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ORIGINAL ARTICLE

Surgical anatomy of the frontal sinus outflow pathway: a cadaveric study

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SUMMARY

Detailed anatomical knowledge of the variability in the drainage pathway in relation to the frontal sinus is a prerequisite for successful sinus surgery. We studied 32 mid-sagittal cadaveric heads and recorded the following parameters: drainage site of the sinus in relation to the uncinate process, attachment of the uncinate process, pneumatization of the agger nasi, and morphometric measurements for the localization of the frontal ostium during endoscopic surgery. Frontal sinus drainage was anterior to the uncinate process in 59.4% and posterior to it in 40.6%. In the majority of cases (59.4%), the uncinate process was found attached to the lamina papyracea. The mean diameter of the frontal ostium was 4.6 ± 1.6 mm. The angle formed by the plane of the frontal ostium to the floor of the nose was 26º ± 5.9º; the distance of the frontal beak to the anterior nasal spine was 46.50 ± 5.7 mm, while the distance of the frontal beak from the columella was 48.7 ± 4.8 mm. The corresponding angle between the frontal beak to the nasal floor (at the anterior nasal spine) was 70º ± 5º, while this decreased to 56.6º ± 7.5º when the columella was the reference point. Pneumatization of the agger nasi was seen in 90% of specimens. The mean distance of the anterior ethmoidal artery was 9.0 ± 1.2 mm from the frontal beak, and 8.4 ± 1.8 mm from the posterior rim of the frontal ostium. These morphometric data should be of help in endoscopic surgery for accurate and safe negotiation of the frontal sinus drainage tract and for avoiding vascular injury.

Key words: Agger nasi – Frontal sinus – Frontal ostium – Frontal recess – Uncinate process

INTRODUCTION

Endonasal frontal sinus surgery aims to create adequate access to the frontal sinus, to remove specific pathologic processes, and to establish permanent and sufficient drainage and ventilation (Weber, 2009). The variety of surgical procedures advocated for the treatment reflects the difficulty in successfully treating this problem (Jacobs et al, 2000). The frontal recess and frontal sinus show the variability and very complex nature of the cellular patterns (van Alyea, 1946; Lang, 1989; Stammberger et al., 1995). A clear understanding of the anatomy of the drainage pathway of the frontal sinus is essential for successful surgical outcome. Thus, the present study was undertaken to study the anatomy of the nasofrontal region in cadaveric dissections performed in North-West Indian population.

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Materials and Methods

Adult male cadavers of North-West Indian populations were taken for study. Thirty-two mid-sagittal sections of cadaver heads were used for dissection and measurements. The nasal septum and middle turbinate were removed from each of the specimen. The drainage from the frontal sinus was identified and followed to its opening in the nose. The measurements were performed with the help of a digital vernier caliper (accurate up to .02 mm) and a protractor. Dissection was performed to identify the following:

A. Drainage pattern of the frontal sinus
   1. Anterior to the uncinate process (UP) (Fig. 1):
      i. In the region of the agger nasi
      ii. Into a space formed by the uncinate process postero-laterally and superior attachment of the middle turbinate anteriorly
   2. Posterior to the uncinate process (Fig. 2):
      i. Into the ethmoid infundibulum or close to the hiatus semilunaris
      ii. Into the ethmoid cells
   3. Hypoplastic frontal sinus

B. Upper attachment of the uncinate process

C. The agger nasi cells:
   1. Pneumatized or not
   2. Number of cells present
   3. Drainage of the agger nasi into the infundibulum or frontal recess

D. Relevant linear and angular measurements (Fig. 3):
   1. Diameter of the frontal ostium measured as the distance between the frontal beak and the posterior rim of the frontal ostium
   2. Angle formed by the plane of the frontal ostium to the floor of the nose
   3. Distance of the frontal beak to the anterior nasal spine
   4. Angle of the frontal beak to the nasal floor with the anterior nasal spine as a reference point
   5. Distance of the frontal beak to the base of the columella
   6. Angle of the frontal beak to the nasal floor with the columella as a reference point
   7. Distance of the anterior ethmoidal artery from the frontal beak
   8. Distance of the anterior ethmoidal artery from the posterior rim of the frontal ostium

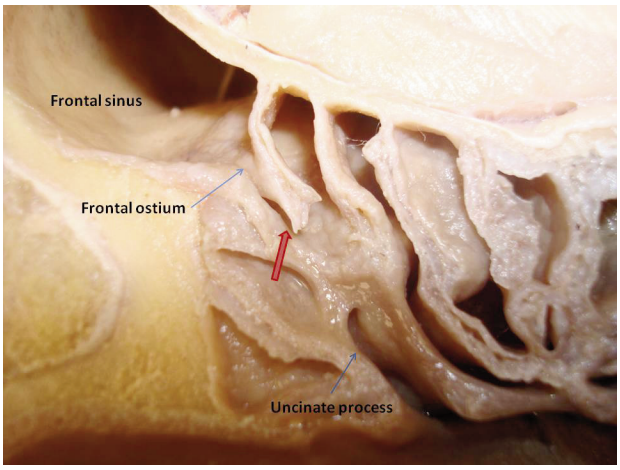

Fig. 1. The superior end of the uncinate process is attached laterally, forming a cul-de-sac. The frontal sinus can be seen draining anteriorly to the uncinate process. The frontal ostium and uncinate process are marked by the arrow.

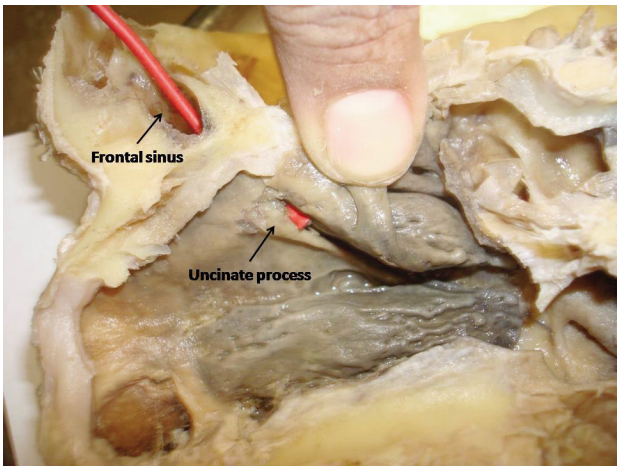

Fig. 2. The frontal sinus drains posteriorly to the uncinate process into the frontal recess. The upper end of the uncinate process is attached to the base of skull.

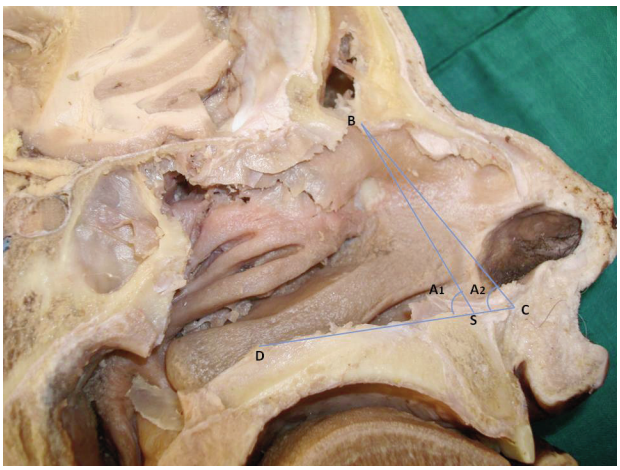

Fig. 3. Image showing: 1. Distance of the frontal beak (B) to the anterior nasal spine (S). 2. Angle of the frontal beak to the nasal floor with the anterior nasal spine as reference point (BSD). 3. Distance of the frontal beak (B) to the base of the columella (C). 4. Angle of the frontal beak to the nasal floor with the columella as reference point (BCD).

Results

Drainage pattern, distance and angles related to the frontal sinus

The frontal sinus drained anteriorly to the uncinate process (UP) in 19 specimens (59.4%). These specimens could be further subdivided into those with the sinus draining in the region of the agger nasi (11 specimens; 34.4%), and those draining into a space formed by the uncinate process postero-laterally and the superior attachment of the middle turbinate anteriorly (08 specimens; 25%). The frontal sinus was found to drain posterior to the UP in 13 specimens (40.6%). In these, in 12 specimens (37.5%) it drained into the ethmoid infundibulum or close to the hiatus semilunaris, while in one specimen the agger nasi sinus drained directly into the ethmoid cells. None of the specimens exhibited a hypoplastic frontal sinus.

The diameter of the frontal ostium was found to range between 2.26 mm and 10.4 mm, with a mean of 4.6 ± 1.6 mm. The angle formed by the plane of agger nasi frontal ostium to the floor of the nose was 26° ± 5.9°, ranging between 13° and 41°. The distance of the frontal beak to the anterior nasal spine ranged between 39.8 mm and 60.8 mm, with a mean of 46.5 ± 5.7 mm. The corresponding angle to the nasal floor was 70° ± 5° ranging between 55° and 80°. When the base of agger nasi columella was taken as the reference point, the distance to the frontal beak increased: 48.7 ± 4.8 mm, with range of 40.5-63.5. In comparison, the angle of the frontal beak to the agger nasi nasal floor decreased, with a mean value of 56.6° ± 7.5° (range 42°-71°).

Upper attachment of the uncinate process (UP) (Fig. 1 and Fig. 2)

The upper end of the UP was found to extend to the ethmoidal roof in 12 specimens (37.5%), but in most cases (19 specimens; 59.4%) it was attached to the lamina papyracea in the form of a dome. The uncinate process was absent in one specimen.

Pneumatization pattern of the agger nasi

The agger nasi featured an absence of pneumatization in 3 cases (9.4%), while it was pneumatized in the other 29 (90.6%) specimens: 5 specimens had one cell each; 11 specimens had two cells each; 3-4 cells were found in 5 specimens, and 3 cases had 5 cells each. Thus, 50% of the specimens demonstrated 1-2 cells in the agger nasi. The agger nasi cells drained into the frontal recess in most of the specimens (26; 81.3%), while in the rest it drained into the infundibulum.

Anterior ethmoidal artery

The artery was found to be present just behind the point where the anterior wall of the bulla meets the skull base. The mean distance of the anterior ethmoidal artery from the frontal beak was 9.0 ± 1.2 mm, with a range between 3.3 mm and 19.2 mm. The distance between the posterior rim of the frontal ostium and the anterior ethmoidal artery ranged from 0.19 mm to 9.6 mm, with a mean value of 8.4 ± 1.8 mm.

Discussion

With the advent of functional endoscopic sinus surgery (FESS) for frontal sinus disease, the concepts of frontal recess and frontal infundibulum have emerged and received considerable attention. The walls and boundaries of the frontal recess belong to the surrounding structures, making the frontal recess a passive space and not a true duct. The degree of patency of the frontal recess is largely determined by these adjacent structures. Extensive pneumatization of the ethmoid bulla posterior to the recess and the agger nasi anterior to the recess gives the space a duct-like appearance in parasagittal sections. The inferior third of the frontal sinus drainage pathway is the anatomic location responsible for most cases of frontal sinusitis (Stammberger et al., 1995; Zeifer, 1998). One of the major causes of surgical failure in creating a permanent large drainage site is the formation of scar tissue within the frontal recess. Successful endoscopic frontal sinusotomy requires a deep anatomical knowledge and considerable surgical skills and accuracy (Stammberger, 1999; Kim et al., 2001).

Determination of the surgical anatomy of the fontal sinus drainage pathways is necessary since curettes and probes are usually placed along this drainage tract. Failure to identify the roof of the ethmoidal cells may result in the probe penetrating and injuring the skull base. The frontal sinus drainage pathway can be plotted best by taking axial cuts on CT, starting well above the frontal ostium. The position of the various cells in the pathway is confirmed by referring to the coronal and parasagittal scans (Wormald, 2005). In the

present study the sinus drained anteriorly to the UP in about 60% of the specimens, and posteriorly to it in the remaining 40% of cases. This was similar to previous reports by Kasper (1936) and Kim et al. (2001), although these findings are different from those reported by Lee et al. (1997), and Gaffar et al. (2001) (Table 1). Lang (1989) found that the frontal sinus drained towards the semilunar hiatus in 67.7%, while in 33.3% it drained outside the semilunar hiatus. The terminology used to define the drainage area might also add to the variation in the results. The difference in the drainage tract of the frontal sinus determines the likelihood of the frontal sinus being affected by accompanying ostiomeatal complex inflammation (Gaffar et al., 2001). A clear understanding of the common drainage patterns of the frontal sinus is essential so that each individual case can be assessed with these patterns in mind, and a clear surgical plan can be developed and executed (Wormwald, 2005).

The distance of the frontal ostium from the nasal aperture is indicated by the distance of the frontal beak from the anterior nasal spine. These two bony points were chosen to ensure accuracy and reproducibility. The distances from the columella were included, since clinically they are easier to apply. The distance of the frontal beak was found to be 46.5 mm (39.8-60.8 mm) from the anterior nasal spine and 48.7 mm (40.5-63.5 mm) from the columella. The corresponding angles to the nasal floor were found to be 70° and 57° respectively. Gaffar et al. (2001) have reported the distances from the frontal beak to the anterior nasal spine as 50.6 mm (38-62 mm), with an angle of 69°, and the distance from the columella to be 57.2 mm (47-69 mm), with an angle of 55°. Our findings suggest that during endoscopic procedure surgeons can expect to locate the frontal ostium within 4-5 cm from the nasal aperture, with the endoscope angled at 50°-70° to the nasal floor.

Identification of anatomical variations of the uncinate process and removal of its upper part are essential for locating the frontal sinus ostium, and hence for creating surgical access to the frontal sinus (Friedman et al., 2000). The upper part of the uncinate process is a dependable anatomic landmark for the localization of the frontal sinus ostium in CT scans and endoscopic frontal sinus surgery (Bing et al., 2008). The upper end of the UP was found to be attached superiorly to the base of the skull in about 40% of cases. In the majority (60%) of specimens it inserted laterally into the lamina papyracea. Lateral attachment of the UP creates a blind cul-de-sac known as the terminal recess, which has been described graphically as an eggshell in an inverted egg-cup by Stammberger (1999) (Fig. 1). Lessa et al. (2007) found UP attachment into the lamina papyracea in 76% of cases, while Gaffar et al. (2001) reported that upper end of the UP had a superior attachment in 83% and a lateral attachment in about 17% of cadavers. In yet

Table 1. Comparative analysis of studies on frontal sinus outflow pathway anatomy.

Study	Demographic profile	Frontal sinus drainage		Upper attachment of UP		Frontal ostium		Frontal beak to anterior nasal spine		Frontal beak to columella	
		Anterior to UP	Posterior to UP	Superior	Lateral	Diameter	Angle	Distance	Angle	Distance	Angle
Lessa et al.	Black-16% Brown-34% White-50%				76.3%						
Kim et al.	Korean	59%	40%								
Jacobs et al.	NA					10.4					
Lee et al.	Whites-75.6% Black-24.4%	29.3%	68.3%							*36.5 #41.0	*58 ° #65°
Kasper	NA	57%	38%								
Gaffar et al.	Egyptian	23.3%	63.3%	83.3%	16.7%	5.6	22 °	50.6	69 °	57.2	55 °
Yang et al.	Chinese			16%	41%	8.5	60.8	70 °			
Present study	Indian	59.4%	40.6%	37.5%	59.4%	4.6	26 °	46.5	70 °	48.7	57 °

UP – Uncinate process NA – Not available
The distances and diameters are in millimeter
*Specimens with frontal sinus drainage anterior to UP
Specimens with frontal sinus drainage posterior to UP

another study by Yang, in 16% of cases the UP extended superiorly while in 41% of cases it was found to be attached laterally, forming a cul-de-sac (Table 1). Lessa et al. (2007) describe the terminal recess as a major anatomical structure that makes recognition of the frontal ostium difficult. The frequency of the terminal recess in the population makes its identification fundamental for correct dissection and access to the frontal ostium (Kasper, 1936). The term agger nasi is Latin for nasal mound. When viewed in anterior rhinoscopy, the eminence located on the lateral nasal wall across from the leading edge of the middle turbinate represents this nasal mound (Stammberger, 1991). According to Wormald (2003), the agger nasi cell forms the key to understanding the anatomy of the frontal recess, since the agger nasi can be readily identified on CT scans and in patients during surgery. The course, width, and depth of the frontonasal pathway in adults are determined by the embryologic pneumatization pattern of the anterior ethmoid cells and the development of the surrounding bony plates. Generally, direct frontal sinus development from the embryologic frontal recess is associated with minimal anterior ethmoid cell pneumatization, and a wider communication with the middle meatus. Conversely, frontal sinus development from one of the several embryologic frontal furrows results in a narrower communication due to the presence of surrounding anterior ethmoidal cells (Schaffer, 1916). Pneumatization of the agger nasi augments its medial bulging, thus making it more difficult to approach the frontal ostium endoscopically. The agger nasi cells can also be pneumatized posteriorly and laterally to narrow the frontal recess and impinge on frontal sinus drainage. Successful endoscopic frontoethmoidectomy for anatomic impingement is generally accomplished by resection of the thin posterior and superior walls of the agger nasi cell along with the face of the ethmoidal bulla (Jacobs et al., 2000; McLaughlin, 2001). Many of the studies report some degree of agger nasi pneumatization in almost 100% of ethmoid sinuses (Bolger et al., 1991; Jacobs et al., 2000; Lessa et al., 2007). Gaffar et al. (2001) found agger nasi pneumatization in 77% of cases. In the present study 90% of specimens demonstrated pneumatization in the region of the agger nasi.

Knowledge of the probable location of anterior ethmoidal artery is necessary to avoid injury to this vessel during endoscopic frontal sinus surgery. During ethmoid surgery the anterior ethmoid artery may be observed in the roof of the ethmoid 2 to 4 mm from the posterior extent of the frontal recess (Lee et al., 1997). The artery continues medially to penetrate the lateral lamella of the cribriform plate and then travels anteriorly in the ethmoidal sulcus, where it gives off a meningeal branch to the dura mater and occasionally to the falx cerebri before passing into the nasal cavity (Som and Curtin, 1996). The weakest point of the entire skull base is the point at which the anterior ethmoidal artery leaves the ethmoid and proceeds anteriorly in the ethmoidal sulcus of the olfactory fossa (Gupta et al., 2012). Stammberger (1991) found that in 29 of 40

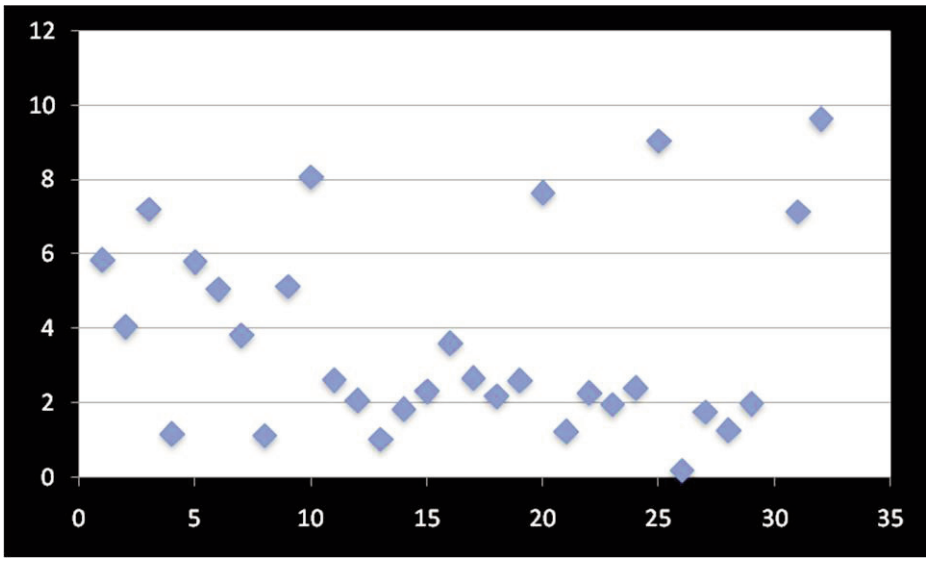

Fig. 4. Scatter diagram depicting the distance between the posterior rim of the frontal ostium and the anterior ethmoidal artery on the Y axis. Number of specimens is on the X axis. In about 75% of specimens this distance was 4mm or less. All the values are in mm.

skulls the anterior ethmoidal artery was surrounded by dura along its entire ethmoidal extent, whereas in 8 of the 40 skulls it entered the dura only during its passage through the ethmoidal sulcus. In only 3 of 40 cases did the artery remain extradural along its entire course. Therefore, injury to the anterior ethmoid artery poses two evident risks, namely, CSF leakage and hemorrhage, resulting in poor surgical visualization. Moreover, if injured close to the orbit, the vessel can retract intraorbitally and lead to intraorbital hematoma and blindness (McLaughlin, 2001). In the present study, the mean distance of the anterior ethmoidal artery from the frontal beak was 9.0 ± 1.2 mm, with a range between 3.3 mm and 19.2 mm. The distance between the posterior rim of the frontal ostium and the anterior ethmoidal artery ranged from 0.19 mm to 9.6 mm. In about 75% of specimens this distance was 4mm or less (Fig. 4), indicating the proximity of the artery to the ostium. Lee et al. (1997), reported similar results with distance of the ethmoidal artery from the frontal beak ranging from 5-20 mm (15.2 ± 3.6 mm) and the distance from the posterior rim of the frontal ostium to the artery as 10.5 ± 3.2 with a range of 1-15 mm.

The variations in the patterns and morphometry of the frontal sinus outflow tract in different studies may be related to the ethnic diversity of the population group (Table 1). The present study used cadavers from a North-West Indian population. In some reports, there is no mention about the ethnic identity of the study group while other authors have addressed Caucasian, Black, Korean, Chinese or Egyptian population. Lang (1989) notes that different ethnicities have a different proportion of aplastic frontal sinuses and drainage patterns. It is thus important to have a good knowledge of the anatomical details of the population in different regional and ethnic groups for accurate surgical planning. The present study documents the patterns of frontal sinus drainage and related morphometric measurements for the localization of the drainage sites in a North-West Indian population. These data should help endoscopic surgeons to achieve good clinical results, and to avoid complications.

References

Bing Z, Demin H, Huachao L, Qian H, Luo Z, Ming L, Yongjie Z (2008) Endoscopic anatomic characterization of the frontal recess and its implications in frontal sinus surgery. *ORL J Otorhinolaryngol Relat Spec,* 70: 84-90.

Bolger WE, Butzin CA, Parsons OS (1991) Paranasal sinus bony anatomic variations and mucosal abnormalities: CT analysis for endoscopic sinus surgery. *Laryngoscope,* 101: 56-64.

Friedman M, Landsbreg R, Schults RA, Tanyeri H, Caldarelli DD (2000) Frontal sinus surgery:endoscopic technique and preliminary results. *Am J Rhinol*, 14: 393-403.

Gaafar H, Abdel-Monem MH, Qawas MK (2001) Frontal sinus outflow tract "anatomic study". *Acta Otolaryngol*, 121: 305-309.

Gupta AK, Bansal S, Sahni D (2012) Anatomy and its variations for endoscopic sinus surgery. *Clin Rhinol An Int J*, 5: 55-62.

Jacobs JB, Lebowitz RA, Sorin A, Hariri S, Holliday R (2000) Preoperative sagittal CT evaluation of the frontal recess. *Am J Rhinol*, 14: 33-37.

Kasper KA (1936) Nasofrontal connections: a study of one hundred consecutive dissections. *Arch Otolaryngol*, 23: 322-343.

Kim KS, Kim HU, Chung IH, Lee JG, Park IY, Yoon JH (2001) Surgical anatomy of the nasofrontal duct: anatomical and computed tomographic analysis. *Laryngoscope*, 111: 603-608.

Lang J (1989) Clinical anatomy of the nose, nasal cavity and paranasal sinuses. Thieme Medical Publishers Inc., New York.

Lee D, Brody R, Har-El G (1997) Frontal sinus outflow anatomy. *Am J Rhinol*, 11: 283.

Lessa MM, Voegels RL, Cunha Filho B, Sakae F, Butugan O, Wolf G (2007) Frontal recess anatomy study by endoscopic dissection in cadavers. *Braz J Otorhinolaryngol*, 73: 204-209.

McLaughlin RB Jr, Rehl RM, Lanza DC (2001) Clinically relevant frontal sinus anatomy and physiology. *Otolaryngol Clin North Am*, 34: 1-22.

Schaeffer JP (1916) The genesis, development, and adult anatomy of the nasofrontal region in man. *Am J Anat*, 20: 125-143.

Som PM, Curtin HD (1996) Head and Neck Imaging, 3th ed. Mosby-Year Book, Chicago.

Stammberger H (1991) Functional Endoscopic Sinus Surgery. DC Becker, Philadelphia.

Stammberger H, Kennedv DW, Bolger WE, Clement PA, Hosemann W, Kuhn FA, Lanza DC, Leopold DA, Ohnishi T, Passàli D, Schaefer SD, Wayoff MR, Zinreich SJ (1995) Paranasal sinuses: Anatomic terminology and nomenclature. The Anatomic Terminology Group. *Ann Otol Rhinol Laryngol suppl*, l67: 7-16.

Stammberger H (1999) "Uncapping The Egg"- The endoscopic approach to frontal recess and sinuses. Endo-Press, Tuttlingen.

Van Alyea OE (1946) Frontal sinus drainage. *Ann Otol Rhino Laryngol*, 55: 267-277.

Wormald PJ (2003) The Agger Nasi Cell. The key to understanding the anatomy of the frontal recess. *Otolaryngol Head Neck Surg*, 129: 497-507.

Wormald PJ (2005) Surgery of the frontal recess and frontal sinus. *Rhinology*, 43: 82-85.

Weber R (2009) Endonasal frontal sinus surgery. Part 1: Frontal sinus drainage, types I and II. *HNO,* 57: 739-750.

Yang QT, Shi JB, Kang T, Lü JT, Xu G (2004) Computer-assisted anatomical study of nasofrontal region. *Zhonghua Er Bi Yan Hou Ke Za Zhi*, 39: 349-352.

Zeifer B (1998) Update on sinonasal imaging: anatomy and inflammatory disease. *Neuroimaging Clin N Am*, 8: 607-630.