C</strong></td>
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<td><strong>Type D</strong></td>
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Variation patterns of the anterior superior alveolar artery (Iwanaga et al. 2019).

<table>
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<tr>
<th>Variation patterns of the anterior superior alveolar artery</th>
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<tr>
<td><strong>Type 1</strong></td>
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<td><strong>Type 2</strong></td>
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<td><strong>Type 3</strong></td>
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</table>

### Tab. 2.29 Variation patterns of the maxillary sinus volume (hypoplasia, hyperplasia, atelectasis); variation patterns related to nerve branching (alveolar nerves) and arterial course. “Intermaxillary lamella”: inferior to the nasal floor, the bilateral palatine recesses are separated only by a sagittal median bony lamella; “sphenomaxillary lamella”: sphenoid sinus and maxillary sinus abut against each other through a bony lamella.
Clinical Hints

- A horizontal line drawn through the posterior medial roof of the maxillary sinus, parallel to the nasal floor (“maxillary roof line”), is considered a reliable landmark. It serves as a reference prior to sphenoidotomy, and the removal of ethmoid cells in a notably dorsal position. The line indicates a plane which lies at a safe distance (≥ 4 mm, 15 mm on average) from the skull base, including the olfactory fossa. The line reaches the anterior wall of the sphenoid sinus at about half of its height. In almost one-third of cases, the sphenoid sinus ostium lies in the same frontal plane as the posterior maxillary sinus wall (Abdullah et al. 2018; Dedhia et al. 2019; Harvey et al. 2010; Lee SJ et al. 2017; Wuttiwongsanon et al. 2015).

- In their posteromedial segment, that is, in the vicinity of the middle meatus, the lacrimal passages are covered only by the very fragile lacrimal bone. In isolated cases, its wall thickness of occasionally less than 0.1 mm does not prevent injuries – particularly when abruptly attempting to anteriorly enlarge neo-ostia in the middle meatus.

- The degree to which the maxillary sinus can be fenestrated in the middle meatus has been divided into grades (Simmen, Jones 2013). Even in case of a maximum fenestration in the middle meatus, however, the maxillary sinus cannot be fully viewed using standard rigid telescopes (0°, 30°, 45°, 70°), much less “controlled” with instruments (Hosemann et al. 2003). Therefore, adjunctive surgical procedures (postlacrimal approach, prelacrimal approach) have been developed (Weber 2015; Zhou et al. 2013).

- If necessary, a prelacrimal approach can be further extended as in an “endonasal Denker operation.” Excessive removal of the bony base of the ala nasi in the region of the medial anterior wall of the maxillary sinus at the junction to the piriform aperture can, however, in extreme cases result in an externally visible sagging of the nasal base (El-Sayed et al. 2011).

- Transoral puncture of the anterior maxillary sinus wall may in the worst case cause damage to a branch of the infraorbital nerve (especially, the anterior superior alveolar nerve) (Tab. 2.29). A relatively safe site for transoral puncture is defined by the intersection of an ipsilateral vertical mid-pupillary line and a horizontal line drawn exactly through the floor of the nasal vestibule (Robinson and Wormald 2005).

- The infraorbital nerve with its potential canal dehiscences at the orbital roof is prone to injury when attempting blind transnasal manipulations through the middle meatus.
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

Special Literature

Lamina cribrosa

The cribriform plate is a bony plate of the ethmoid bone which transmits olfactory fibers from the rima olfactoria to enter the olfactory fossa. The lateral lamella (lateral wall of the fossa) is one of the thinnest bony plates of the anterior skull base.

The cribriform plate is about 21 mm (15–28 mm) long and presents distinct morphological variation patterns (Tab. 2.31). Anteriorly, for example, it is often only about 3 mm wide. Dorsally, its width increases to approx. 6 mm. Also the posterior extensions of the cribriform plate are often below the adjacent ethmoid sinus roof. The cribriform plate contains 18–22 smaller foramina on both sides, each < 1 mm in diameter, arranged almost in two sagittal rows. Individual canaliculi of the cribriform plate may terminate intranasally lateral to the vertical lamella of the middle turbinate or run caudally in the turbinate bone.

Aside from the penetration sites of the olfactory fibers, the anterior cribriform plate exhibits two more bony openings, the cribroethmoidal foramen and the ethmoidal foramen. The former is about 1 x 1.5 mm in size and transmits a terminal branch of the anterior ethmoid artery, accompanied by a small branch of the anterior ethmoidal nerve, to the inner part of the nose. Anteriorly, the cribroethmoidal foramen leads to a “cribroethmoidal groove” and occasionally to a small canal inferior to the frontal sinus floor. Posteriorly and medially, the ethmoidal foramen, which is approx. 1 x 4 mm in size, abuts the crista galli; it is closed by connective tissue.

Morphological variation patterns of the cribriform plate in a view of the skull base from above (Kawahara, after Vasvari et al. 2005).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Width increases in an a.-p. direction, medially curved crista frontoethmoidalis, swallowtail posteriorly (36%).</td>
</tr>
<tr>
<td>2</td>
<td>Width increases in an a.-p. direction, exact direct touchlines diverging towards the planum sphenoidale (33%).</td>
</tr>
<tr>
<td>3</td>
<td>Very narrow, parallel laminae (14%).</td>
</tr>
<tr>
<td>4</td>
<td>Very wide laminae with medially convex lateral boundaries (10%).</td>
</tr>
<tr>
<td>5</td>
<td>Laterally convex lateral boundaries (7%)</td>
</tr>
</tbody>
</table>

Clinical Hints
- The ethmoidal foramen, when lined with connective tissue, can become the site of "spontaneous meningoceles or CSF leaks."
- The anterior ethmoid artery with its site of exit from the cribroethmoidal foramen represents a key landmark in maximized endonasal frontal sinus procedures (more so than the first olfactory fiber).

Special Literature
Lamina papyracea

The lamina papyracea is a very thin (0.2–0.4 mm thick) bony lamella which forms the medial orbital wall. The bone presents natural dehiscences anteriorly and becomes thicker dorsally. The convex medial orbit shows an inconsistent relationship with the sagittal plane of the medial maxillary sinus wall (Fig. 2.63). Dorsally, the orbital periosteum is continuous with the dural layers from the optic canal. Within the orbit, the intraconal, conal, and extracanal space are distinguished with respect to the extraocular muscles. The recti muscles emanate dorsally from the annulus of Zinn, which lies above the opening of the optic canal and above parts of the superior orbital fissure (Fig. 2.64).

Smaller focal dehiscences in the lamina papyracea are found in about 30% of cases. Rarely (<1%), primary or secondary (e.g., posttraumatic) dehiscences cause the orbital tissue to bulge toward the ethmoidal infundibulum, mainly anterior to the basal lamella of the middle turbinate, i.e., in the ethmoid bulla region.

<table>
<thead>
<tr>
<th>Relative position of the convex medial lamina papyracea (LP) in relation to the attachment of the inferior turbinate in the plane of the natural ostium of the maxillary sinus (= inferior margin of a regular antrostomy) in a coronal CT scan (Herzallah et al. 2015).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
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<tr>
<td>1</td>
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<td>2</td>
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<td>2a</td>
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<td>3</td>
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<tr>
<td>3a</td>
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<td>3b</td>
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</table>

Fig. 2.63 Relative positions of the medial convexity of the lamina papyracea and the lateral nasal wall in the area of the natural ostium of maxillary sinus (from: Herzallah et al. 2015; see Tab. 2.32 and also Figs. 2.60, 2.61, 2.66). Vertical line of reference (-----) drawn through the insertion of the inferior turbinate (O) in the coronal plane of the natural ostium.

Clinical Hint

In patients with a distinct lateral or medial displacement of the orbit (lamina papyracea) in relation to the medial maxillary sinus wall, the resulting anatomic variation pattern is associated with an elevated risk of injury during middle meatal antrostomy (Fig. 2.60, 2.61). The same is true for a generally higher vulnerability of the orbit in the area of natural bony dehiscences of the lamina papyracea.

Special Literature

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*a* see also: Fissura orbitalis superior; Maxillary sinus (Middle meatus, Lateralization); Orbit

*b* see also: Middle meatus
Maxillary line

The maxillary line is a vertically oriented linear reference used in procedures on the anterior ethmoid (e.g., infundibulotomy, frontal sinusotomy) or the large lacrimal passages. It is the vertex of a vertically oriented, hemispheric bulge in the lateral nasal wall superior to the inferior turbinate and anterior to the attachment of the middle turbinate (Fig. 2.65). In 90% of cases, the maxillary line lies directly over the nasolacrimal duct, and in 2/3 of cases, it also lies over the maxillolacrimal suture (Tab. 2.48).

Fig. 2.65 Endoscopic view of the anterior middle meatus on the right. The maxillary line (➤) starts off at the insertion (Co.m.) of the middle turbinate and takes a sloping course (with minor dorsal extension) toward the insertion of the inferior turbinate (Co.i.). Nasal septum (S); Uncinate process (Pr.u.).

<table>
<thead>
<tr>
<th>Type 1</th>
<th>“Normal length” of maxillary line 15 ± 3.5 mm (68%).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 2</td>
<td>“Short” maxillary line, &lt; 11.5 mm (17%).</td>
</tr>
<tr>
<td>Type 3</td>
<td>“Long” maxillary line, &gt; 18.5 mm (15%).</td>
</tr>
</tbody>
</table>

Tab. 2.33 Variations in the length of the maxillary line with prevalence data (from: Raikos et al. 2015; see Fig. 2.65).

Maxillary strut

Middle turbinate

Middle meatus, lateralization

In some cases, the lateral nasal wall can be fused with the medial orbital floor in the middle meatus region (Fig. 2.66; Maxillary sinus atelectasis, grade 1 – see Fig. 2.60, Tab. 2.29). In the anterior inferior meatus, similar alterations can lead to an approximation between the lateral nasal wall and a collapsing canine fossa.

Clinical Hint

In the above cases, fenestration of the maxillary sinus in the middle meatus is associated with a relevant risk of injury to orbital structures.

Middle ethmoid sinus

“Middle ethmoid sinus” is a misleading term for bulla cells, which in most cases are pneumatized from the suprabullar/retrobullar recess. For anatomic and physiological reasons, only anterior and posterior ethmoid cells should be distinguished based on their separation by the basal lamella of the middle turbinate.

a see also: Lacrimal passages
b see: Fissura orbitalis superior
c see: Concha media, see also: Concha superior, Concha suprema
d see also: Maxillary sinus (Maxillary sinus atelectasis)
Nasal turbinates
N. abducens
N. canalis pterygoidei (N. Vidianus)
N. infraorbitalis, N. maxillaris

The infraorbital nerve can be divided into four segments:

- **Cutaneous segment**, distal to the infraorbital foramen, with 5–11 terminal branches.
- **Orbitomaxillary segment**, between the infraorbital foramen and the pterygopalatine fossa. The infraorbital nerve typically runs in a groove at the orbital floor for approx. 13 mm and is then encased by a regular bony canal for a further 14 mm. The orbitomaxillary segment commonly forms a variable angle of about 28° ±10° with the sagittal and horizontal planes.
- **Pterygopalatine segment**, from the dorsal infraorbital sulcus to the foramen rotundum (approx. 13 mm long). In its pterygopalatine segment, the maxillary nerve both in the figurative and literal sense separates the pterygopalatine fossa (medially) from the infratemporal fossa (laterally). In the fossa, the nerve runs mediadly in its anteroposterior course (Fig. 2.45).
- **Cavernous segment**, from the foramen rotundum to the trigeminal ganglion (approx. 15 mm long).

In 60% of cases, the infraorbital foramen is found in the center of a horizontal plane through the superior one-third of the anterior maxillary sinus wall, and in 40% of cases, it is a little more lateral to this position. The distance between the foramen and the infraorbital margin is approximately 8 mm. In almost 30% of cases, smaller accessory foramina are seen, and in 2.5% of cases, a true doubling.

The prevalence ratios of specific variation patterns in the course of the infraorbital nerve in its orbitomaxillary segment are summarized in Tab. 2.34. These variations are observed unilaterally in about half of cases and bilaterally in the other. In case the nerve descends anteriorly from the maxillary sinus root, this segment starts 11 mm (5–24 mm) posterior to the infraorbital margin. The nerve is more likely to be “suspended” from the maxillary sinus roof in the presence of an infraorbital ethmoid cell and also in cases of concomittant maxillary sinus septa (Fig. 2.67). Infraorbital cells which extend far laterally require special attention since the infraorbital nerve may be incorporated in their lateral wall.

At the orbital floor, the infraorbital nerve is accompanied by a branch of the maxillary artery. The relative positions of the nerve and accompanying artery vary: In ¾ of cases, the artery is inferior or posterolateral to the nerve, while it is anteromedial in 15%.

Before the maxillary nerve becomes the infraorbital nerve, it gives rise to the posterior superior alveolar nerve. The anterior superior alveolar nerve originates in the orbitomaxillary segment. The middle superior alveolar nerve is constant; it originates from the maxillary/infraorbital nerve, in half of the cases in the orbitomaxillary segment and in the other half in the pterygopalatine segment. These nerves form among others an alveolar plexus at the maxillary sinus floor in many varying forms.

| Course of the infraorbital canal in relation to the maxillary sinus, with pooled prevalence data (Fontollet et al. 2019; Haghnegahdar et al. 2018; Yenigun et al. 2016c). |
|---|---|
| Type 1 | Canal runs freely through the anterior maxillary sinus (ca. 15%). |
| Type 2 | Canal partially droops into the anterior maxillary sinus (ca. 45%). |
| Type 3 | Canal lies in the bone of the maxilla (ca. 40%). |

| Microanatomic variations of the infraorbital canal (Acar et al. 2018). |
|---|---|
| Type 1 | Infraorbital canal lies within the bony maxillary sinus roof (55%). |
| Type 2 | Infraorbital canal partially droops into the maxillary sinus (27%). |
| Type 3 | Infraorbital canal lies inferior to the maxillary sinus roof and is suspended from it by a “mesentery” (10%). |
| Type 4 | Infraorbital canal located in the outer (lateral) region of the zygomatic recess (8%). |

| Course of the infraorbital nerve and infraorbital canal in relation to the maxillary sinus and infraorbital cells (Ference et al. 2015). |
|---|---|
| Type 1 | The nerve is entirely contained within the maxillary sinus root (60%). |
| Type 2 | The nerve canal drops below the maxillary sinus root (27%). |
| Type 3 | The nerve drops into the lumen, is connected to the roof by a “septum” or runs in the wall of an infraorbital cell (13%). |

| Length of septum (prominence) in case of an infraorbital nerve which is “suspended” from the maxillary sinus roof (Lantos et al. 2016). |
|---|---|
| Class 1 | Length of 1 – 3 mm (48%). |
| Class 2 | Length of 4 – 6 mm (33%). |
| Class 3 | Length of 7 – 11 mm (19%). |

| Shape of the anterior infraorbital canal (Lee et al. 2006b). |
|---|---|
| Tubular canal (69%) |
| Funnel-shaped canal (25%) |
| Pinched canal (6%) |

Tab. 2.34 Variations in the course/shape of the infraorbital canal in the area of the maxillary sinus roof and in the maxillary sinus lumen.

---

a see: Concha media; Concha superior; Concha suprema
b see: Clivus; Sinus cavernosus
c see: Canalis pterygoideus
d see also: Fossa pterygopalatina
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

N. oculomotorius

The oculomotor nerve (CN III) is divided into three segments before entering the orbit: the interpeduncular and cisternal segment, followed by the intracavernous segment through the cavernous sinus. The latter segment is relevant in rhino-neurosurgical procedures. In the cavernous sinus, CN III travels inferior to the lower margin of the anterior clinoid process and lateral to the anterior carotid genu in the lateral cavernous sinus wall toward the superior orbital fissure. The nerve is found medial to the ophthalmic nerve (CN V1) and trochlear nerve (CN IV) and posterosuperior to the abducens nerve (CN VI).

Special Literature
Abuzayed et al. 2010c.

N. opticus

N. palatinus major

Clinical Hints

- During endoscopic procedures, the infraorbital nerve is at risk of injury given a "suspended" course from the maxillary sinus roof (Fig. 2.67).
- On endoscopy, the nerve is seen to traverse through the (partially removed) posterior maxillary sinus wall to run from the infraorbital canal in a dorsomedial direction toward the foramen rotundum (Herzallah et al. 2007).
- Approx. 8 mm laterocranial to the ostium of the ptgnyoid canal lies the foramen rotundum. The latter is found once the infraorbital nerve at the maxillary sinus roof is dissected free and followed in a dorsal direction (Caution: the nerve often presents a drooped and "suspended" course). In some cases, it may be advisable to make an incision and transpose the periosteal layer at the posterior wall of the pterygopalatine fossa to expose the foramen rotundum at the anticipated site.
- When tracing the maxillary nerve in the pterygopalatine fossa, dissection is carried toward a target area enclosed by the following boundaries:
  - Upper boundary: transverse or horizontal line between foramen rotundum and infraorbital canal,
  - Lower boundary: horizontal line through the sphenopalatine foramen (or pterygoid canal),
  - Medial boundary: vertical line through the foramen rotundum,
  - Lateral boundary: vertical line through the entrance of the infraorbital canal (Herzallah et al. 2007).
- When puncturing the anterior maxillary sinus wall, branches of the infraorbital nerve (alveolar nerve) must be spared. A favorable puncture site is the intersection between a vertical reference line drawn through the ipsilateral pupil (when looking straight forward) and a horizontal line through the floor of the nasal vestibule.
- In an "endonasal Denker approach to the maxillary sinus" (or a prelacrimal approach with partial removal of the pteriform aperture), the superior anterior alveolar nerve with its peripheral branches and anastomoses is at risk (a lesion may result in sensory impairment of the alveolar ridge, incisors and ipsilateral canines). Lateral bone removal in the inferior pteriform aperture area is prone to cause this adverse effect. (Schreiber et al. 2017).

Special Literature

In 90% of cases, the maxillary artery is inferior to the nerve in the pterygopalatine fossa; in 10%, a loop of the artery containing the origin of the accompanying artery lies medially in front of the nerve. The cavernous segment of the carotid artery is found medial to the foramen rotundum (canalis rotundus), and the petrous segment lies in inferior and posterior aspects.

N. oculomotorius

The oculomotor nerve (CN III) is divided into three segments before entering the orbit: the interpeduncular and cisternal segment, followed by the intracavernous segment through the cavernous sinus. The latter segment is relevant in rhino-neurosurgical procedures. In the cavernous sinus, CN III travels inferior to the lower margin of the anterior clinoid process and lateral to the anterior carotid genu in the lateral cavernous sinus wall toward the superior orbital fissure. The nerve is found medial to the ophthalmic nerve (CN V1) and trochlear nerve (CN IV) and posterosuperior to the abducens nerve (CN VI).

Special Literature
Abuzayed et al. 2010c.
N. Vidianus

Onodi cell

Optic strut

The optic strut is a bony column which lies between the sphenoid body and the lesser sphenoid wing. It forms the floor of the optic canal, runs to the medial inferior part of the anterior clinoid process, and separates the optic canal from the superior orbital fissure (as well as parts of the internal carotid artery). Depending on the degree of pneumatization, the optic strut corresponds to a more or less deep opticocarotid recess in the lateral wall of the sphenoid sinus.

Orbit (from the standpoint of endonasal surgery)

Of special interest in endoscopic endonasal surgery are the medial intraconal/extraconal orbit as well as the orbital apex. The extracranial medial area and the anteroinferior intraconal space are considered to be best amenable to transnasal surgical treatment and visual control—major neurovascular structures are rare in this region. In the anterior ethmoid, the medial orbital floor at its junction to the medial orbital wall lies, on average, approx. 8 mm away from the medial rectus and the inferior rectus muscle. The posterior intraconal compartment is much narrower and slightly harder to access—the distance between the medial rectus muscle and the optic nerve often measures only 1 mm in this area, while there are only minimal options to mobilize and medially retract the muscle.

At first, the relative position of the eyeball should be assessed endoscopically: The frontal portion of the basal lamella of the middle turbinate lies approx. 4 mm posterior to the eyeball. The eyeball is approx. 26 mm anterior to the orbital apex.

A major vessel in the orbit is the ophthalmic artery (approx. 1.7 mm in diameter; Fig. 2.68). In 90% of cases, it enters the orbital cavity inferolateral to the optic nerve (1st segment) and then turns cranially and medially (2nd segment). In its further course, it typically (in approx. 75% of cases) runs above the optic nerve and below the superior rectus muscle. In 25% of cases, a variant of the artery is seen to run below the optic nerve. In the following course, the artery travels in the superomedial segment of the orbit (3rd segment) in an anterior direction.

The ophthalmic artery gives rise to branches which present with numerous morphological variation patterns. In 26% of cases, the first branch is the central retinal artery. The ethmoidal arteries are typically branches of the 3rd segment, with the posterior ethmoid artery coursing in a medial direction above the superior oblique muscle, and the anterior ethmoid artery, below this muscle (and over the medial rectus muscle). In about 85% of cases, the ophthalmic artery also gives rise—approx. 9 mm anterior to the anterior sphenoid sinus wall—to 1–4 interomedial branches (approx. 1.5 mm diameter), which supply the inferior rectus muscle, inferior oblique muscle, and medial rectus muscle. The medial rectus muscle is approx. 12 mm “wide” (superior-to-inferior dimension) —the vessels enter in the middle of the muscle (less commonly near the inferior border). Other peripheral branches of the ophthalmic artery (supraorbital and supratrochlear artery) are usually of no relevance to endonasal surgery.

The orbital veins lack a reliable topography or consistent anatomical relationships. Near the ophthalmic artery and nasociliary nerve, mostly below the superior rectus muscle, a vessel often courses, referred to as the superior ophthalmic vein (Fig. 2.68). The inferior ophthalmic vein is less constant.

The oculomotor nerve (CN III) divides into two branches 2–3 mm in front of (posterior to) the superior orbital fissure. Both run laterally through the annulus of Zinn. The superior branch runs superiorly to the optic nerve and sends branches toward the levator palpebrae muscle and the superior rectus muscle. The inferior branch reaches the orbit via the inferomedial part of the superior orbital fissure. It runs between the medial rectus muscle and the inferior rectus muscle and divides into three branches (to the medial rectus muscle, inferior rectus muscle, and inferior oblique muscle). Before entering the muscle, the corresponding nerve branches to the medial rectus muscle can course

Special Literature


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Fig. 2.68

a. Frontal MRI scan of a right ophthalmic artery (→) which is shown to lie in close proximity to the optic nerve (↔); bright rim corresponds to liquor.

b. Axial MRI scan showing the superior ophthalmic vein, bilaterally (↔).
freely – in some cases accompanied by smaller arteries – along the lateral surface of the *medial rectus muscle*, up to 17 mm anterior to the plane of the *anterior sphenoid sinus wall* (based on different calculations, up to 14 mm anterior to the posterior maxillary sinus wall).

The *trochlear nerve* (CN IV) enters the orbit through the *superior orbital fissure* outside the *common tendinous ring*. It usually (in 72% of cases) runs toward the *superior oblique muscle* with two branches located superior to the *superior rectus muscle*.

The *ophthalmic nerve* (CN V1) divides into three branches: the *lacrimal nerve*, *frontal nerve*, and *nasociliary nerve*. The first two branches enter the orbit via the *superior orbital fissure* outside the *common tendinous ring*, while the *nasociliary nerve* runs inside. The *nasociliary nerve* intersects the optic nerve 10 mm anterior to the fissure, runs in the superior part of the intracranial space in the vicinity of the *ophthalmic artery*, and then gives rise to the *anterior ethmoidal* and *posterior ethmoidal nerves*, among others. Distally, it becomes the *infraorbital nerve*.

The *abducens nerve* (CN VI) runs through the *superior orbital fissure* and the *common tendinous ring* and turns laterally. It innervates the *lateral rectus muscle* with 3–5 branches; in 80% of cases, it does so within the first (posterior) third of the muscle.

**Clinical Hints**

- The *medial rectus muscle* is a key landmark used to expose the posterior two-thirds of the intracranial space. To facilitate the approach, it is best to mobilize the muscle medially and cranially. Caudal transposition is prone to cause injury if traction is applied to the ethmoidal arteries (particularly the *anterior ethmoid artery* near the upper margin of the *medial rectus muscle*) (Dallan et al. 2010b; Lin et al. 2016).

- Up to a frontal plane 14 mm anterior to the posterior maxillary sinus wall, manipulations at the upper side and the lateral margin of the *inferior rectus muscle* are susceptible to the risk of injury to branches of the *oculomotor nerve* (to the inferior rectus muscle and inferior oblique muscle). Similarly, the same applies to *inferomedial branches* of the *ophthalmic artery* if manipulations up to 20 mm anterior to the posterior maxillary sinus wall are attempted (Maxfield et al. 2018).

- The major “friendly landmarks” in paranasal sinus surgery are the *lamina papyracea*, the *orbital floor*, and the posterior end of the *lacrimal bone*, the *arc of the choana*, the attachment of the *anterior middle turbinate* (axilla), and the nasal septum (May et al. 1994).

- In patients with thyroid-related orbitopathy, the *medial rectus muscle* commonly lies closer to the lamina papyracea than in controls – this circumstance must be considered when undertaking manipulations. In all individuals, the muscle is anteriorly farther from the lamina than posteriorly: in the plane of the maxillary ostium, this distance measures approx. 2.8 mm, and in the plane of the posterior ethmoid artery, only 1 mm.

**Os palatinum*\(^a\)**

**Ostiomeatal unit**

This is a functional term encompassing the drainage pathways of the *middle meatus* along with adjacent clefts and passages to the *frontal sinus*, *maxillary sinus*, and *anterior ethmoid cells* (including the *semilunar hiatus* and *ethmoid infundibulum*).

**Ostium maxillare*\(^b\)**

**Planum sphenoidale**

The planum sphenoidale forms the *anterior roof* of the *sphenoid sinus* and is continuous with the two *lesser wings of the sphenoid*. In this area, the bone is 0.6–1 mm thick. The plane surface lies between the *optic canals* and is posteriorly continuous with the *sellar tubercle*.

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**Clinical Hints**

- The *roof of the entire sphenoid sinus* in conjunction with the *planum sphenoidale* forms a key landmark in posterior-to-anterior ethmoidectomy.

- Apart from that, the *planum sphenoidale* represents one of the most important anatomic target structures in rhino-neurological (transsphenoidal/transplanum) procedures.

**Special Literature**

Ozcan et al. 2010; Rhoton 2002b.

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\(^a\) see: Palatine bone

\(^b\) see: Maxillary sinus
### Pneumosinus dilatans, pneumocele

**Processus clinoideus anterior, processus clinoideus posterior, processus clinoideus medialis**

The anterior clinoid process (PCA) is a bony extension of the posterior lesser wing of sphenoid. Two bony struts serve as a guide to the PCA: the one lying posteroinferiorly is referred to as the optic strut. It separates the optic canal from the superior orbital fissure and in part from the internal carotid artery, and it can be pneumatized from the sphenoid sinus via the lateral optico-carotid process. The anterior bony strut also forms the roof of the optic canal.

According to literature, the degree of pneumatization of the anterior clinoid process varies widely (Andrianakis et al. 2019, Mikami et al. 2007). Pneumatization originates from the sphenoid sinus in approx. 80% of cases, the ethmoid in approx. 15%, and a combination of both structures in 5%. The optic strut is pneumatized in 12% of cases and the anterior clinoid process in 15%. Extensive pneumatization is associated with a much greater likelihood of a prominent optic nerve in the sphenoid sinus and with dehiscences in the bony optic canal (the latter in 75% of cases). In distinct cases, the optic canal is prone to course more or less freely through parts of the sphenoid sinus (Fig. 2.23).

In 20–50% of cases, a medial clinoid process can be defined, taking the form of a bony extension toward the anterior clinoid process, lateral to the tuberculum sellae. In 3% of cases, contact is complete and the carotid artery is fully encased by a bony ring. Endonasally, the medial clinoid process corresponds with a medial optico-carotid recess.

---

**Fig. 2.23**

Variations related to the lateral extension of the optico-carotid recess (OCR) and to the degree of pneumatization of the anterior clinoid process (PCA) (Andrianakis et al. 2019).

<table>
<thead>
<tr>
<th>Variations related to the lateral extension of the optico-carotid recess (OCR)</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Sub-optical OCR”</td>
<td>14%</td>
</tr>
<tr>
<td>“Latero-optical OCR”</td>
<td>14%</td>
</tr>
<tr>
<td>“Supra-optical recess”</td>
<td>0,5%</td>
</tr>
<tr>
<td>“Peri-optic recess”</td>
<td>1%</td>
</tr>
</tbody>
</table>

---

**Tab. 2.35a** Variations of pneumatization of the anterior clinoid process (PCA) and posterior clinoid process (PCP) (from: Abuzayed et al. 2010a).

<table>
<thead>
<tr>
<th>Origin of pneumatization anterior clinoid process (PCA)</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pneumatization (66%).</td>
<td></td>
</tr>
<tr>
<td>In case of pneumatization:</td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>Pneumatization of the PCA is less than 50% (37%).</td>
</tr>
<tr>
<td>Type 2</td>
<td>Pneumatization of the PCA is more than 50%, less than 100% (36%).</td>
</tr>
<tr>
<td>Type 3</td>
<td>Complete pneumatization (26%).</td>
</tr>
</tbody>
</table>

---

**Tab. 2.35b** Origin of pneumatization of the anterior clinoid process (PCA) (Mikami et al. 2007).

<table>
<thead>
<tr>
<th>Type 0</th>
<th>No pneumatization (66%).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Pneumatization from the (inferior) optic strut (75%).</td>
</tr>
<tr>
<td>Type 2</td>
<td>Pneumatization from the anterior upper trunk of the clinoid process (14%).</td>
</tr>
<tr>
<td>Type 3</td>
<td>Pneumatization from the optic strut as well as the anterior upper trunk of the clinoid process (11%).</td>
</tr>
</tbody>
</table>

---

**Tab. 2.35c** Variations related to the lateral extension of the optico-carotid recess (OCR) and to the degree of pneumatization of the anterior clinoid process (PCA) (Andrianakis et al. 2019).
and interlence ratios of variation patterns vary greatly in the literature, approx. 60 µm in about half of cases, and about 275 µm in the other half. The mucosa is similar in structure on both sides but differs from regular mucosa, for instance at the turbinates, in part due to the large number of glands. In about 2% of cases, the mucosa is very often continuous with the anterior bulla wall and forms a “suprainfundibular plate” (viewed from medially, appearing as an “anterior ethmoidal genu”).

Endoscopically, the anterior face of the uncinate process presents the “classic” form in 85% of cases; it is turned medially or spreads across a large bulla in 15% of cases.

The distance between the free posterior margin of the uncinate process and the lamina papyracea is approx. 2 mm (0.1–5 mm). Distances above 5 mm are occasionally referred to as “medial deviation.” In 28% of cases, a small cell extension is interposed between the process and the orbit (Fig. 2.70). Additional morphological variation patterns include a pneumatized process or everted process with a medially oriented edge. If this edge extends not only medially but also anteroinferiorly, the appearance of an “accessory middle turbinate” arises in endoscopy (see: Concha media, Fig. 2.32).

The posteroinferior portion of the uncinate process has a highly variable morphology as well (Tab. 2.37). It is typical to find delicate processes extending to the bone of the inferior turbinate, to the bulla, and/or to the palatine bone. The bone may also flatten out or be entirely absent in the posterior region. The first of these processes divides the membranous portions of the medial wall of the maxillary sinus into an anterior and posterior fontanelle.

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**Special Literature**

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**Tab. 2.35** Variations of pneumatization of the posterior clinoid process (PCP) (Burulday et al. 2017).

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No pneumatization (85%). In the presence of pneumatization:</td>
</tr>
<tr>
<td>1</td>
<td>Less than 50 % of the PCP are pneumatized (61 %).</td>
</tr>
<tr>
<td>2</td>
<td>More than 50 %, but less than 100 % of the PCP are pneumatized (26 %).</td>
</tr>
<tr>
<td>3</td>
<td>Totally pneumatized PCP (13 %).</td>
</tr>
</tbody>
</table>

---

**Processus pterygoideus**

**Processus uncinnatus**

The uncinate process (UC) is a flat, “crescent-shaped” segment of the anterior ethmoid bone in the area of the anterior lateral nasal wall and extends from anterosuperior to posteroinferior in a sickle-shaped course (Fig. 2.69). It is the rudiment of the first ethmotosubinal and, with the agger nasi, forms the remnant of the first basal lamella. The uncinate process is major structural element of the ethmoidal infundibulum; its unattached margin forms the semilunar hiatus. The bone itself is thin, at approx. 60 µm in about half of cases, and about 275 µm in the other half. The mucosa is similar in structure on both sides but differs from regular mucosa, for instance at the turbinates, in part due to the large number of glands. In about 2% of cases, the mucosa is very often continuous with the anterior bulla wall and forms a “suprainfundibular plate” (viewed from medially, appearing as an “anterior ethmoidal genu”).

Anteriorly, the uncinate process attaches to the lacrimal bone or the medial face of the lacrimal fossa. At the level of the ostium of the common lacrimal duct, the uncinate process overlaps the fossa to a highly variable extent (i.e., between 0% and 100%) – as a general guide, one-quarter of anteroposterior overlap is seen in 17% of cases. Superoposteriorly, the uncinate process is very often continuous with the anterior bulla wall and forms a “suprainfundibular plate” (viewed from medially, appearing as an “anterior ethmoidal genu”).

Endoscopically, the anterior face of the uncinate process presents the “classic” form in 85% of cases; it is turned medially or spreads across a large bulla in 15% of cases.

The distance between the free posterior margin of the uncinate process and the lamina papyracea is approx. 2 mm (0.1–5 mm). Distances above 5 mm are occasionally referred to as “medial deviation.” In 28% of cases, a small cell extension is interposed between the process and the orbit (Fig. 2.70). Additional morphological variation patterns include a pneumatized process or everted process with a medially oriented edge. If this edge extends not only medially but also anteroinferiorly, the appearance of an “accessory middle turbinate” arises in endoscopy (see: Concha media, Fig. 2.32).

The posteroinferior portion of the uncinate process has a highly variable morphology as well (Tab. 2.37). It is typical to find delicate processes extending to the bone of the inferior turbinate, to the bulla, and/or to the palatine bone. The bone may also flatten out or be entirely absent in the posterior region. The first of these processes divides the membranous portions of the medial wall of the maxillary sinus into an anterior and posterior fontanelle.
Structural Elements of the Paranasal Sinuses

Antero-superior insertion of the uncinate process (Bolger 2001).

- **Type 1**: Insertion into the *lamina papyracea*.
- **Type 2**: Insertion into the skull base close to the insertion of the middle turbinate.
- **Type 3**: Insertion into the skull base lateral to the insertion of the middle turbinate.

![Fig. 2.69](image) Specimen of a right-sided *uncinate process* (UC) following resection. Free margin of the UC with intact mucosa. On the contralateral side, the resection line is found in the junction to the mucosal lining of the *frontal process of maxilla* or the *lacrimal bone*. The two cranial sites of insertion (at the *vertical lamella of the middle turbinate* and at the *skull base*) are marked by 1.

Antero-superior insertion of the uncinate process (Landsberg and Friedman 2001).

- **Type 1**: Insertion into the *lamina papyracea* (52%).
- **Type 2**: Insertion into the posteromedial wall of an *agger nasi cell* (18.5%).
- **Type 3**: Insertion both into the *lamina papyracea* and into the junction of the *middle turbinate* and the *cribriform plate* (17.5%).
- **Type 4**: Insertion into the junction of the *middle turbinate* and the *cribriform plate* (7%).
- **Type 5**: Insertion into the *skull base* (3.6%).
- **Type 6**: Insertion into the *middle turbinate* (1.4%).

![Tab. 2.36a](image) Anatomic variation patterns of the superior insertion of the *uncinate process* (part 1, continued overleaf: see Tab. 2.36b).
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

Tab. 2.36b  Anatomic variation patterns of the superior insertion of the uncinate process (part 2, continued from page 78).
Tab. 2.37  Anatomic variation patterns of the inferior / posterior insertion of the uncinate process.

**Clinical Hints**

- Unawareness about the patient-specific microanatomy is often the cause of an inadvertently incomplete excision of the uncinate process.
- The frontal sinus drainage pathway far more often follows a medial rather than a lateral course from the superior insertion of the uncinate process – the former variation pattern is, however, associated with a higher rate of frontal sinusitis (Turgut et al. 2005).

**Special Literature**

Recessus frontalis

The frontal recess (FR) is formed by the anterosuperior part of the middle meatus or anterior ethmoid, inferior to the frontal sinus opening. This “opening” of the frontal sinus is defined in a sagittal CT scan (a true “ostium” of the frontal sinus does not exist). In this view, the contours of the frontal sinus and frontal recess present as an hourglass-shaped structure (Fig. 2.71). The narrowest part of this hourglass is located in the plane of the superior nasal spine and corresponds to the mentioned frontal sinus “opening” – which is not to be confused with a “frontal sinus ostium” and not equivalent to a frontal sinus “outflow tract” or “drainage zone.”

Anteriorly, the frontal recess terminates at the frontal process of maxilla and at the lacrimal sulcus. The medial wall is formed by the anterosuperior vertical lamella of the middle turbinate. If the uncinate process (UP) curves medially toward this lamella and is fused with it, the UP can become contiguous with the medial wall of the frontal recess. The lateral wall of the FR is made up of the anterosuperior lamina papyracea, the orbital plate of the frontal bone, and the lacrimal bone. If the UP curves laterally and is fused with the lamina (resulting in a terminal recess), it can form part of the lateral wall and “floor.” A posterior continuous wall exists only if a well-developed second basal lamella (ethmoid bulla) extends to the skull base. Otherwise, the frontal recess is dorsally continuous with the suprabullar recess (Fig. 2.74). The floor of the recess cannot be consistently defined due to a wide range of anatomical variability. Agger nasi cells are seen outside the frontal recess.

The “frontal sinus drainage pathway” results from the variable formation of cells in the inferior frontal sinus and frontal recess. Neither a frontal ostium nor a nasofrontal duct in the narrow sense do exist.

Special Literature

Recessus optico-carotideus lateralis

The variable anatomy of the lateral optico-carotid recess can present as a smaller groove or a deeper recess in the strict sense and is located in the lateral sphenoid sinus wall between the optic canal and the anterior carotid genu (cavernous segment). Its prevalence is about 90%. The form of the optico-carotid recess is determined by the extent of pneumatization of the optic strut, this pneumatization, in turn, can variably extend as far as the anterior clinoid process (see Tab. 2.35a–c; Fig. 2.5).

Special Literature
**Recessus optico-carotideus medialis**

On endoscopy, a medial optico-carotid recess can be identified medial to the carotid artery (cavernous segment), inferior to the optic nerve, and superior to the sella prominence in approx. 40% of cases. Viewed from anteriorly, in the mentioned cases, a teardrop-shaped protuberance is found in the lateral aspect of the suprasellar notch (tuberculum sellae), with its tip pointing toward the lateral optico-carotid recess (Tab. 2.38). Intracranially, the medial optico-carotid recess corresponds to the medial clinoid process. The clinical relevance of the recess is based, among others, on the fact that the ophthalmic artery is given off in this area by the internal carotid artery behind the sphenoid sinus wall.

**Recessus praelacrimalis**

The prelacrimal recess is an anterior and medial (in some cases also superior) bulge in the maxillary sinus which lies lateral and anterior to the vertically oriented bulge of the lacrimal canal in the area of the anterior medial wall of the maxillary sinus (Fig. 2.72, 2.73). The prevalence of the prelacrimal recess is about 30%. The (anteroposterior) depth of the recess is approx. 8 mm in the inferior region and only 5 mm superiorly (Tab. 2.39). Its height is approx. 26 mm. The above dimensions are approx. 2 mm smaller in women than in men; in addition, ethnic differences exist.

**Clinical Hint**

A prelacrimal recess is a significant finding because even after maximum fenestration in the middle meatus, the anterior maxillary sinus is commonly neither amenable to complete endoscopic assessment nor to surgical manipulation with instruments. When planning prelacrimal approaches to the maxillary sinus, this recess receives special consideration.
Recessus sphenoethmoidalis

Recessus supra- et retrosellaris

In posterior aspects of the ethmoid bulla, a mostly narrow groove is often found in the lateral nasal wall; it can be accessed through the superior semilunar hiatus. Dorsally, the groove can be more or less distinctly partitioned by a tissue bridge which lies between the bulla and the basal lamella of the middle turbinate. In an overall view, the well-defined configuration presents as suprabullar recess and retrobullar recess (Fig. 2.74) – however, a clear anatomic distinction between the two recesses is feasible only in some cases (30%). The recesses generally extend to the lamina papyracea in approx. 70% of cases and to the skull base in 45% of cases. If the ethmoid bulla does not cranially extend to the skull base, the suprabullar recess is anteriorly continuous with the frontal recess. In these cases, the suprabullar recess is bounded cranially by the skull base, caudally by the ethmoid bulla, medially by the middle turbinate, and laterally by the lamina papyracea. From this location, supraorbital recesses can arise (see also: Supraorbital recess).

In many cases (60%), however, the posterior wall of the bulla is fused to the third basal lamella over a variable distance, resulting in the absence or hypoplasticity of the superior semilunar hiatus and suprabullar/reetrobullar recess (Tab. 2.40). Conversely, a pronounced retrobullar recess can, in about 30% of cases, “push” the basal lamella of the middle turbinate in a dorsal direction; such recesses were in the past termed “lateral sinus of Grünwald.” In some of these cases, the basal lamella of the middle turbinate reportedly presents a dehiscence, with the anterior and posterior ethmoid communicating via the said sinus.

<table>
<thead>
<tr>
<th>Morphological variations of the retrobullar recess and suprabullar recess (Kim et al. 2001c).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 The posterior wall of the ethmoid bulla is fully separated anatomically from the basal lamella of the middle turbinate; suprabullar recess and retrobullar recess can be precisely defined (41%).</td>
</tr>
<tr>
<td>Type 2 In its inferior aspects, the posterior wall of the ethmoid bulla is fused with the basal lamella of the middle turbinate, retrobullar recess is absent (suprabullar recess exists) (38%).</td>
</tr>
<tr>
<td>Type 3 The posterior wall of the ethmoid bulla is fused with the basal lamella of the middle turbinate over a longer segment; retrobullar recess and suprabullar recess are absent (21%).</td>
</tr>
</tbody>
</table>

Tab. 2.40 Morphological variations of retrobullar recess and suprabullar recess.

Recessus supraorbitalis

The supraorbital recess is the result of a pneumatized orbital roof with pneumatization emanating mostly from the suprabullar recess (prevalence approx. 6%). In individual cases, it may turn out to be difficult to differentiate a supraorbital recess from a true supraorbital ethmoid cell (SOEC – see: Frontoethmoidal cells).

Recessus terminalis

If the uncinate process inserts anteriorly and superiorly into the lamina papyracea, the ethmoid infundibulum anterosuperiorly terminates in a blind pouch, forming the terminal recess. A terminal recess is reportedly found in approx. 80% of cases.

---

See: Concha superior

See also: Frontoethmoidal cells

See also: Processus uncinatus
**Regio olfactoria (olfactory mucosa), cribriform plate**

The olfactory mucosa is a mucosal area of variable size which lies in the area of the posterosuperior nasal septum, the cribriform plate, and the superoposterior parts of the middle turbinate and superior turbinate (Fig. 2.75). Apart from that, the olfactory mucosa can extend, in some individuals and in an age-related manner, to the anterior aspects of the cranial middle turbinate and probably also to individual structures of the middle meatus or the mucosa of the anterior wall of sphenoid sinus. The typical surface area of the olfactory mucosa in the region of the lateral nasal wall is reportedly about 150 mm².

The olfactory nerve fibers (fila olfactoria) course in the bone in the superior vertical lamella of the middle turbinate – in 10% of cases also in the mucosa lateral to the bony vertical lamella. The lamella commonly exhibits indentations for the olfactory nerves, and these structures can serve as landmarks. At the ethmoid sinus roof, approx. nine, and at the nasal septum, five endoscopically detectable olfactory fibers are found.

**Clinical Hints**
- To spare the olfactory mucosa, “preventive” resection of larger parts of the superior turbinates is strongly discouraged.
- About 20% of olfactory fibers at the nasal septum reportedly pass through the nasal septum to the contralateral mucosa. This fact can be of oncological relevance.

**Special Literature**


**Rima olfactoria**

**Saccus lacrimalis**

**Sella turcica**

The anatomic relationship of the sella and the sphenoid sinus innately depends on the extent of local pneumatization. As a matter of principle, microanatomy plays a major role, e.g., in transnasal-suprasellar procedures with a surgical corridor along or in the vicinity of the pituitary, optic chiasm, and prechiasmatic sulcus. At this site, for instance, the so-called sellar tubercle is located – “tubercle” is a misnomer from the perspective of transnasal surgery since a specific bony prominence can be made out solely in a transcranial view (Fig. 2.76, Tab. 2.41). From a transnasal perspective, this site appears as a rather minor depression (suprasellar notch, tubercular recess) of the posterior wall of sphenoid sinus. Given a well-pneumatized sphenoid sinus, the bone thickness in the area of the tubercle is approx. 1 mm (0.2–4 mm).

**Angle of supra- and suprasellar notches**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Angle of less than 118°</td>
<td>17%</td>
</tr>
<tr>
<td>Type 2</td>
<td>Angle from 118° – 138°</td>
<td>71%</td>
</tr>
<tr>
<td>Type 3</td>
<td>Angle of more than 138°</td>
<td>12%</td>
</tr>
</tbody>
</table>

**Morphological variations of the prechiasmatic sulcus**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Narrow, steep angle</td>
<td>30%</td>
</tr>
<tr>
<td>Type 2</td>
<td>Narrow, flat angle</td>
<td>22%</td>
</tr>
<tr>
<td>Type 3</td>
<td>Wide, steep angle</td>
<td>19%</td>
</tr>
<tr>
<td>Type 4</td>
<td>Wide, flat angle</td>
<td>29%</td>
</tr>
</tbody>
</table>

**See also:**
- Regio olfactoria
- Lacrimal passages
- Sphenoid sinus; Recessus optico-carotidus medialis, Sinus cavernosus

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Fig. 2.75 Schematic drawing of the right lateral nasal wall showing the typical position and areal extent of the olfactory region (red) (from: Lang 1988).
Between the posterior foramina of the bilateral optic canals lies a transversely oriented bony groove, the prechiasmatic sulcus (Fig. 2.77; Tab. 2.42, 2.43). This groove does not present as a distinct prominence in the sphenoid sinus, i.e., it cannot be identified precisely in a transsphenoidal approach. In embryogenesis and fetogenesis, the chiasm is presumably located in this sulcus for some time – but later, it often moves posteriorly, thus leaving behind a prechiasmatic sulcus with a small bony ridge (limbus of sphenoid) as the posterior extension of the planum sphenoidale. Inferior to the sulcus lies the sellar tubercle, and laterally and inferiorly, the optic strut.

The optic chiasm is typically located superior to the sellar diaphragm. In 10–30% of cases, it exhibits minor circumscribed variations in the horizontal plane – it is referred to as “prefixed” if it is located superior to the sellar tubercle and “postfixed” if situated superior to the dorsum sellae. Secondary changes are related to the relative position and angle of the pituitary stalk.

**Clinical Hint**

In transnasal procedures, the sellar tubercle, in conjunction with the medial optico-carotid recess, serves as a landmark to identify the proximal opening of the optic canal.

**Ethmoid roof** (foveolae ethmoidales, anterior skull base)$^4$

For the most part, the ethmoid roof is formed by medial extensions of the orbital plate of the frontal bone – with small, half shell-shaped depressions caused by the ethmoidal complex (foveolae ethmoidales). The mean distance from one orbit to the other is about 25 mm in the middle of the cribiform plate. The bone of the nasal skull base (ethmoid roof) is considerably thicker in the posterior third than in the anterior two thirds. The weakest point is where the anterior ethmoid artery exits the ethmoid bone and enters the olfactory fossa. The ethmoid roof (foveae ethmoidales) is about 9 mm wide in the area of the fossa.

In a medial aspect, the ethmoid roof is continuous with the lateral lamella of the olfactory fossa, lateral to the cribiform plate. There is considerable variation in the tilt and bend of the ethmoid roof in the frontal plane (Tab. 2.44). Side-to-side asymmetry is generally found in up to 60% of cases, slightly less frequently in Type 1 (Fig. 2.44). This asymmetry is related to the height of the ethmoid roof in 10% of cases and variations in shape (flattening, angle in the frontal contour) in approx. 50% of cases. In 9% of cases, the right ethmoid roof is at a slightly lower level than the left one, and vice versa in 1% of cases. Height differences are rare in the posterior ethmoid roof, but anteriorly, in the vicinity of the “opening” of the frontal sinus, side-to-side differences of more than 3 mm are found in approx. 8% of cases.

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$^4$| see also: Fossa olfactoria; Lamina cribrosa |
**Ethmoid cell system**

The key structural features of the ethmoid bone have already been described in Chapter 1. The ethmoid cell system measures 4–5 cm in total anteroposterior dimension, it is 2.5–3 cm high, and presents a variable width in anterior (approx. 0.7 cm) versus posterior aspects (approx. 1.5 cm). Caudally, it is 1 cm wider than cranially. There are 2–10 anterior and 2–6 posterior ethmoid cells; the mean volume of all cells on one side is approx. 6 mL.

Variation patterns of anterior ethmoidal cells have already been discussed in detail. Fig. 2.78 outlines a few special variations of the posterior ethmoid in its junction to the sphenoid sinus.

At a prevalence of approx. 2%, a so-called “ethmomaxillary sinus” is found when posterior ethmoid cells extend into the posterior maxillary sinus. The separating wall is straight in half of the cases and convex to the maxillary sinus in the other half. Approx. 1/5 of cases concomitantly show a maxillary sinus hypoplasia. The ethmomaxillary sinus drains into an enlarged and deeply seated superior meatus; another variation is related to an extension of the actual superior meatus into the posterior maxillary sinus wall. Conversely, a “doubled maxillary sinus” drains into the ethmoidal infundibulum (Fig. 2.78c; see also Fig. 2.62; Sphenoid sinus; Maxillary sinus).

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**Clinical Hint**

- The anterior skull base is the target area or corridor for a series of special procedures encompassed in the collective term rhino-neurosurgery. Classification schemes addressing such procedures are found in: Castelnuovo and Locatelli 2014; de Notaris et al. 2008; Dessi et al. 1994; Gera et al. 2018; Gotlib et al. 2014; Hosemann and Schroeder 2015; Jones et al. 2002; Kasemsiri et al. 2013; Kassam et al. 2011a,b; Schwartz et al. 2008; Hosemann and Schroeder 2015.

**Special Literature**

Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

**Sinus cavernosus**

The **cavernous sinus** is a complex venous structure enclosed by meninges and periosteum. It is essentially located lateral to the sella and may in simple terms be considered a three-dimensional space with 5 or 6 walls (Fig. 2.79). The lateral wall is the largest one, extending anterosuperiorly to the **anterior clinoid process**, anteroinferiorly to the **superior orbital fissure**, posterosuperiorly to the **petrous apex**, and posteroinferiorly to the lateral aspect of the **foramen lacerum**.

The medial wall is very thin and comprises two segments (*sphenoidal* and *sellar* segment), which are made up of only a connective tissue layer. Its relationship to the adjacent anatomic structures is remarkably variable; the *sellar segment* covers an area of approx. 7 x 9 mm. The other walls are made up of two connective tissue layers (meninges and periosteum), which commonly can be detached from one another. The external layer is thicker and gray, while the inner layer is semi-transparent. In the area of the lateral wall, the latter contains CN III and IV superiorly and CN V1 and CN V2 inferiorly. Within the sinus, CN VI runs directly lateral to the **internal carotid artery**. The lateral and medial wall of the sinus is fused anteriorly in the area of the **superior orbital fissure** and inferiorly along the superior margin of the **maxillary nerve** (CN V2) – in some locations, the shape of the sinus resembles a ship’s keel. Viewed from above, the roof of the cavernous sinus can be divided into two triangles (the **oculomotor triangle** posterolaterally and the **carotid triangle** anteromedially) and an area formed by the **anterior clinoid process**.

Both cavernous sinuses communicate across the midline through an **anterior** and/or **posterior intercavernous sinus** of variable size and location. An anterior intercavernous sinus is present in almost 80% of cases, while a separate posterior sinus exists in approx. 30% of cases. The entire anterior wall of the sella is covered by a venous network in 3% of cases, and the entire posterior wall, in 5% of cases (Tab. 2.45). The anterior sinus is typically larger – it can in principle take up the entire anterior wall of the sella. Rarely, a smaller, **inferior intercavernous sinus** exists as well; in approx. 20% of cases, an extensive, “circular sinus” is found between the two cavernous sinuses.

**Special Literature**


**Fig. 2.78** Schematic drawings showing examples of special variations of *posterior ethmoid cells*.

a. Ethmo-maxillary sinus (shown in frontal section). Cell of the posterior ethmoid (★), which extends into the posterosuperior aspects of the maxillary sinus and drains into the superior meatus. Given a distinct lateral extension and absent ostium, the resulting structure may also be interpreted as a pterygopalatine recess of the superior meatus (see also Tab. 2.30).

b. Cell of the posterior ethmoid (★), which extends laterally beyond the sagittal plane of the medial maxillary sinus wall, i.e., in a retromaxillary direction (shown in frontal section). Such a cell, of variable size, is present in approx. 80% of cases. It must be differentiated from an anterior infraorbital ethmoid cell (in the past referred to as “Haller’s cell”). The latter is typically seen in the vicinity of the natural ostium of the maxillary sinus (siehe: *Infraorbital ethmoid cell* and Figs. 2.52, 2.53).

c. Spheno-maxillary plate (★, shown in axial section) – the anterior sphenoid sinus wall forms part of the superior medial posterior wall of the maxillary sinus (see also Fig. 2.62).

**Tab. 2.45** Anatomical variations related to the morphology of the intercavernous sinus

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Separate anterior and posterior SI (80 %)</td>
</tr>
<tr>
<td>Type 2</td>
<td>Circular SI (20 %; Subgroup of Type 1)</td>
</tr>
<tr>
<td>Type 3</td>
<td>Exclusive anterior SI (17 %)</td>
</tr>
<tr>
<td>Type 4</td>
<td>Exclusive posterior SI (3 %)</td>
</tr>
</tbody>
</table>
The parasellar/cavernous internal carotid artery courses in the central parts of the cavernous sinus – in approx. 50% of cases, it directly contacts the pituitary. The small branches of the cavernous carotid artery are subject to distinct variability. A meningohypophyseal trunk becomes the origin of the inferior hypophyseal artery and supplies the neighboring cranial nerves; alternatively, up to 3 separate arterial branches can exist. A second, inferolateral arterial trunk gives rise to 3–4 small branches to the dura and the cranial nerves. The ophthalmic artery originates from the distal internal carotid artery outside the cavernous sinus.

A widest possible view of the sinus and its lateral wall containing the cranial nerves requires the cavernous internal carotid artery to be released from its dural rings at the anterior clinoid process and to be medialized. Viewing onto the inner and surrounding structures of the sinus, up to 10 different “anatomic triangles” (or rectangles) of varying definitions and terminology are then differentiated (Fig. 2.80). For instance, a clinoidal, oculomotor, supratrochlear, and infratrochlear (Parkinson’s) triangle have been described. Viewing toward the middle cranial fossa, there is an anteromedial (Mullan’s) triangle between CN V1 and CN V2, while an anterolateral triangle is seen between CN V2 and CN V3. Dorsally, a postero-lateral (Glasscock’s) and a postero-medial (Kawase’s) triangle, and caudally, an inferolateral paracaval and an inferomedial paracaval triangle are seen. For the purposes of endonasal surgery, the focus is on the 3 triangles or squares in the lateral cavernous sinus wall formed by CN III, CN V2, and CN VI and the nerve of the pterygoid canal. Alternatively, after medialization of the carotid artery, the exposed CN III, CN V2, and CN VI form an “S-shaped” configuration.

In terms of microanatomy, the individual cranial nerves present some notable features in the cavernous sinus region. For instance, the oculomotor nerve (CN III) lies at the roof of the cavernous sinus, and it is dorsally accompanied by a special oculomotor cistern for a length of approx. 6 cm. The trochlear nerve (CN IV) is the smallest nerve in the lateral cavernous sinus wall; it is the most difficult to visualize and, in relative terms, CN IV most commonly presents variations of its course. In the anterolateral region of the sinus, when viewed from medially, CN V1 is partially overlapped by the abducens nerve (CN VI) even though CN V1 is significantly thicker than CN VI. Exposure of CN V1 requires CN VI to be mobilized superiorly. CN V3 has no relationship with the lateral sphenoid sinus wall; it does not pass through the cavernous sinus. The proximal abducens nerve (CN VI) runs from Dorello’s canal into the cavernous sinus, superior to the carotid artery in the foramen lacerum region. It then courses (as the only cranial nerve directly in the cavernous sinus) transversely in an anterosuperior direction toward the superior orbital fissure, medial to CN V1 and lateral to the internal carotid artery. Local pathological alterations can lead to displacement of CN VI.

Lateral to the cavernous sinus lies the trigeminal cavity (Meckel’s cave). It is formed by a dural pouch which covers the trigeminal ganglion in the posterior cranial fossa.

At the anterior junction of the three branches of the trigeminal nerve with the cave wall a “cribriform” tissue layer is found around the fascicles to close the cavity (Meckel’s cave).

Clinical Hints

- For transnasal surgical inspection of the cavernous sinus, the following local landmarks should be initially defined following sphenoethmoidectomy:
  - Anteriorly: Junction of the dorsal medial orbital wall and the lateral sphenoid sinus wall;
  - Superiorly: Optic nerve;
  - Inferiorly: Maxillary nerve;
  - Posteriorly: Prominence of the internal carotid artery in the lateral sphenoid sinus wall (Felippu et al. 2013).
To expose and explore the posterior parts of the cavernous sinus, a bilateral or contralateral transnasal approach is considered a good option, including resection of the posterior nasal septum, rostrum, and sphenoid sinus septa (Cavallo et al. 2005a; Chowdhury et al. 2012).

Tracing the petrous part of the carotid artery along the nerve of the pterygoid canal, and following the maxillary nerve from the foramen rotundum in a posterior direction gives access to Meckel’s cave (“quadrangular space” or “front door to Meckel’s cave”; approx. 16 mm²). The respective cavity is bounded medially by the paraclival carotid artery, inferiorly by the petrous carotid artery, laterally by CN V2, and cranially by CN VI (in the cavernous sinus) (Dolci et al. 2016; Gu et al. 2015; Kassam et al. 2009). Another anteromedially located triangle (between CN V1, CN VI, and CN V2) has also been described as an access to the middle cranial fossa (Dolci et al. 2015). Access to the lateral aspect of Meckel’s cave can be obtained via an expanded transpterygoid approach (Truong et al. 2018).

Special Literature

Sinus lateralis of “Grünwald” a

Skull base b

Sphenoid sinus c

Sphenoethmoidal cell (“Onodi cell”, “overriding ethmoidal cell”)

A sphenoethmoidal cell is a posterior ethmoidal cell with direct contact to the optic canal (Fig. 2.81). The dimensions of this cell are highly variable (Tab. 2.46). Above the optic nerve, a sphenoethmoidal cell often has a bone thickness of only approx. 0.3 mm; dehiscences are found in 12% of cases.

In a broader sense and with some terminological overlap with sphenethmoidal cells, “overriding (posterior) ethmoidal cells” are described as well, with their definition focusing on extension beyond the level of the anterior sphenoid sinus wall in a dorsal direction, not solely contact to the optic nerve. Considered as a very rare special form, a central sphenoethmoidal cell lies in the median line, with the intersphenoidal septum being laterally displaced. In such a configuration, the cell is in contact with an optic nerve (or even both of them) in the posterior segment.

Rarely (3%), the optic canal courses freely in a posterior ethmoidal cell. Based on literature, the prevalence of sphenoethmoidal cells varies widely, ranging from 10–65%. Ethnic differences exist, with prevalence ratios typically being lower in radiological examinations than in clinical studies.

![Image](https://example.com/image.png)

Fig. 2.81 Lateral view of a right paranasal sinus specimen (sella type) of a sphenoethmoidal cell, see Tab. 2.46. The basal lamella of the middle turbinate (BL) has been skeletonized and exposed by removing the ethmoid cells. The optic nerve (D.n.I.) lies in an ethmoid cell which extends over the sphenoid sinus. The arrow points to the fundus of the lacrimal sac (nasolacrimal duct, D.n.I.) (from: Hosemann 1989).

<table>
<thead>
<tr>
<th>Extension of a sphenoethmoidal cell, defined by the location of its posterior wall (= lateral part of the anterior sphenoid sinus wall) (Wada et al. 2015).</th>
<th>Type 1 “Skull base type”— the entire anterior wall of the sphenoid sinus is cranially contiguous with the skull base; a sphenoethmoidal cell in the strict sense is absent (49%).</th>
<th>Type 2 “Optic canal type”— the lateral anterior wall of the sphenoid sinus is fused with the optic canal (35%).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 3 „Sella type”— the lateral and middle anterior wall of the sphenoid sinus is contiguous with the sellar ridge (11%).</td>
<td>Type 4 „Infrasellar type”— the lateral and middle anterior wall of the sphenoid sinus extends well below the sellar ridge (5%).</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 2.46 Anatomic variations of the extension of sphenoethmoidal cells in relation to the sphenoid sinus, with prevalence ratios.

---

a see: Recessus supra- et retrobullaris
b see: Sphenoid sinus; Lamina cribrosa; Ethmoid roof
c see: Sphenoid sinus
The presence of a sphenoid cell is often associated with a well-pneumatized clinoid process, with a prominence and with dehiscences of both the optic canal and the internal carotid artery in the sphenoid sinus. However, the sphenoid cell has no effect on the development of any prominence of the pterygoid canal (Tab. 2.10).

Clinical Hint
- In the differential diagnosis of sphenoid cells CT scans in multiple planes are required – the use of imaging modalities in more than 2 planes is generally considered international standard (Driben et al. 1998).

Special Literature

Spina nasalis superior (Spina nasalis ossis frontalis, “naso-frontal beak”)
The superior nasal spine (nasofrontal beak), is an anatomic structure which is based on a variety of definitions and diverse terminology. Its use may be sensible as a clinical descriptive term for a compact bony element in the anterior medial frontal sinus floor, superior to the nasal cavity and the anterior ethmoid bone (Figs. 2.82–2.84).

The superior nasal spine is formed mainly by the frontal and nasal bones. In the mid-sagittal plane, it has an (a.-p.) diameter of 5–11 mm (approx. 8 mm) and a height of about 10–16 mm. The distance between the posterior edge of the superior nasal spine and the anterior skull base (olfactory fossa) is 2–17 mm (approx. 8 mm) in the mid-sagittal plane. The depth of the entire frontal sinus floor, including the superior nasal spine, is 6–17 mm.

Fig. 2.82
a. Schematic drawing of the “superior nasal spine” (red) of the frontal sinus (sagittal plane).
b. Schematic drawing of the ethmoid-frontal sinus junction following resection of local ethmoid cells. (Draf type IIa access – in anteromedian aspects, the variable superior nasal spine remains). Note the mean distance of a neo-ostium of a Draf type IIa frontal sinus from the anterior ethmoid artery is 9 mm (I), the mean length of the neo-ostium is 7 mm (3–12 mm) (II), and the mean width is 5 mm (2–9 mm) (III) (from: Hosemann and Fanghänel 2004).

Fig. 2.83
A moderately well-developed “superior nasal spine” in a right-sided anatomical specimen (parasagittal and axial planes), following ethmoidectomy. The same specimen is shown from a medial (a), inferior oblique (b) and superior aspect (c). The bony “spine” is outlined in red.
Clinical Hints

The superior nasal spine forms part of the anteromedial frontal sinus floor which offers relevant resistance to endonasal frontal sinusotomy types IIb or III with pertinent instruments.

In an endoscopic view from caudally, the vertical dimension (i.e., the volume) of this bone cannot be readily assessed precisely – an exact preoperative analysis of the CT scans is mandatory in this case to establish a realistic plan about the anticipated bone removal, the suitable instruments, and the resulting wound surface areas.

- When performing a frontal sinus drainage procedure of Draf type III, a foramen caecum covered completely with connective tissue is often exposed (Fig. 2.85). Rarely, a venous vessel which requires coagulation is found in this location.

Sternberg’s canal (“Canalis craniopharyngealis lateralis”)

In the presence of a well-pneumatized sphenoid sinus, a congenital bone defect in the lateral sphenoid sinus wall can manifest lateral to the maxillary nerve. It is caused by defective fusion of the presphenoid and greater wing of sphenoid bone. In principle, this bony defect is reportedly detectable in 4% of adults. Under special circumstances (e.g., elevated CSF pressure), a spontaneous CSF fistula or meningoencephalocele develops at the site of this “canal” in isolated cases. The typical location of the canal (lateral to the maxillary nerve) and the cited prevalence of the underlying bony defects have, to some degree, been critically questioned in the literature.

Special Literature

Frontal sinus, frontal sinus drainage pathway\(^a\)

The mean volume of a frontal sinus is about 6 mL. It is larger in men, and reportedly tends to decrease to a minor degree in advanced age. Unilateral frontal sinus aplasia is observed in about 4% of cases and bilateral aplasia in 1% – with ethnic differences and a wide range of variance.

\(^a\) see also: Frontoethmoidal cells; Infundibulum ethmoidale; Recessus frontalis; Spina nasalis superior

The height of the frontal sinus is 6–50 mm, and in 50% of cases incomplete septa are found. Only about 10% of frontal sinuses extend laterally beyond the supraorbital nerve. A lateral extent in the frontal plane generally correlates with the depth in the sagittal plane. Pneumatization of the interfrontal septum or the crista galli is a relatively common finding (see: Frontoethmoidal cells, Crista galli, Fig. 2.86, Tab. 2.21–2.23). In 30% of cases, the superior bony nasal septum is also pneumatized to a depth of 1–6 mm from the floor of the frontal sinus (“rostrum” of frontal sinus). The
angle formed by the posterior frontal sinus wall and the anterior skull base is 130°–170°; in individual cases, one may encounter atypical anatomic variation patterns (Fig. 2.44, Fig. 2.86).

The anteroposterior diameter of the frontal sinus tends to correlate with the size of agger nasi cells. Large and septated frontal sinusles are more commonly observed in the presence of supraorbital ethmoid cells. Furthermore, a large frontal sinus is correlated with a deeper olfactory fossa and an anterior ethmoid artery which is suspended from the skull base.

An ostium is generally defined as a “mouthlike opening in a bodily part” – in that sense, the frontal sinus does not possess an ostium, but rather a “drainage pathway” through the frontal recess with its frontoethmoidal cells. The location and width of the drainage pathway are determined by the variable occurrence and extent of anterior ethmoidal cells (see: Frontoethmoidal cells). In consideration of the lack of an ostium in the strict sense, the term frontal sinus “opening” denotes the junction of the inferior frontal infundibulum and the frontal recess. This structure lies in the horizontal plane of the superior nasal spine, and in the sagittal CT, it resembles the “bottleneck” of an hourglass (see Fig. 2.71).

The frontal sinus drainage pathway is a cleft between structures and cells rather than a defined nasofrontal duct in the strict sense. Reports on variations in the course of the drainage pathway and their relative prevalences differ widely. In principle, the pathway is at a similar angle to the horizontal plane (approx. 110°) as the nasolacrimal duct. Due to the superior attachment of the uncinate process, the drainage pathway drains inside the ethmoidal infundibulum much less commonly then outside (70–90%). Accordingly, in the frontal plane, the drainage pathway is seen more often immediately lateral to the vertical lamella of the middle turbinate, i.e., medial to the uncinate process or medial to an infundibular (frontoethmoidal) cell (60% of cases). Chinese research suggests ethnic differences by reporting a more balanced ratio. The posterior wall of the drainage pathway is typically formed by cells or structures which are contributed by the ethmoid bulla.

The detailed planning of microsurgical manipulations in the frontal sinus drainage pathway can be based on CT images in 3 planes, in conjunction with a digital 3D building block reconstruction of the anterior (frontoethmoidal) cells (“box model” according to Wormald 2006). Given an adequately high quality of the preoperative image data, it is possible to exactly define the frontal sinus drainage pathway, which is used intraoperatively for a targeted approach. Special software for reliable surgical planning and navigation (“tracking”) is commercially available.

In 70–90% of cases, cranial probing of the ethmoidal infundibulum does not access the frontal sinus.

If the cells of the frontal recess are removed step-by-step while progressing toward the frontal sinus, the drainage pathway is in most cases found immediately lateral to the vertical lamella of the anterior middle turbinate. Laterally, the approach is typically bounded by a sagittally oriented bony lamella (remnant of an Agger nasi cell). This lamella can be used as a specific landmark (“vertical bar” according to Starrrn et al. 2009) in minimally invasive frontal sinusotomoty.

In the direction of the frontal sinus, an opening (neo-ostium, corridor) with a depth of approx. 1 cm (0.4–2.4 cm) can be made (with appropriate instruments) in the mid-sagittal plane between the spared superior nasal spine anteriorly and the skull base posteriorly.

If the superior nasal septum below the frontal sinus floor is partially pneumatized from the frontal sinus (rostrum, see above), transseptal frontal sinusotomy as a first step of a more extensive approach is an option in case of other impassabilities (Eviatar et al. 2018).

Embarking on a maximum frontal sinus drainage (Draf type III) in endonasal surgery per se requires the surgeon to prevent injury to the cribriform plate while removing bone at the median frontal sinus floor and progressing in a dorsal direction (note local impassabilities, Figs. 2.44, 2.86). Given careful dissection of the first olfactory fiber (approx. 5 mm posterior to the head of the middle turbinate) or – as an alternative option – of the distal branch of the anterior ethmoid artery at the site where it exits the skull base to return into the nasal cavity (nasal branches), bone removal should terminate in a frontal plane 4–6 mm anterior to the said olfactory.
Sulcus praechiasmaticus

Superior turbinate

Supraorbital ethmoid cells

Supraorbital ethmoid cells is a term used for cells of the frontal sinus supraorbital plate, which are found lateral to the lamina papyracea and dorsal to the inferior frontal sinus. These cells reportedly occur in 20–30% of cases, with inter-ethnic variations in prevalence. The point of access lies in front of the anterior ethmoid artery and posterolateral to the frontal sinus drainage pathway. The cells present a variable lateral or dorsal extent. In fiber (or anterior to the arterial branch). A surgical landmark, the “frontal T”, should thus be clearly revealed (Fig. 2.85). In the vertical plane, the “T” consists of the cut edge of the perpendicular plate, and in the horizontal plane, of the cut edge through the attachment of remnants of the frontal sinus floor (Draf and Minovi 2006; Upadhyay et al. 2016).

- When using a diamond burr to achieve a maximum Draf type III frontal sinus drainage, anterolateral bone removal carries the risk of injury to the trochlea. The site of the trochlea can be assessed from an endonasal perspective – anterolaterally, it is located at a 40° angle to the frontal plane through the first olfactory neuron, about 20 mm away from the latter (Locker et al. 2017).

- There is a general need to further differentiate the established Draf classification system for endonasal frontal sinus procedures (Draf 1991). Amendments and alternatives are found in the literature, e.g. in: Eloy et al. 2016, Wormald et al. 2016.

Clinical Hint

The mentioned relationships between the frontal sinus and supraorbital ethmoid cell are of particular importance, if the goal is to achieve adequate and sustained drainage of all compartments of the ethmoid and frontal sinus in the course of endonasal procedures. A corresponding preoperative analysis of CT scans in two, or optimally three, planes is requisite to success.

Special Literature

Suprasellar notch

Torus lateralis / Torus bullaris

Lacrimal passages

The lacrimal passages are composed of the lacrimal sac in cranial, and the nasolacrimal duct, in caudal aspects. Cranially, the lacrimal sac terminates blind in the lacrimal sac fundus (apex, fornix). About 2–5 mm inferior to the fundus is the drainage site of the common duct of the lacrimal canaliculi; separate terminal segments, i.e., separate drainage sites of the superior and inferior canaliculi, reportedly exist in approx. 30% of cases (Fig. 2.88–2.90).

The bony lacrimal fossa is formed by a lacrimal groove of the maxilla and a corresponding groove which is made up of the relatively fragile lacrimal bone. The entire fossa is approx. 10 mm long and 6–8 mm wide, and it is caudally directed toward the bony nasolacrimal canal. The lacrimal bone encloses the mediodorsal 2.5 mm of the sac; it is located directly before (and in part covered by) the uncinate process, and commonly, it only measures approx. 100 μm in thickness – less than 1/10 of the thickness of the adjacent frontal process of maxilla (Tab. 2.47, 2.48).

The soft-tissue lacrimal sac is about 12 mm long, its sagittal diameter is 5–6 mm, and its transverse diameter, 4–5 mm. In about 30% of cases, trapped air in the lacrimal passages is commonly detectable by radiography. An air-filled lacrimal sac usually has an enlarged diameter.

The bony lacrimal canal is approx. 12 mm long. The canal's entry is ovaloid in shape and measures approx. 7 x 5 mm. However, its diameter quickly decreases caudally to 5–3.5 mm. The soft-tissue nasolacrimal duct, which lies in the canal, has a length of approx. 11 mm; inferior to the nasolacrimal canal, the distance to the valve of Hasner (plica lacrimalis) is approx. another 5 mm.

The longitudinal axis of the lacrimal sac is oriented posteriorly to a minor degree. At the junction to the nasolacrimal duct, the angle to the vertical plane increases by another approx. 10°, to then equal 15°–25° (Fig. 2.91).

The punctiform or slit-shaped opening of the nasolacrimal duct in the inferior meatus lies about 24 mm posterior to the anterior nasal spine, approx. 14 mm posterior to the anterior attachment of the inferior turbinate, about 5 mm inferior to the insertion of the inferior turbinate into the lateral nasal wall, and 11–14 mm superior to the nasal floor. In 80% of cases, a lacrimal fold (Hasner’s valve) of variable morphology is visible in this location on endoscopy (Tab. 2.49).

<table>
<thead>
<tr>
<th>Degree of (anteroposterior) coverage of the lacrimal sac by the uncinate process at the height of the opening of the common duct (Soyka et al. 2010).</th>
<th>Coverage of 0 %</th>
<th>Prevalence 20 %.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage of 25 %</td>
<td>Prevalence 17 %.</td>
<td></td>
</tr>
<tr>
<td>Coverage of 50 %</td>
<td>Prevalence 25 %.</td>
<td></td>
</tr>
<tr>
<td>Coverage of 75 %</td>
<td>Prevalence 10 %.</td>
<td></td>
</tr>
<tr>
<td>Coverage of 100 %</td>
<td>Prevalence 28 %.</td>
<td></td>
</tr>
</tbody>
</table>

| Relative location of lacrimal sac and maxillary line (Orhan et al. 2009b). |
|---------------------------------|-----------------|
| Group 1                         | Maxillary line lies in the middle of the sac (45 %). |
| Group 2                         | Maxillary line lies in the posterior half of the sac (25 %). |
| Group 3                         | Maxillary line lies in the anterior half of the sac (20 %). |
| Group 4                         | Maxillary line lies completely anterior to the sac (10 %). |

| Relative location of lacrimal sac and axilla of the middle turbinate (Orhan et al. 2009b). |
|---------------------------------|-----------------|
| Group 1                         | Axilla lies superior to the lacrimal sac in parts of the anteroposterior diam. (75 %). |
| Group 2                         | Axilla lies superior to the lacrimal sac over the entire anteroposterior diam. (15 %). |
| Group 3                         | Axilla lies posterior to the lacrimal sac (10 %). |

Tab. 2.47 Variability in terms of the location of the uncinate process, the maxillary line and the axilla relative to the lacrimal sac in the area of the lateral nasal wall.

<table>
<thead>
<tr>
<th>Spatial relationship between the anterior wall of the maxillary sinus and the lacrimal canal (Wang et al. 2018).</th>
<th>“Fusion Type”</th>
<th>The anterior lacrimal duct is contiguous with the anterior wall of the maxillary sinus (40 %).</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Separation Type”</td>
<td>The anterior lacrimal duct is not contiguous with the anterior wall of the maxillary sinus (60 %).</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relationship between the junction (angle) of the anterior wall of the maxillary sinus lateral nasal wall and lateral circumference of the lacrimal canal (Wang et al. 2018).</th>
<th>“Lateral Type”</th>
<th>The junction (angle) is lateral to the lacrimal canal (36 %).</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Anterior Type”</td>
<td>The junction (angle) is anteromedial to the lacrimal canal (64 %).</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 2.48 Variations in the relative location of the lacrimal canal versus the anterior maxillary sinus wall, and versus the junction between anterior wall and lateral nasal wall.
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

Tab. 2.49 Variations related to the shape of the lacrimal passage opening and the lacrimal fold (Hasner’s valve) in the inferior meatus.

<table>
<thead>
<tr>
<th>Shape of the lacrimal passage opening and the lacrimal fold (Hasner’s valve) in the inferior meatus (Orhan et al. 2009a).</th>
<th>Type 1</th>
<th>Vertical sulcus (70 %).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 2</td>
<td>Oblique sulcus (10 %).</td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>Oblique fissure (10 %).</td>
<td></td>
</tr>
<tr>
<td>Type 4</td>
<td>Vertical fissure (5 %).</td>
<td></td>
</tr>
<tr>
<td>Type 5</td>
<td>Anteroposterior fissure (5 %).</td>
<td></td>
</tr>
</tbody>
</table>

From endonasally, the maxillary line (see above) and the axilla of the middle turbinate are useful reference points for tracing the large lacrimal passages. In 70% of cases, the maxillary line lies in the maxillolacrimal suture, while it is anterior to this suture in 30% of cases. The anteriormost aspect of the middle turbinate overlaps parts of the nasolacrimal pathways for a length of 2–3 mm in 70% of cases. With its fornix, the lacrimal sac extends 8–10 mm beyond the attachment of the middle turbinate in a cranial direction; in 55% of cases, an agger nasi cell overlaps the superior lacrimal sac. The distance of the lacrimal passages from the natural maxillary sinus ostium is about 4 mm – but in some instances, it is only 1 mm.

Fig. 2.88 Anatomy of the lacrimal drainage system.

Fig. 2.89 Schematic drawing of the medial orbital wall, viewed from laterally.

The ethmoid extends anteriorly over the lacrimal passages to a variable degree (lacrimal fossa). The percentages are to be read as follows: e.g., in 32% of cases, the ethmoid covers half of the anteroposterior dimension of the lacrimal fossa (from: Whitnall 1932).

Fig. 2.90 Vertical distance of the fundus of the lacrimal sac from the anterior insertion of the middle turbinate. The vertical distance (measurement ➊), is approx. 10 mm. This distance is about 2 mm less when measured along the longitudinal axis of the lacrimal sac (opposite side in the diagram). The entrance of the common duct into the lacrimal sac lies approximately 5 mm below the fundus (measurement ➋) (from: Wormald et al. 2000).
Clinical Hint

The nasolacrimal duct may be seriously jeopardized by excessive enlargement of the natural maxillary sinus ostium in the anterior direction with the backbiting punch. Such injury is reported in 15% of patients, but fortunately, it causes specific symptoms in only every 10th case.

Special Literature


Fig. 2.91 Schematic drawing of the right lateral nasal wall, viewed from medially. Note the orientation (longitudinal axis) of the lacrimal sac (S) and lacrimal canal (C) relative to the vertical plane (-----) (from: Janssen et al. 2001; Park et al. 2012).

Tuberculum opticum

Tuberculum sellae

Vidian nerv

V-R line

The VR line serves to clarify and assess the presence/extent of pneumatization in lateral and lateroinferior aspects of the sphenoid sinus (Fig. 2.92). In the frontal CT scan, a line is drawn between the Vidian nerve (pterygoid canal) and the foramen rotundum (VR line). Relevant to this assessment is any pneumatization extending beyond this line in a lateral and lateroinferior direction.

Fig. 2.92 The VR line runs between the pterygoid canal (Vidian nerve) and the foramen rotundum. The line (-----) serves to demonstrate the presence / extent of inferolateral sphenoid sinus pneumatization, which is positively identified on the left side of the patient (a) while there is none on the right (b).
At birth, the anterior skull base is in large part made up of cartilage. The ossification process takes about 2 years to complete. Pneumatization of the paranasal sinuses continues after birth; the normal development of the individual paranasal sinus segments is summarized in Tab. 3.1.

At birth, all (approx. 6–10) ethmoid cells are present – but they are still “round” and separated by large amounts of connective tissue. At birth, the nasal meatuses still appear closed. In terms of morphology and topography, the uncinate process, however, already resembles that of adults. At the age of 1 to 12 months, the olfactory cleft is still relatively flat (Keros type 1). Beyond this age, olfactory fossa anatomy (i.e., the frequency distribution of the depth of the olfactory fossa in the Keros classification) is similar to that of adults. However, a free course of the ethmoid artery is less common in children.

The maxillary sinus has a volume of 6–8 mm³ at birth, and the nasal floor lies 4 mm inferior to the maxillary sinus floor. With increasing size, the maxillary sinus floor develops to the level of the nasal floor at the age of 8–12 years. In adults, the maxillary sinus floor is even farther inferior, by approx. 4–5 mm. At the age of 4 years, a frontal sinus is already visible. Its outline exceeds the plane of the supraorbital margin by the age of 6 years and increases synchronously with skull growth up to about the age of 19 years.

In some cases, pneumatization of the sphenoid sinus starts at approx. 15 months. At about the age of 4, the anterior segment of the sphenoid sinus is present; at the age of 8 years, pneumatization may extend as far as the pituitary region. At the age of 10–14 years, pneumatization is largely complete. Sphenethmoidal cells are less common in children than in adults.

<table>
<thead>
<tr>
<th>Paranasal sinus</th>
<th>Postnatal development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethmoid sinus</td>
<td>All cells are present at birth; rapid growth at the age of 6–8 years.</td>
</tr>
<tr>
<td>Maxillary sinus</td>
<td>Present at birth; two phases of development (0–4 years; 8–12 years); development is complete at the age of approx. 22–24 years.</td>
</tr>
<tr>
<td>Frontal sinus</td>
<td>Present at birth; two phases of development (0–4 years; 8–12 years); development is complete at the age of approx. 22–24 years.</td>
</tr>
<tr>
<td>Sphenoid sinus</td>
<td>Rudimentary or missing at birth – pneumatization starts at the age of 4 years; development is complete at the age of approx. 18 years.</td>
</tr>
</tbody>
</table>

Tab. 3.1 Postnatal development of the paranasal sinuses (from: Hajiioannou et al. 2010).
### Preoperative CT-based checklist for planning of elective routine paranasal sinus procedures

|   | Absolute and relative dimensions || Anatomy of the frontal sinus drainage pathway |
|---|-----------------------------------|-----------------------------------------------|
| 1 | Anterior and posterior width of the ethmoid bone. || Agger nasi. |
|   | **Height** of the ethmoid bone, relationship between height of the ethmoid bone and maxillary sinus as well as orbit (“low skull base”). || Type, number and size of fronto-ethmoidal cells. |
| 2 | Uncinate process || Anteroposterior dimension of the inferior frontal sinus, extent of superior nasal spine. |
|   | Anterosuperior zone of insertion into orbit, lateral or medial skull base. || Infraorbital ethmoid cells (“Haller cells”). |
| 3 | Orbit / lamina papyracea || Sphenoethmoidal cells (“Onodi cells”). |
|   | Spacial relationship between the orbit and the natural ostium of maxillary sinus. || Optic canal |
|   | Focal medial bulge in the medial orbital wall (congenital, post-traumatic). || Position, extent of exposure / prominence (free, courses fully exposed). |
|   | Lateral groove in the medial maxillary sinus wall (occasionally fused in part with the medial orbital floor, maxillary sinus atelectasis). || Internal carotid artery |
|   | Thinned bone / dehiscence of the bony coverage. || Thinned bone / dehiscence of the bony coverage. |
|   | Occasionally, medial prominence into the sphenoid sinus. || Occasionally, medial prominence into the sphenoid sinus. |
|   | Occasionally, insertion from intersphenoidal septum, incomplete septa. || Occasionally, insertion from intersphenoidal septum, incomplete septa. |
| 4 | Ethmoid roof / cribiform plate || Bony dehiscences / postoperative defects |
|   | Integrity of the ethmoid roof. || Lamina papyracea. |
|   | Supraorbital ethmoid cells. || Lateral wall of the olfactory fossa. |
|   | In coronal plane: (Low) level of the cribiform plate. Height and slant of the lateral wall of the olfactory fossa, slant of the lateral nasal base. || Sphenoid sinus. |
|   | In sagittal plane: Angle formed by skull base and horizontal plane. || Maxillary sinus (infraorbital nerve). |
|   | Side-to-side asymmetry. || |
| 5 | Anterior ethmoid artery || |
|   | Topographic relationship to the skull base. || |
|   | Position and size of the orbital “extension” relative to the canal of the anterior ethmoid artery (between medial rectus and superior oblique muscles in coronal CT images). || |

*Tab. 4.1 Checklist for preoperative analysis of the individual paranasal sinus microanatomy with the aid of CT scans (from: Hosemann 2013).*

**Fig. 4.1** Exemplary schematic drawing suggested for analysis of the patient-specific microanatomy on the basis of a CT scan. *Infraorbital ethmoid cell* (1); Lamellar type of a *concha bullosa* (2); Side-to-side difference in the depth of the *olfactory fossa* – note: bony dehiscence of the *lateral fossa wall* (3); “Conchal sinus” as a special form of a *concha bullosa* (4); *Ethmoid bulla* (5); *Uncinate process* (6).


Bibliography


**HOPKINS® Telescopes**

Diameter 4 mm, length 18 cm

- **HOPKINS® Straight Forward Telescope 0°**, enlarged view, diameter 4 mm, length 18 cm, **autoclavable**, fiber optic light transmission incorporated, color code: green

- **HOPKINS® Forward-Oblique Telescope 30°**, enlarged view, diameter 4 mm, length 18 cm, **autoclavable**, fiber optic light transmission incorporated, color code: red

- **HOPKINS® Forward-Oblique Telescope 45°**, enlarged view, diameter 4 mm, length 18 cm, **autoclavable**, fiber optic light transmission incorporated, color code: black

- **HOPKINS® Lateral Telescope 70°**, enlarged view, diameter 4 mm, length 18 cm, **autoclavable**, fiber optic light transmission incorporated, Color code: yellow

It is recommended to check the suitability of the product for the intended purpose prior to use. Please note that the described products in this medium may not be available yet in all countries due to different regulatory requirements.
Accessories

723770 STAMMBERGER Telescope Handle, flat, standard model, length 11 cm, for use with HOPKINS® straight forward telescopes 0° with diameter 4 mm and length 18 cm

723772 STAMMBERGER Telescope Handle, round, standard model, length 11 cm, for use with HOPKINS® telescopes 30°–120° with diameter 4 mm and length 18 cm

Instruments

474000 FREER Elevator, double-ended, semisharp and blunt, length 20 cm

474205 FREER-WEBER Elevator, double-ended, one side slightly curved FREER elevator, semisharp, other side strongly curved, sharp, length 19 cm

479100 COTTLE Elevator, double-ended, semisharp and blunt, graduated, length 20 cm

628001 Sickle Knife, pointed, length 19 cm

628702 Antrum Curette, oblong, small, length 19 cm

628712 KUHN-BOLGER Frontal Sinus Curette, 55° curved, oval, forward cutting, length 19 cm

629820 Probe, double-ended, maxillary sinus ostium seeker, ball-shaped ends diameter 1.2 and 2 mm, length 19 cm

629824 CASTELNUOVO Frontal Sinus Probe, double-ended, curved, length 22 cm
Instruments

586026  v. EICKEN Antrum Cannula,
LUER-Lock, with cut-off hole, long curve,
outer diameter 2.5 mm, length 12.5 cm

586030  v. EICKEN Antrum Cannula,
LUER-Lock, long curved, outer diameter 3 mm,
length 12.5 cm

529309  FRAZIER Suction Tube,
with mandrel and cut-off hole,
with distance marking at 5– cm, 9 Fr.,
working length 10 cm

213314  WULLSTEIN Scissors,
curved, sharp/sharp, length 14 cm

174200  COTTLE Metal Mallet,
length 18 cm

484004  COTTLE Chisel,
flat, graduated, straight, width 4 mm,
length 18.5 cm
Nasal Forceps

451000B  GRÜNWALD-HENKE RHINOFORCE® II Nasal Cutting Forceps, straight, through-cutting, BLAKESLEY shape, size 0, width 3 mm, with cleaning connector, working length 13 cm

451500B  GRÜNWALD-HENKE RHINOFORCE® II Nasal Cutting Forceps, 45° upturned, through-cutting, BLAKESLEY shape, size 0, width 3 mm, with cleaning connector, working length 13 cm

456001B  BLAKESLEY RHINOFORCE® II Nasal Forceps, straight, size 1, with cleaning connector, working length 13 cm
Nasal Forceps

456501B BLAKESLEY-WILDE RHINOFORCE® II Nasal Forceps, 
45° upturned, size 1, with cleaning connector, 
working length 13 cm

634824 STRÜMPBEL Forceps, 
with oval, fenestrated, cupped jaws, straight, width 2.5 mm, 
working length 12.5 cm

651010 STAMMBERGER RHINOFORCE® II Double Spoon Forceps, 
vertical opening, 65° upturned, spoon diameter 3 mm, 
with cleaning connector, working length 12 cm
Nasal Scissors

663300  **Scissors,**
straight, working length 18 cm

663307  **Scissors,**
45° curved upwards, extra delicate,
working length 18 cm
Punches

459010  STAMMBERGER RHINOFORCE® II Antrum Punch,
upside backward cutting, with cleaning connector,
working length 10 cm

459040  PARSONS RHINOFORCE® II Punch,
for resection of the uncinate process, upward backward cutting,
movable jaw with round tip, diameter 2.5 mm,
with cleaning connector, working length 10 cm

651065  STAMMBERGER Punch,
circular cutting, 65° upturned, for frontal sinuses recess,
diameter 4.5 mm, with cleaning connector, working length 17 cm,
including Cleaning Tool 651050 R
HOSEMAND Frontal Sinus/Recess Punches and Sphenoid Punch

with integrated irrigation channel

HOSEMAND Frontal Sinus/Recess Punch,
70° upturned, slender model, punch head diameter 3.5 mm, not through-cutting, upper part of punch fixed, lower part of punch movable, sheath diameter 2.5 mm, central irrigation channel with concealed LUER-Lock irrigation adaptor, working length 13 cm

HOSEMAND Sphenoid Punch,
straight, slender model, punch head diameter 3.5 mm, not through-cutting, front part of punch fixed, rear part of punch movable, sheath diameter 2.5 mm, central irrigation channel with concealed LUER-Lock irrigation adaptor, working length 13 cm

HOSEMAND Frontal Sinus/Recess Punch,
70° upturned, robust model, punch head diameter 5.5 mm, not through-cutting, upper part of punch fixed, lower part of punch movable, sheath diameter 3.5 mm, central irrigation channel with concealed LUER-Lock irrigation adaptor, working length 13 cm
STAMMBERGER Antrum Punches

459051  STAMMBERGER Antrum Punch,
right side downward and forward cutting,
with cleaning connector, working length 10 cm

459052  STAMMBERGER Antrum Punch,
left side downward and forward cutting,
with cleaning connector, working length 10 cm
**KERRISON Bone Punches**

662122  
KERRISON Bone Punch, detachable, rigid, upbiting 40° forward, size 2 mm, working length 17 cm

662123  
KERRISON Bone Punch, detachable, rigid, upbiting 40° forward, size 3 mm, working length 17 cm
UNIDRIVE® S III ENT SCB
UNIDRIVE® S III ECO

40701620-1

UNIDRIVE® S III ENT SCB, motor control unit with color display, touch screen, two motor outputs, integrated irrigation pump and SCB module, power supply 100–240 VAC, 50/60 Hz including:
- Mains Cord
- Irrigator Rod
- Two-Pedal Footswitch, two-stage, with proportional function
- Clip Set, for use with silicone tubing set
- SCB Connecting Cable, length 100 cm
- Single Use Tubing Set*, sterile, package of 3

40701420

UNIDRIVE® S III ECO, motor control unit with two motor outputs and integrated irrigation pump, power supply 100–240 VAC, 50/60 Hz including:
- Mains Cord
- Two-Pedal Footswitch, two-stage, with proportional function
- Clip Set, for use with silicone tubing set
- Single Use Tubing Set*, sterile, package of 3

Specifications:

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<tr>
<th>Feature</th>
<th>UNIDRIVE® S III ENT SCB: 6.4*/300 cd/m²</th>
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<th>Weight</th>
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<td>Flow</td>
<td>9 steps</td>
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<tr>
<td>Power supply</td>
<td>100–240 VAC, 50/60 Hz</td>
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*Single Use Tubing Set is sterile.
**DRILLCUT-X® II Shaver Handpiece and DRILLCUT-X® II N Shaver Handpiece**

**Special Features:**
- Oscillation mode for shaver blades, max. 10,000 rpm
- Rotation mode for sinus burrs, max. 12,000 rpm
- Straight suction channel and integrated irrigation

- Suitable for use in washer and autoclavable at 134° C
- Quick coupling mechanism facilitates exchange of work inserts

---

**Optional Accessories:**

**40712050** DRILLCUT-X® II Shaver Handpiece, for use with UNIDRIVE® S III ECO/ENT/NEURO/OMFS

**40712055** DRILLCUT-X® II N Shaver Handpiece, adaptable to shavertracker 40800122, for use with UNIDRIVE® S III ECO/ENT/NEURO

**40712090** Handle, adjustable, for use with DrillCut-X® II and DrillCut-X® II N

**41250RA** Cleaning Adaptor, Luer-Lock, for cleaning DRILLCUT-X®/DRILLCUT-X® II shaver handpieces
**Shaver Blades, straight**
for Nasal Sinuses and Skull Base Surgery

For use with all DRILLCUT-X® II and DRILLCUT-X® II-35 Handpieces

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<td>double serrated cutting edge, diameter 4 mm, color code: blue-yellow</td>
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<td>41201KSA</td>
<td>serrated cutting edge, diameter 3 mm, color code: blue-yellow</td>
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**Shaver Blades, curved**
for Nasal Sinuses and Skull Base Surgery

For use with all DRILLCUT-X® II and DRILLCUT-X® II-35 Handpieces

<table>
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<tr>
<th>Detail</th>
<th>for use with handpieces</th>
<th>Shaver Blade</th>
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<td>DRILLCUT-X® II, DRILLCUT-X® II N, DRILLCUT-X® II-35 and DRILLCUT-X® II-35 N</td>
<td>Shaver Blade length 12 cm</td>
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<td>41204KKB</td>
<td>curved 40°, cutting edge serrated backwards, double serrated, diameter 3 mm, color code: blue-yellow</td>
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**Optional Accessory:**

| 41200RA | **Cleaning Adaptor**, LUER-Lock, for cleaning the inner and outer blades of reusable Shaver Blades 412xx |
Anatomy of the Paranasal Sinuses and Anterior Skull Base – Fundamentals of Endoscopic Endonasal Surgery

Shaver Blades, curved
for Nasal Sinuses and Skull Base Surgery

For use with all DRILLCUT-X® II and DRILLCUT-X® II-35 Handpieces

![Shaver Blades, curved 65°, sterilizable](image)

<table>
<thead>
<tr>
<th>Detail</th>
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<th>Shaver Blade</th>
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<td>length 12 cm</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Cleaning Adaptor, Luer-Lock, for cleaning the inner and outer blades of reusable Shaver Blades 412xx</th>
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<tr>
<td>41200RA</td>
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Optional Accessory:

Sinus Burrs, curved
for Nasal Sinuses and Skull Base Surgery

For use with DRILLCUT-X® II and DRILLCUT-X® II N

![Sinus Burrs, curved 70°/15°, for single use](image)

<table>
<thead>
<tr>
<th>Sinus Burrs, curved 70°/15°, for single use, sterile, package of 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detail</td>
</tr>
<tr>
<td>--------</td>
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<tr>
<td>Sinus Burr</td>
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<td>length 12 cm</td>
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| 41305RN | curved 15°, diamond head, drill diameter 3 mm, shaft diameter 4 mm, color code: red-yellow |
| 41305DN | curved 70°, diamond head, drill diameter 3.6 mm, shaft diameter 4 mm, color code: red-yellow |

Additional blades or burrs can be found in the UNIDRIVE catalog excerpt as well as in the ENT catalog.
DRILLCUT-X® II-35 Handpiece with 35k Sinus Burrs

Power meets precision

- **Handpiece**
  Compatible for use with sinus burrs up to 35,000 rotations per minute, and the already existing portfolio of shaver blades

- **35k Burr inserts**
  Five different models available

- **Compatibility**
  Handpiece and burr inserts can be used with the existing UNIDRIVE® S III ENT motor system

- **EM navigation**
  Can be expanded with the shaver blade tracker for electromagnetic navigation of sinus burrs and shaver attachments

---

407120 35  DRILLCUT-X® II-35 Shaver Handpiece, for use with UNIDRIVE® S III ENT/NEURO
407125 35  DRILLCUT-X® II-35 N, shaver handpiece, adaptable to Optical Shaver Tracker 40800122, for use with UNIDRIVE® S III ENT/NEURO and NAV1® PICO or NAV1® OPTICAL
407120 90  Handle, adjustable, for use with DRILLCUT-X® II N shaver handpiece

Optional Accessory:
41250RA  Cleaning Adaptor, Luer-Lock, for cleaning DRILLCUT-X®/DRILLCUT-X® II shaver handpieces
**35k Sinus Burrs**
for Nasal Sinuses and Skull Base Surgery

For use with DRILLCUT-X® II-35 Shaver Handpiece 40712035 and DRILLCUT-X® II-35 N Shaver Handpiece 40712535

<table>
<thead>
<tr>
<th>Detail</th>
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<td>41335W</td>
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<td>curved 15°, bud drill, burr diameter 4 mm, shaft diameter 4 mm</td>
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<td>41335DW</td>
<td>curved 40°, diamond head, burr diameter 5 mm, shaft diameter 4 mm</td>
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<td>41335DT</td>
<td>curved 70°, diamond head, burr diameter 3.6 mm, shaft diameter 4 mm</td>
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<td>41335DS</td>
<td>curved 40°, diamond-shaped cutting, burr diameter 4 mm, shaft diameter 4 mm</td>
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</table>
KARL STORZ NAV1® ELECTROMAGNETIC
For precise navigation in FESS and ear surgery

The navigation system NAV1® ELECTROMAGNETIC supports surgeons in otorhinolaryngology and skull base surgery. It uses a sophisticated electromagnetic measurement system.

Benefits of the KARL STORZ NAV1® ELECTROMAGNETIC
• Low follow-up costs thanks to reusable EM instruments in proven KARL STORZ quality.*
• High precision thanks to sensors in the instrument tips.
• Compact design for easy integration into the OR.
• Possible to update the system with the optical measurement technology.
• User-friendly interface thanks to clearly defined control elements and menu navigation.

* Up to 30 applications guaranteed.

• Possible to update NAV1® SINUSTRACKER™ planning software, navigated endoscope and navigated shaver tracker.
• Planning and monitoring of risk structures with intra-operative distance control.
• Automatic and reliable documentation of the navigated procedure.
• Intraoperative re-registration enables manual correction of any inaccuracies, particularly in deeper regions.
KARL STORZ NAV1® ELECTROMAGNETIC

Components of the NAV1® ELECTROMAGNETIC

40820001 NAV1® ELECTROMAGNETIC

including:

NAV1® Module
NAV1® ELECTROMAGNETIC Module
NAV1® ELECTROMAGNETIC Field Generator
Headband, for navigation, for single use
EM Patient Tracker
EM Probe
2x Mains Cord, length 300 cm
Module Connecting Cable
Optical Mouse
Instruments for NAV1® ELECTROMAGNETIC

40820105  EM Probe, with atraumatic tip, bayonet-shaped, for patient registration, tip diameter 1.9 mm, cable length 250 cm, working length 10.5 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820110  EM Palpation Probe, with atraumatic tip, malleable, straight, tip diameter 1.7 mm, cable length 250 cm, working length 8.5 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820112  EM Palpation Probe, with atraumatic tip, malleable, curved 63°, tip diameter 1.7 mm, cable length 250 cm, working length 8.5 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820111  EM Frontal Sinus Probe, with atraumatic tip, 77° gebogen, tip diameter 1.2 mm, cable length 250 cm, working length 7 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820145  EM Suction Tube, with cut-off hole, straight, LUER, outer diameter 3.5 mm, cable length 250 cm, working length 10 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820165  EM Suction Tube, with cut-off hole, curved 60°, LUER, outer diameter 3.5 mm, cable length 250 cm, working length 10 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC
Instruments for NAV1® ELECTROMAGNETIC

40820163  EM Suction Tube, with cut-off hole, curved 60°, Luer, outer diameter 3.5 mm, cable length 250 cm, working length 10 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820175  EM Suction Tube, with cut-off hole, double-curved, Luer, outer diameter 3 mm, cable length 250 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820131  EM Antrum Curette, small, oblong, cable length 250 cm, length 19 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820132  EM Frontal Sinus Curette, forward cutting, curved 55°, oval, cable length 250 cm, length 18 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

40820130  EM Frontal Sinus Curette, forward cutting, curved 90°, oval, cable length 250 cm, length 18 cm, autoclavable, for use with NAV1® ELECTROMAGNETIC

39556A  Wire Tray, provides safe storage of up to 4 EM navigation instruments (408201xx) and one EM patient tracker during cleaning and sterilization, external dimensions (w x d x h) 460 x 150 x 80 mm
NAV1® SINUSTRACKER™

The innovative planning software for new routes in FESS surgery

The NAV1® SINUSTRACKER™ planning software enhances the KARL STORZ NAV1® ELECTROMAGNETIC system with the automatic planning of access paths in paranasal sinus and skull base surgery. On the basis of a preoperatively set starting and destination point in the patient's radiological data, the software allows the surgeon to determine a precise access path that is specially adapted to the individual anatomic structures of the patient. The physician then reviews and modifies the suggested access path at their discretion. Intraoperatively, the selected route is visualized on the navigation screen so that the actual position in the site is under constant control.

Benefits of the NAV1® SINUSTRACKER™

- Multiple Path Planning enables the preoperative planning and naming of up to eight access paths and alternatives.
- Intraoperative visualization and control of access paths.
- Less preoperative planning required thanks to automatic preplanning.
- Flexible, pre- and intraoperative adaptation of the access path possible.

Set waypoints by clicking into the 2D views.
NAV1® EM Endoscope Tracker
Augmented FESS endoscopy with the new electromagnetic navigated endoscope adaptor

Using augmented endoscopy, which was specially developed for the NAV1® SinusTracker™, the real-time endoscopic image can be enhanced with information obtained from the preoperative virtual planning of the access route. Adaptor 40820150/40820151 is used in conjunction with KARL STORZ HOPKINS® telescopes with 0° (7230AA), 30° (7230BA) or 45° (7230FA) directions of view for augmentation. The position and direction of view of the employed telescope is displayed in the radiology images in such a way that the endoscopic image can be precisely assigned to the exact in-situ location.

Benefits of augmented endoscopy

- Possible to display planning elements in the standard endoscopic image.
- Visual navigation of non-navigated instruments along the preoperatively planned route.
- Spatial mapping of the direction of view and the position of the telescope in the site.

40820150 EM Endoscope Tracker, universal, cable length 250 cm, autoclavable, reusable 30 times, for use with NAV1® ELECTROMAGNETIC 40820001, HOPKINS® Telescope 0° 7230AA, HOPKINS® Telescope 30° 7230BA, HOPKINS® Telescope 45° 7230FA, and NAV1® SINISTRACKER™ 40810600

40820151 EM Endoscope Tracker 2.0, universal, cable length 250 cm, autoclavable, reusable 30 times, for use with NAV1® ELECTROMAGNETIC 40820001, HOPKINS® Telescope 0° 7230AA, HOPKINS® Telescope 30° 7230BA/BLA/BVA, HOPKINS® Telescope 45° 7230FA/FLA/FVA, and NAV1® SINISTRACKER™ 40810600

The telescopes shown above are not included in the scope of delivery.
With the IMAGE1 S™ camera platform, KARL STORZ once again sets a new milestone in endoscopic imaging, consolidating their reputation as an innovative leader in minimally invasive surgery. The IMAGE1 S™ camera platform offers surgeons a single system for all applications. As a modular camera platform, IMAGE1 S™ combines various technologies (e.g., rigid, flexible and 3D endoscopy) in one system and is therefore adaptable to individual customer needs. Furthermore, the camera platform offers expanded compatibility and connectivity for ICG-enhanced near-infrared (NIR) fluorescence imaging, the integration of operating microscopes and the use of VITOM® 3D exoscopes.

Brilliant imaging

- Versatile visualization options for diagnosis and therapy
- Innovative S-Technologies for easy differentiation of tissue structures
- Very good image quality
- Natural color rendition
- Automatic light source control

CLARA: Homogeneous illumination

Standard Image  CLARA

*SPECTRA A: Color hue shift and exchange (filtering reds)

Standard Image  *SPECTRA A

CHROMA: Contrast enhancement

Standard Image  CHROMA

*SPECTRA B: Spectral color shift (intensification of greens and blues)

Standard Image  *SPECTRA B

* SPECTRA A: Not available for sale in the U.S.A.
* SPECTRA B: Not available for sale in the U.S.A.
As individual as your requirements

Innovative Design

- Side-by-side View: Parallel display of standard image and visualization mode possible
- Multiple source management: Simultaneous control, display and documentation of two image sources possible (e.g., hybrid procedures)
- Intuitive user guidance (dashboard, live menu and setup menu)
- Intelligent icons display settings and status
- Individual presets possible
- 50 patient data records can be archived

Economical and futureproof

- Modular platform: Rigid, flexible and 3D technology can be selected according to individual preferences
- Easy integration of new technologies
- Forward and backward compatibility
- No additional equipment (e.g., special light sources) required for S-Technologies

*SPECTRA A: Not available for sale in the U.S.A.
*SPECTRA B: Not available for sale in the U.S.A.
IMAGE1 S™
As individual as your requirements

IMAGE1 S™ 3D
IMAGE1 S™ 3D is a further component in the IMAGE1 S™ camera platform. The 3D system provides surgeons with excellent depth perception. Furthermore, the 3D stereoscopic imaging system is particularly valuable for activities that demand a high degree of spatial perception. The 3D camera platform from KARL STORZ impresses with its wide range of applications – from laparoscopy, gynecology, ENT to microsurgical interventions.

Benefits of IMAGE1 S™ 3D
• Brilliant and high-quality imaging in 2D and 3D
• Switchover from 3D to 2D at the touch of a button
• Easy integration into the IMAGE1 S™ platform
• CLARA, CHROMA, SPECTRA* in 2D and 3D
• 3D system with video endoscopes with diameters of 10 mm and 4 mm as well as VITOM® 3D

Benefits of 3D integration into the IMAGE1 S™ camera platform
• Communication between all units
• One system for multiple applications
• Reduced space requirements
• One user interface for all applications
• Synergy effects between the OR workflow and financing

Available in 0°/30°
Autoclavable
Optimal sharpness in the working area
Lightweight and ergonomic design
CLARA, CHROMA, SPECTRA* in 2D and 3D
Easy documentation in 2D via USB flash drive
Programmable camera head buttons
Easy switchover from 3D to 2D

*SPECTRA: Not available for sale in the U.S.A.
IMAGE1 S™ – A System for all Requirements

Connects all technologies IMAGE1 S CONNECT®

- 10 mm 3D video endoscope
- 4 mm 3D video endoscope
- Flexible video endoscopes
- 1-chip camera heads
- PDD in FULL HD
- VITOM® 3D
- 4K camera head
- 3D endoscopy IMAGE1 S D3-LINK™
- 4K endoscopy IMAGE1 S 4U-LINK
- Open for future technologies
- 3D rigid / flexible endoscopy IMAGE1 S X-LINK
- 2D endoscopy IMAGE1 S H3-LINK
- Near-Infrared (NIR/ICG) 3-chip camera head FI
- IMAGE1 S H3-M COVIEW® 3-Chip FULL HD C-Mount Camera Head

4 mm 3D video endoscope

Flexible video endoscopes

1-chip camera heads

PDD in FULL HD

VITOM® 3D

4K camera head

3D endoscopy IMAGE1 S D3-LINK™

4K endoscopy IMAGE1 S 4U-LINK

Open for future technologies

3D rigid / flexible endoscopy IMAGE1 S X-LINK

2D endoscopy IMAGE1 S H3-LINK

Near-Infrared (NIR/ICG) 3-chip camera head FI

IMAGE1 S H3-M COVIEW® 3-Chip FULL HD C-Mount Camera Head
TC201EN*  IMAGE1 S CONNECT® II, connect module, for use with up to 3 link modules, 4K technology, resolution 3840 x 2160 and 1920 x 1080 pixels, with integrated KARL STORZ SCB or KS HIVE and digital image processing module, power supply 100 – 240 VAC, 50/60 Hz, including:

- Mains Cord, length 300 cm
- DVI-D Connecting Cable, length 300 cm
- DisplayPort Cable, length 300 cm
- SDI Cable, length 300 cm
- SCB Connecting Cable, length 100 cm
- USB Flash Drive, 32 GB
- USB Silicone Keyboard, with touchpad, US

*Available in the following languages: DE, ES, FR, IT, PT, RU
Please specify the desired language when placing your order.

## Technical Specifications

<table>
<thead>
<tr>
<th>Video outputs</th>
<th>Power supply</th>
<th>200–240 VAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Format of signal outputs</td>
<td>Power frequency</td>
<td>50/60 Hz</td>
</tr>
<tr>
<td>Link video inputs</td>
<td>Protection class / degree</td>
<td>1 / CF-Defib</td>
</tr>
<tr>
<td>USB interface</td>
<td>Dimensions (w x h x d)</td>
<td>305 x 54 x 320 mm</td>
</tr>
<tr>
<td>Unit communication</td>
<td>Weight</td>
<td>3.1 kg</td>
</tr>
<tr>
<td>2x Display Port 1.2, 1x 12G/3G-SDI, 1x DVI-D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>max. 3840 x 2160p, 50/60 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4x USB, (2x front, 2x rear)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 x 6-pin Mini-DIN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## For use with IMAGE1 S CONNECT® II Module TC201EN

TC304  IMAGE1 S 4U-LINK, link module, for use with IMAGE1 S™ 4U camera heads, power supply 100 – 240 VAC, 50/60 Hz, including:

- Mains Cord, length 300 cm
- Link Cable, length 20 cm, for use with IMAGE1 S CONNECT® TC200EN or IMAGE1 S CONNECT® II TC201EN

## Technical Specifications

<table>
<thead>
<tr>
<th>Interfaces</th>
<th>Power consumption</th>
<th>86 VA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power frequency</td>
<td>50/60 Hz</td>
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<tr>
<td>Power supply</td>
<td>200–240 VAC</td>
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</tr>
<tr>
<td>Dimensions (B x H x T)</td>
<td>305 x 54 x 320 mm</td>
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<tr>
<td>Weight</td>
<td>1.86 kg</td>
<td></td>
</tr>
<tr>
<td>Cleaning</td>
<td>wipe disinfection</td>
<td></td>
</tr>
<tr>
<td>Degree of ingress protection</td>
<td>IPX0</td>
<td></td>
</tr>
<tr>
<td>Protection class / degree</td>
<td>1 / CF-Defib</td>
<td></td>
</tr>
</tbody>
</table>
IMAGE1 S™
Camera Head 4U One-Chip 4K UHD and Camera Head 4U RUBINA Two-Chip 4K UHD

IMAGE1 S™ 4U One-Chip 4K UHD camera head, for use with TC304, IMAGE1 S 4U-LINK, module for 4K endoscopy

TH120

IMAGE1 S™ 4U One-Chip 4K UHD Camera Head, S-technologies available, progressive scan, soakable, EtO sterilization, H₂O₂ (hydrogen peroxide), focal length f = 18 mm, 2 freely programmable camera head buttons, for use with IMAGE1 S™ 4U-LINK

Technical Specifications

<table>
<thead>
<tr>
<th>Frame rate</th>
<th>50 / 60 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image sensor</td>
<td>One-chip</td>
</tr>
<tr>
<td>Resolution</td>
<td>3840 x 2160 pixels</td>
</tr>
<tr>
<td>Scanning mode</td>
<td>progressive scan</td>
</tr>
<tr>
<td>Lens</td>
<td>fixed focus</td>
</tr>
<tr>
<td>Focal length</td>
<td>f = 18 mm</td>
</tr>
<tr>
<td>Dimensions (w x h x l)</td>
<td>46 x 37 x 133 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>210 g</td>
</tr>
</tbody>
</table>

Cable length | 300 cm |
Cable routing | angled |
Camera head buttons | freely programmable |
Grip mechanism | standard eyepiece adaptor |
Reprocessing | soakable, EtO sterilization, H₂O₂ (hydrogen peroxide) |
S-Technologies | CLARA, CHROMA, SPECTRA* |
Degree of protection | in conjunction with camera control unit IMAGE1S™: CF-Defib |

* SPECTRA A / SPECTRA B: Not for sale in the U.S.A.

IMAGE1 S™ 4U RUBINA, OPAL1® NIR/ICG, Two-Chip 4K UHD Camera Head
for use with TC201EN, IMAGE1 S CONNECT® II and TC304, IMAGE1 S 4U-LINK, module for 4K endoscopy

TH121

IMAGE1 S™ 4U RUBINA, OPAL1® NIR/ICG, Two-Chip 4K UHD Camera Head, S-technologies available, for NIR/ICG fluorescence imaging in combination with Power LED RUBINA, OPAL1® NIR/ICG, progressive scan, soakable, EtO sterilization, H₂O₂ (hydrogen peroxide), focal length f = 19 mm, 2 freely programmable camera head buttons, for use with IMAGE1 S CONNECT® II and IMAGE1 S 4U-LINK

Technical Specifications

<table>
<thead>
<tr>
<th>Frame rate</th>
<th>50 / 60 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image sensor</td>
<td>Two-chip</td>
</tr>
<tr>
<td>Resolution</td>
<td>3840 x 2160 pixels</td>
</tr>
<tr>
<td>Scanning mode</td>
<td>progressive scan</td>
</tr>
<tr>
<td>Lens</td>
<td>fixed focus</td>
</tr>
<tr>
<td>Focal length</td>
<td>f = 19 mm</td>
</tr>
<tr>
<td>Dimensions (w x h x l)</td>
<td>150 x 55 x 41 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>260 g</td>
</tr>
</tbody>
</table>

Cable length | 300 cm |
Cable routing | angled |
Camera head buttons | freely programmable |
Grip mechanism | standard eyepiece adaptor |
Reprocessing | soakable, EtO sterilization, H₂O₂ (hydrogen peroxide) |
S-Technologies | CLARA, CHROMA, SPECTRA* |
Degree of protection | in conjunction with camera control unit IMAGE1S™: CF-Defib |

* SPECTRA A / SPECTRA B: Not for sale in the U.S.A.
Monitors

TM342  31" 4K Monitor, screen resolution 3840 x 2160, image format 16:9, video inputs: DP 1.2a, 2x DVI-D, 12G-SDI, 3G-SDI, USB Typ-B, RS-232C, GPI, video outputs: DVI-D, 12G-SDI, 3G-SDI, power supply 100 – 240 VAC, 50/60 Hz, with VESA 100 and VESA 200 adaption including:
  1x External 48 VDC Power Supply
  1x Mains Cord
  1x Cable Cover
  2x Screws for cable cover
  4x Mounting Screws M4
  4x Mounting Screws M6
  1x Instruction Manual

TM220  27" FULL HD Monitor, screen resolution 1920 x 1080, image format 16:9, video inputs: 2x DVI, 3G-SDI, VGA, S-Video, Composite, video outputs: DVI, 3G-SDI, Composite, power supply 100 – 240 VAC, 50/60 Hz, 5 V DC output (1 A), wall mount with VESA 100 adaption including:
  1x External 24 VDC Power Supply
  1x Mains Cord
  1x Cable Cover
  4x Mounting Screws M4
Monitors
Technical Specifications of 31" 4K Monitor and 27" FULL HD Monitor

<table>
<thead>
<tr>
<th>KARL STORZ 4K and FULL HD Monitors</th>
<th>TM342</th>
<th>TM220</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen size</td>
<td>31.1&quot;</td>
<td>27&quot;</td>
</tr>
<tr>
<td>Resolution</td>
<td>3840 x 2160 Pixel</td>
<td>1920 x 1080 Pixel</td>
</tr>
<tr>
<td>Signal format display</td>
<td>16:9</td>
<td>16:9</td>
</tr>
<tr>
<td>Contrast ratio</td>
<td>1500:1</td>
<td>1000:1</td>
</tr>
<tr>
<td>Brightness</td>
<td>350 cd/m²</td>
<td>500 cd/m²</td>
</tr>
<tr>
<td>Max. viewing angle</td>
<td>178° vertical/horizontal</td>
<td>178° vertical</td>
</tr>
<tr>
<td>Video inputs</td>
<td>2x DVI-D, 1x 12G-SDI, 1x 3G-SDI, 1x Display Port</td>
<td>2x DVI-D, 1x 3G-SDI, 1x RGBS (VGA), 1x S-Video, 1x Composite</td>
</tr>
<tr>
<td>Video outputs</td>
<td>1x DVI-D, 1x 12G-SDI, 1x 3G-SDI</td>
<td>1x DVI-D, 1x 3G-SDI, 1x S-Video, 1x Composite</td>
</tr>
<tr>
<td>RS-232C serial port</td>
<td>—</td>
<td>1x</td>
</tr>
<tr>
<td>5V phone connector</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>USB socket</td>
<td>5V/1A</td>
<td>5V/1A</td>
</tr>
<tr>
<td>Mount</td>
<td>100/200 mm VESA</td>
<td>100 mm VESA</td>
</tr>
<tr>
<td>Power supply pack</td>
<td>external, DC 48V</td>
<td>external</td>
</tr>
<tr>
<td>Technical features</td>
<td>picture-in-picture function</td>
<td>picture-in-picture function</td>
</tr>
<tr>
<td>Rated power</td>
<td>139.2 W</td>
<td>72 W</td>
</tr>
<tr>
<td>Power supply, frequency</td>
<td>100–240 VAC, 50/60 Hz</td>
<td>100–240 VAC, 50/60 Hz</td>
</tr>
<tr>
<td>Dimensions (w x h x d)</td>
<td>760 x 444 x 87 mm</td>
<td>660 x 400 x 87 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>11.2 kg</td>
<td>8.5 kg</td>
</tr>
<tr>
<td>Hygienic Reprocessing</td>
<td>wipe disinfection</td>
<td>wipe disinfection</td>
</tr>
<tr>
<td>Degree of protection against ingress of humidity</td>
<td>IP45 front</td>
<td>IP32</td>
</tr>
<tr>
<td>Pedestal</td>
<td>9832SFH, 9826SF</td>
<td>9826SF</td>
</tr>
</tbody>
</table>
Documentation
KARL STORZ AIDA® – Exceptional Documentation

WD300-EN*
AIDA®, Documentation System Set, for recording still images and videos, dual channel up to FULL HD, 4K, 2D/3D, power supply 100 – 240 VAC, 50/60 Hz, including:
AIDA®
USB Silicone Keyboard, with US English character set, with touchpad

WD350-EN*
AIDA® with SMARTSCREEN®, Documentation System Set, for recording still images and videos, dual channel up to 4K, 2D/3D, power supply 100 – 240 VAC, 50/60 Hz, including:
AIDA®
OR1™ SMARTSCREEN®
USB Silicone Keyboard, with US English character set, with touchpad

* Please, specify the language code when placing your order.
Available in English (EN), German (DE), Spanish (ES), French (FR), Italian (IT), Portuguese (PT) and Russian (RU).
Documentation
KARL STORZ AIDA® – Workflow-Oriented Use

Patient
AIDA® seamlessly integrates into the existing infrastructure such as HIS and PACS. Data can be entered manually or via a DICOM worklist.

Checklist
Central administration and documentation of time-out. The checklist simplifies the documentation of all critical steps in accordance with clinical standards. All checklists can be adapted to individual needs.

Record
High-quality documentation, with still images and videos being recorded in FULL HD and 3D. The Dual Capture function allows for the parallel (synchronous or independent) recording of two sources. All recorded media can be marked for further processing with just one click.

Edit
With the Edit module, simple adjustments to recorded still images and videos can be rapidly completed. Recordings can be quickly optimized and then directly placed in the report. In addition, freeze frames can be cut out of videos and edited and saved. Existing markings from the Record module can be used for quick selection.

Complete
AIDA® offers a large selection of storage locations. The data exported to each storage location can be defined. The Intelligent Export Manager (IEM) then carries out the export in the background. To prevent data loss, the system keeps the data until they have been successfully exported.

Reference
All important patient information is always available and easy to access. Completed procedures including all information, still images, videos, and the checklist report can be easily retrieved from the reference module.
Fiber Optic Light Cable

495NAC

Fiber Optic Light Cable, with straight connector, extremely heat-resistant, with safety lock, increased light transmission, diameter 3.5 mm, length 230 cm, can be used for NIR/ICG fluorescence imaging.

Cold Light Fountain Power LED 300

TL300

Cold Light Fountain Power LED 300, with integrated KARL STORZ-SCB, high-performance LED module and one KARL STORZ light outlet, power supply 100–240 VAC, 50/60 Hz, including:
Mains Cord

Cold Light Fountain POWER LED RUBINA

TL400

Cold Light Fountain POWER LED RUBINA, for NIR/ICG fluorescence imaging and standard endoscopic diagnosis, with 2 LEDs and KARL STORZ light cable connection, with integrated KS HIVE connection, power supply: 100 – 125/220 – 240VAC, 50/60 Hz, including:
Mains Cord
Patch Cable
Sync Connecting Cable
**Equipment Cart**

- **Equipment Cart**
  - wide, high, rides on 4 antistatic dual wheels
  - equipped with locking brakes
  - 3 shelves
  - mains switch on top cover
  - central beam with integrated electrical subdistributors
  - with 12 sockets, holder for power supplies
  - potential earth connectors and cable winding on the outside.

- **Dimensions:**
  - Equipment cart: 830 x 1474 x 730 mm (w x h x d),
  - shelf: 630 x 510 mm (w x d),
  - caster diameter: 150 mm

- **Including:**
  - Base module equipment cart, wide
  - Cover equipment, equipment cart wide
  - Beam package equipment, equipment cart high
  - 3x Shelf, wide
  - Drawer unit with lock, wide
  - 2x Equipment rail, long
  - Camera holder

---

**Monitor Swivel Arm,**

- height and side adjustable,
- can be turned to the left or the right side,
- swivel range 180°, overhang 780 mm,
- overhang from centre 1170 mm,
- load capacity max. 15 kg,
- with monitor fixation VESA 75/100,
- for usage with equipment carts UGxxx
Recommended Accessories for Equipment Cart

**UG310**
*Isolation Transformer,*
200 V–240 V; 2000 VA with 3 special mains socket, expulsion fuses, 3 grounding plugs, dimensions: 330 x 90 x 495 mm (w x h x d), for usage with equipment carts UGxxx

**UG410**
*Earth Leakage Monitor,*
200 V–240 V, for mounting at equipment cart, control panel dimensions: 44 x 80 x 29 mm (w x h x d), for usage with isolation transformer UG310

**UG510**
*Monitor Holding Arm,*
height adjustable, inclinable, mountable on left or right, turning radius approx. 320°, overhang 530 mm, load capacity max. 15 kg, monitor fixation VESA 75/100, for usage with equipment carts UGxxx