Relationship between sphenoid sinus volume and accessory septations: a 3D assessment of risky anatomical variants for endoscopic surgery

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ABSTRACT

Sphenoid sinus accessory septations involve serious complications during their removal for the injury of the internal carotid artery (ICA) and the optic nerve (ON). The relationships of this anatomical variant with sphenoid size still remain to be analysed.

Two-hundred and sixty patients (male:female ratio 1:1, aged between 18 and 92 years) were retrospectively assessed. Number of accessory septations and their relationship with ICA and ON was recorded. From each CT-scan the 3D model of sphenoid sinuses was extracted. Pearson's coefficient was calculated to assess a possible correlation between the volume of sphenoid sinuses and the number of septations, separately in males and females ($p<0.05$). Sex-related differences in prevalence of septations inserted onto ICA or ON were assessed through Chi-square test ($p<0.05$). Differences in volume between patients with and without ICA or ON septal insertions were assessed through Mann-Whitney, separately for males and females ($p<0.05$).

In most of cases two septations were found (24.6%), whereas only 21.9% of patients did not show any septum. ICA and ON septal insertions were found in 20.8% and 7.7% of cases, respectively. Number of septations significantly increased with sinus volume, both in males and in females ($p<0.001$). Moreover, volume was significantly higher in patients with ICA septal insertion ($p<0.001$), whereas no differences were found between subjects with and without ON septal insertion ($p>0.05$).

The present study first proved that septations and probability of ICA insertion are related with sphenoid volume. On the other side, ON insertion does not depend upon sphenoid sinuses size.

Keywords: sphenoid sinus, septations, endoscopic sinus surgery, CT-scan, 3D segmentation

INTRODUCTION

Sphenoid sinuses are pneumatic spaces within the body of sphenoid bone. They start to develop at the 3^{rd}-4^{th} month of foetal life as bilateral concavities of the nasal mucosa (Elwany et al., 1983; Vidic, 1968). The formation of air spaces begins at the 3^{rd}-4^{th} year of life and ends between 12 and 16 years (Jaworek-Troc et al., 2018). Sphenoid sinuses represent very variable structures in the human body and may be affected by several morphological and metrical variants (Jaworek-Troc et al., 2018). Sphenoid sinuses are considered the most variable structure human body (Teatini et al., 1987); not only they widely vary in shape and size, but also their pneumatization degree may range from absent to extensive (Hewaidi and Omami, 2008), and may include the anterior clinoid processes, pterygoid processes, greater wings, clivus, as well as also as vomer, palatine and occipital bone (Yune et al., 1975; Fujoka and Jung, 1978). In addition, these air spaces may be further segmented by accessory septa, showing various geometry and orientation (Bonneville and Dietemann, 1981).

In the last years sphenoid sinuses have gained a novel attention for the progressive diffusion of endoscopic endonasal transsphenoidal approach, widely recognized as a reference surgical technique (Jankowski et al., 1992; Perez-Pinas et al., 2000). In fact, it is minimally invasive and proved to be less traumatic than traditional microsurgical approaches (Unal et al., 2006). With time the fields of applications progressively increased, including not only the removal of pituitary tumors (Jankowski et al., 1992), but also the treatment of lesions in other skull areas, such as anterior and posterior cranial fossa, cavernous sinus and clivus (Jho, 2001; Lu et al., 2011).

However, this surgical approach is affected by limits and risks of complications, mainly due to the high anatomical variability of sphenoid sinuses (Anusha et al., 2014; Gibelli et al., 2019). Sphenoid sinuses are separated by the main septum, but accessory septa may be found within each sinus (Jaworek-Troc et al., 2018). The possible presence of intrasphenoid accessory septa represents the most serious surgical issue for several reasons: they may reduce the space for collocation and movement of surgical instrumentation and therefore they are often removed. In fact, the technique is based on the creation of a single rectangular cavity within the sphenoid sinuses, adequate to host the devices, including the endoscope. The correct placement of the endoscope is critical for a sufficient visualization and maneuverability of instruments (Kassam et al., 2005). However, septations may insert on the bone wall covering the internal carotid artery (ICA) and the optic nerve (ON). In these cases, the violent cracking of these septations during endoscopic procedures may lead to damage of ICA and ON, with consequent uncontrollable bleeding and blindness (Unal et al., 2006; Hudgins, 1993). In detail, the injury of ICA provides the most catastrophic consequences and is reported in 0.4-1.1% of cases of transsphenoidal surgery, with a mortality rate of 14% and a morbidity rate of 24% (Dusick et al., 2007; Oskouian et al., 2006; Raymond et al., 1997).

Although literature has explored the frequency of sphenoid septations in different populations (Jaworek-Troc et al., 2018; Elwany et al., 1983; Abdullah et al., 2001; Mutlu et al., 2001; Sareen et al., 2005; Seddighi et al., 2014; Hamid et al., 2008; Lee et al., 2003), very few studies have analysed the frequency of ICA and ON insertion (Unal et al., 2006; Elwany et al., 1999; Basak et al., 1998; Fernandez-Miranda et al., 2009). In addition, at our knowledge no study has analysed the possible relationship between sphenoid septations, possible insertion on ICA and ON bone walls and general size of sphenoid sinus. Yet verifying the anatomical characteristics of sphenoid sinuses which may be linked to septations and insertion of ICA and ON is crucial for reducing the risk of involuntary injury of these sensitive structures.

This study aims at assessing the prevalence of septations and ICA and ON septal insertion in a CT-scan population, verifying the possible relationships between these anatomical variants and sphenoid volume. The results may be useful for improving the knowledge of these important anatomical variants and to improve endoscopic transsphenoidal surgical techniques.

MATERIALS AND METHODS

For the study 260 patients (equally divided between males and females) were retrospectively assessed from a hospital CT-scan database. Subjects were aged between 18 and 92 years (49.0±19.4 years and 52.2±21.0 years, respectively for males and females). Maxillofacial CT-scans were chosen, performed through a second generation dual-source scanner, Somatom Definition Flash (Siemens, Forchheim, Germany) with the following parameters of acquisition: kV: 120, mAs: 320, collimation: 40 x 0.6 mm, tube rotation: 1 sec;

reconstruction thickness: 3 mm; reconstruction filters: H21s smooth for soft tissues and H60 sharp for bone. CT-scans were performed in most of cases as a screening of cranial fractures in traumatic events (57.3%), for the diagnosis and assessment of chronic sinusitis (20.0%), or for neurological symptoms (12.7%). Patients affected by congenital or acquired pathologies involving the sphenoid sinuses as well as by traumatic injuries were excluded from the study.

The study follows local and international laws and guidelines (Helsinki Declaration) and was approved by the local ethical committee (7331/2019).

Each CT-scan was analysed to assess the number of intrasphenoidal accessory septa and their possible relationship with the internal carotid artery and the optic nerve. Septations were considered accessory when they divided the intrasphenoidal space and did not follow the intersphenoid septum. A septum was considered inserted onto ICA or ON whenever it showed a contact with them, in transversal and/or coronal planes (Fig. 1).

From each patient the 3D model of sphenoid sinuses was extracted through ITK-SNAP free software (Fig. 2): the segmentation protocol followed a semi-automatic approach through the collocation of “seeds” within each sinus and the automatic inclusion of the entire air space according to grey level differences with the surrounding tissues (Yushkevich et al., 2006; Gibelli et al., 2018).

Volume of sphenoid sinuses was automatically calculated through VAM® software (Vectra Analysis Module, version 2.8.3, Canfield Scientific®, Inc.).

Pearson's correlation coefficient was calculated between the volume of sphenoid sinuses and the number of accessory septations, separately in males and females.

Possible differences in prevalence of septations inserted onto ICA or ON according to sex were assessed through Chi-square test. In addition, Mann-Whitney (MW) test was applied to assess possible differences in volume between subjects showing a close contact between septa and ICA or ON and subjects without any septal insertion, separately for males and females.

All the statistical analyses were performed through SPSS® software (IBM®, version 25) with a significance level of 5%.

RESULTS

No significant age difference was observed between males and females (Student's t-test, $p>0.05$).

Results are exposed in Tables 1 and 2. In total, 306 accessory septations were found in males, and 335 in females (on average two for person), almost equally divided according to side (51.3% on the right side versus 48.7% on the left side for males, 52.5% versus 47.5% for females). The maximum number of septations was nine, both in males and in females; most of subjects showed 2 accessory septations (24.6%). Only 22.0% of subjects did not show any accessory septum (26.2% in males, 17.7% in females).

Almost one fifth of the entire population showed a septal insertion on ICA, whereas in less than one tenth an insertion on ON was observed (Table 1). ICA septal insertion was most frequently bilateral (14 cases out of 31 in males, 10 out of 23 in females), whereas ON insertion was more often on the left side (4 cases/ 7 in males, 7 cases/ 13 in females). No statistically significant difference was found in prevalence of ICA and ON septal insertion between males and females (Chi-square: 1.5, $p=0.22$; Chi-square: 1.95, $p=0.16$, respectively).

Table 2 shows volumes of sphenoid sinuses according to number of accessory septations and their possible insertion on ICA and ON. Septations significantly increased in number with sinus volume, both in males and in females, with Pearson's coefficients of 0.48 and 0.39, respectively ($p<0.001$).

Volume was significantly larger in subjects with septal insertion on ICA both in males and females (MW: 715.5, $p<0.001$; MW: 655.0, $p<0.001$, respectively); on the other side, no significant differences were found between subjects with and without septal insertion on ON, in both sexes (males MW: 332.5, $p=0.312$; females MW: 551.0, $p=0.104$).

DISCUSSION

Endonasal transsphenoidal surgery is progressively widening its fields of applications; however, the surgical procedures strongly depend upon anatomical variants of sphenoid sinus, among which accessory septations are the most critical because of their possible strict relationship with ICA and ON (Kassam et al., 2005).

Accessory septa have been widely analysed by literature: Jaworek-Troc et al., (2018) found accessory septations in 78.0% of cases in a Polish population, being the variant with two septa the most prevalent form (32.9%), in accordance with the present study. Similar data were reported by Abdullah et al. in a Malaysian sample (2001) with 80.0% of subjects showing accessory septa and 30.0% with two septa. High percentage of septations were reported also by Elwany et al. in an Egyptian group (1983, 76.0%) and Seddighi et al. in an Iranian one (2014, 71.9%). Lower prevalence of this anatomical variant was reported in the Korean (Lee et al., 2003, 52.0%) and Turkish (Mutlu et al., 2001, 42.0%) populations, highlighting the importance of the ethnic variability in determining this phenomenon (Jaworek-Troc et al., 2018).

Surprisingly, less data is available concerning the frequency of ICA and ON septal insertion: Abdullah et al. (2001) reported ICA insertion in 31.0% of subjects, similarly to the present study. However, Fernandez-Miranda et al. (2009) observed ICA in 89.0% of patients. Unal et al. (2006), Elwany et al. (1999) and Basak et al. (1998) found ICA insertion respectively in 26.7%, 12.9% and 8.0% of sinuses, considering separately the right from the left side. Even fewer information is available about the prevalence of ON insertion: Unal et al. (2006) reported it in 19.6% of sinuses, Elwany et al. (1999) in 5.9% and Basak et al. (1998) in 8.0%. The present results and the comparison with literature confirms that the risky variants of sphenoid septations are not rare and therefore should be considered with caution in the management of endoscopic transsphenoidal procedures.

The present study adds a novel contribution to the existing literature concerning sphenoid septations, exploring the relationships with sphenoid sinus size: in detail, the number of accessory septations proved to significantly correlate with sphenoid volume. In other words, the largest the sphenoid sinus, the highest the number of accessory septations which may be found. This result proves that septations are created contextually during the development of the sphenoid sinuses, and that they increase in number with the enlargement of sphenoid air spaces.

The second important result concerns the relationships between sphenoid volume and ICA and ON insertions: frequency of ICA insertion increases with volume of sphenoid sinuses, whereas the same was not verified for ON insertion. These data are of great importance, as they suggest caution in the managing surgical techniques to avoid optic nerve injuries: ICA insertion in fact can be expected in case of large sphenoid sinuses, whereas ON insertion may occur also in small size sinuses. In this case, detailed pre-operative radiological analysis is crucial to assess possible septations and verify their insertion on ICA or ON (Unal et al., 2006).

This study has an important limit which consisted in including every type of accessory septation in the analysis: however, the need for septation removal and the definition of risky septation variant depends upon the type of surgical intervention and its specific target. In the present study we aimed at assessing generally the profile of sphenoid septations, verifying the prevalence of ICA and ON insertion, independently from the possible surgical procedure.

In conclusion, the present study first analysed the relationships between risky sphenoid septation profiles and the volume of sphenoid sinuses. Results confirmed once more that size and shape of sphenoid sinuses are fundamental in managing the transsphenoidal surgical procedure, as also suggested by literature (Hamid et al., 2008).

CONFLICT OF INTEREST

No conflict of interest.

REFERENCES

Abdullah BJ, Arasaratnam A, Kumar G, Gopala K. 2001. The sphenoid sinuses: computed tomographic assessment of septation, relationship to the internal carotid arteries and sidewall thickness in the Malaysian population. J HK Coll Radiol 4:185-188.

Anusha B, Baharudin A, Philip R, Harvinder S, Mohd Shaffie B. 2014. Anatomical variations of the sphenoid sinus and its adjacent structures: a review of existing literature. Surg Radiol Anat 36:419–427.

Basak S, Karaman CZ, Akdilli A, Mutlu C, Odabasi O, Erpek G. 1998. Evaluation of some important anatomical variations and dangerous areas of the paranasal sinuses by CT for safer endonasal surgery. Rhinology 36:162-167.

Bonneville JF, Dietemann JL. 1981. Radiology of the sella turcica. Berlin: Springer.

Dusick JR, Esposito F, Malkasian D, Kelly DF. 2007. Avoidance of carotid artery injuries in transsphenoidal surgery with the Doppler probe and micro-hook blades. Neurosurgery 60:322-328.

Elwany S, Elsaeid I, Thabert H. 1999. Endoscopic anatomy of sphenoid sinus. J Laryngol Otol 113:122-126.

Elwany S, Yacout YM, Talaat M, El-Nahass M, Gunied A, Talaat M. 1983. Surgical anatomy of the sphenoid sinus. J Laryngol Otol 97:227-241.

Fernandez-Miranda JC, Prevedello DM, Madhok R, Morera V, Barges-Coll J, Reineman K, Snyderman CH, Gardner P, Carrau R, Kassam AB. 2009. Sphenoid septations and their relationship with internal carotid arteries: anatomical and radiological study. Laryngoscope 119:1893-1896.

Fujoka M, Yung L. 1978. The sphenoid sinuses: radiographic patterns of normal development and abnormal findings in infants and children. Radiology 129:133-139.

Gibelli D, Cellina M, Gibelli S, Oliva AG, Codari M, Termine G, Sforza C. 2018. Volumetric assessment of sphenoid sinuses through segmentation on CT-scan. Surg Radiol Anat 40:193-198.

Gibelli D, Cellina M, Gibelli S, Cappella A, Oliva AG, Termine G, Dolci C, Sforza C. 2019. Relationship between sphenoid sinus volume and protrusion of internal carotid artery and optic nerve: a 3D segmentation study on maxillofacial CT-scans. Surg Radiol Anat 41:507-512.

Hamid O, El Fiky L, Hassan O, Kotb A, El Fiky S. 2008. Anatomic variations of the sphenoid sinus and their impact on transsphenoidal pituitary surgery. Skull Base 18:9-15.

Hewaidi GH, Omami GM. 2008. Anatomical variation of sphenoid sinus and related structures in Libyan population: CT scan study. Libyan J Med 3:128-133.

Hudgins PA. 1993. Complications of endoscopic sinus surgery. Radiol Clin North Am 31:21-32.

Jankowski R, Auque J, Simon C. 1992. Endoscopic pituitary tumor surgery. Laryngoscope 102:198-203.

Jaworek-Troc J, Zarzecki M, Mroz I, Troc P, Chrzan R, Zawilinski J, Walocha J, Urbanik A. 2018. The total number of septa and antra in the sphenoid sinuses – evaluation before the FESS. Folia Med Cracov 3:67-81.

Jho HD. 1999. Endoscopic pituitary surgery. Pituitary 2:139-154.

Kassam AB, Snyderman CH, Mintz A, Gardner P, Carrau RL. 2005. Expanded endonasal approach: the retrocaudal axis. Part I. Crista galli to the sella turcica. Neurosurg Focus 19:E3.

Lee JC, Chuo PI, Hsiung MW. 2003. Ischemic optic neuropathy after endoscopic sinus surgery: a case report. Eur Arch Otorhinolaryngol 260:429-431.

Lu Y, Pan J, Qi S, Shi J, Zhang X, Wu K. 2011. Pneumatization of the sphenoid sinus in Chinese: the differences from Caucasian and its application in the extended transsphenoidal approach. J Anat 219:132-142.

Mutlu C, Unlu HH, Goktan C, Tarhan S, Egrilmez M. 2001. Radiologic anatomy of the sphenoid sinus for intranasal surgery. Rhinology 39:128-132.

Oskouian RJ, Kelly DF, Laws ER. 2006. Vascular injury and transsphenoidal surgery. Front Horm Res 34:256-278.

Perez-Pinas I, Sabatè J, Carmona A, Catalina-Herrera CJ, Jimenez-Castellanos J. 2000. Anatomical variations in the human paranasal sinus region studied by CT. J Anat 197:221-227.

Raymond J, Hardy J, Czepko R, Roy D. 1997. Arterial injuries in transsphenoidal surgery for pituitary adenoma: the role of angiography and endovascular treatment. AJNR Am J Neuroradiol 18:655-665.

Sareen D, Agarwall AK, Kaul JM, Sethi A. 2005. Study of the sphenoid sinus anatomy in relation to endoscopic surgery. Int J Morphol 23:261-266.

Seddighi A, Seddighi AS, Mellati O, Ghorbani J, Raad N, Soleimani MM. 2014. Sphenoid sinus: anatomic variations and their importance in transsphenoidal surgery. Int J Neurosci J 1:31-34.

Teatini G, Simonetti G, Salvolini U, Masala W, Meloni F, Rovasio S, Dedola GL. 1987. Computed tomography of the ethmoid labyrinth and adjacent structures. Ann Rhinol Laryngol 96:239-250.

Unal B, Bademci G, Bilgili YK, Batay F, Avci E. 2006. Risky anatomic variations of sphenoid sinus for surgery. Surg Radiol Anat 28:195-201.

Vidic B. 1968. The postnatal development of the sphenoidal sinus and its spread into the dorsum sellae and posterior clinoid processes. Am J Roentgenal Radium The Nucl Med 104:177-183.

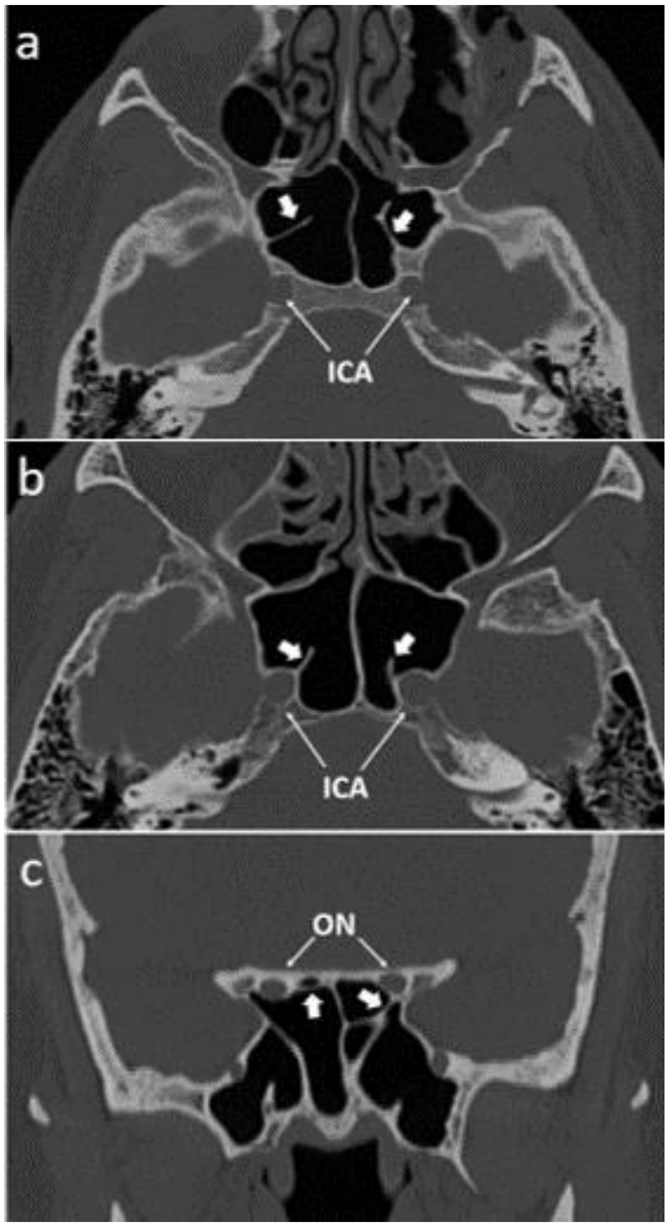
Yune H, Holden R, Smith J. 1975. Normal variations and lesions of the sphenoid sinus. Am J Roentgenol Radium Ther Nucl Med 124:129-138.

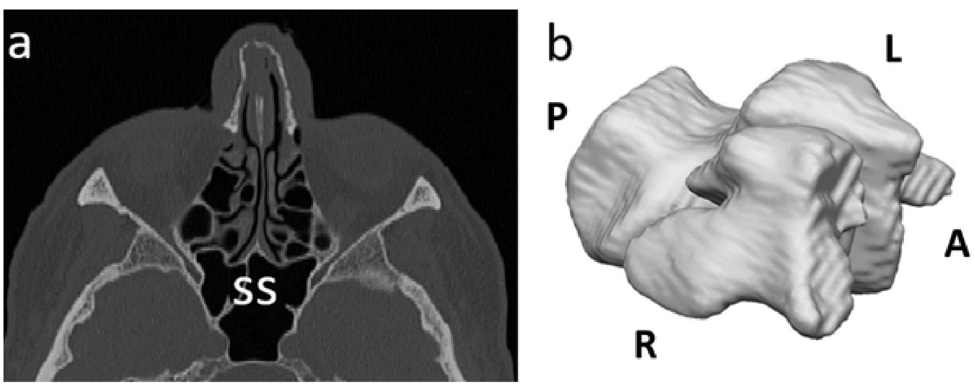
Yushkevich PA, Piven J, Hazlett HC, Smith RG, Ho S, Gee JC, Gerig G. 2006. User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. Neuroimage 31:1116-1128.

LEGEND TO FIGURES

Fig. 1: example of different types of septations: a) transverse plane: two accessory septations within sphenoid sinuses (thick arrows); b) transverse plane: two accessory septations with insertion on ICA (thick arrows); c) coronal plane: two accessory septations with insertion on ON (thick arrows)

Fig. 2: example of segmentation of sphenoid sinuses (SS): a) CT-scan image on transverse plane; b) segmented 3D model; A: anterior; P: posterior; R: right; L: left


a
ICA
b
ICA
c
ON


a
SS
b
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Number of accessory septations	Males (%)	Females (%)	Total (%)
0	26.2	17.7	21.9
1	10.0	9.2	9.6
2	22.3	26.9	24.6
3	10.8	18.5	14.6
4	15.4	13.8	14.6
5	10.0	6.9	8.5
6	2.3	2.3	2.3
7	2.3	2.3	2.3
8	0.0	1.5	0.8
9	0.8	0.8	0.8
Septal insertion on:	**Males (%)**	**Females (%)**	**Total (%)**
ICA	23.8	17.7	20.8
ON	5.4	10.0	7.7

Table 1: prevalence of accessory septations (divided according to number of septa) and septal insertion on ICA and ON in 130 males, 130 females and the entire population. Intersphenoid septum was not considered as accessory and was not included.

		Volume of sphenoid sinus	
		Males (n=130)	Females (n=130)
No accessory septations	Mean	7.7	6.8
	SD	3.9	3.1
1-3 accessory septa	Mean	9.7	7.7
	SD	4.1	3.0
4-6 accessory septa	Mean	11.1	10.2
	SD	4.7	3.8
7-9 accessory septa	Mean	21.7	10.6
	SD	4.9	2.8
No septations on ICA	Mean	9.0	7.8
	SD	4.3	3.1
Septal insertion on ICA	Mean	13.8	10.6
	SD	5.6	3.7
No septations on ON	Mean	10.0	8.1
	SD	4.9	3.5
Septal insertion on ON	Mean	12.7	9.5
	SD	7.3	2.5

Table 2: volume of sphenoid sinuses according to number of accessory septations and possible insertion on ICA or ON. All the values are expressed in cm^3