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Classification, neurovascular relations and ostia of the sphenoid air sinus: a cadaveric study

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SUMMARY

The sphenoid air sinus is located deep at the base of the skull and is intimately related to delicate neurovascular structures. The purpose of this study was to describe the variations of the sphenoid sinus in relation to pneumatisation within the sphenoid bone, its ostium and the structures related to the walls of the sinus. Twenty-five cadaveric specimens were cut mid-sagittally and studied bilaterally (n=50). The pre-sellar, sellar and post-sellar sphenoid sinus types were observed in 16%, 36% and 48% cases, respectively. The protrusion of the internal carotid artery (ICA) in relation to the sinus walls was observed in 70% cases, while bulges of the optic (ON), maxillary (MN) and Vidian (VN) nerves were observed in 56%, 32% and 22% cases, respectively. Protrusions of ICA, ON and VN were prevalent in post-sellar sinuses and the bulge of MN was prevalent in the sellar sinuses. The ICA had a longer course in sellar and post-sellar sphenoid sinuses. The sphenoid sinus ostium shape was oval in 72.55% cases and round in 27.45% cases. The ostia were located superiorly on the anterior wall of the sinus in 34.69% cases and in the middle in 65.31% cases. Knowledge on the level of complexity and variability of the sphenoid sinus plays a pivotal role in preparing for safer endoscopic trans-sphenoid surgical approaches.

Key words: Sphenoid sinus – Paranasal sinus – Neurovascular relations – Pneumatisation – Endoscopic endonasal trans-sphenoidal procedures

INTRODUCTION

The sphenoid air sinus serves as a surgical passage in accessing the sella turcica (ST) in order to access the base of the skull during trans-sphenoidal surgeries (Kaplanoglu et al., 2013; Solari et al., 2014). The sphenoid sinus is an air-filled chamber located in the body of the sphenoid bone at the center of the skull base (Tan and Ong, 2007). There are two sphenoid sinuses commonly divided asymmetrically in size and position by the intersinus septum (Lang, 1989). In some cases, these sinuses may extend into the pterygoid process or plates (of the sphenoid bone), laterally into greater and lesser wings of the sphenoid bone and posteriorly into the basilar part of the occipital bone and into the clivus (Kayalioglu et al., 2005; Kapur et al., 2012; Stokovic et al., 2016). The walls of the sphenoid sinus are related to delicate neurovascular structures [viz. internal carotid artery (ICA), optic nerve (ON), branches of the trigeminal nerve and the nerve of the pterygoid canal also known as the Vidian nerve (VN)] (D'Souza et al., 2013; Anusha et al., 2014; ELKammash et al., 2014; Priyadarshini et al., 2014; Standring et al., 2016). These relations make access to the sphenoid sinus a challenge if anatomy of the sinus is not thoroughly understood (Kapur et al., 2012; Chougule

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and Dixit, 2014), and the septa of the sphenoid sinus may add more complications as they may be found attaching to the bony bulges of the neurovascular structures related to the walls of this sinus (Lund et al., 2014; Ngubane et al., 2018). According to Lund et al. (2014), another structure that can be found intimately related to the sphenoid sinus is the posterior ethmoidal artery, which courses on the superior aspect of the anterior wall of the sinus. However, this study reported that this structure is less commonly found below the base of the skull and thus it is less susceptible to damage or injury during procedures related to the sphenoid sinus.

The level of pneumatisation of the sphenoid sinus in relation to the ST is substantially variable (Kayalioglu et al., 2005). This has led to the classification of the sinus by Hammer and Radberg (1961) into three major types, viz. conchal (this is regarded as a rare type as the area of the sphenoid bone below the sella turcica is not pneumatised), pre-sellar (the level of pneumatisation extends into the frontal plane of the sella turcica and not beyond the tuberculum sellae) and sellar (this is the commonest type where the degree of pneumatisation extends beyond the tuberculum sellae (TS) and the ST bulges into the roof of a well formed sinus). Later, Lang (1989) added a fourth type known as the post-sellar or occipito-sphenoidal type (which is described as over pneumatisation of the sinus extending beyond the dorsum sellae and sometimes reaching the clivus) (Kayalioglu et al., 2005; Sareen et al., 2005; Baldea and Sandu, 2012). The sphenoid sinus normally drains into the nasal cavity through a highly variable structure known as the ostium via the spheno-ethmoidal recess, which is located medially to the superior turbinate bone (Quinn, 2002; Sareen et al., 2005; D'Souza et al., 2013). During trans-sphenoidal endoscopic approaches, locating the ostium is a challenge and this structure varies in location as well as in shape, thus understanding its anatomy and having knowledge of possible variations are of great significance for safer procedures (D'Souza et al., 2013). The sphenoid sinus ostium may be easy to identify if found located medially to the superior turbinate; however, locating the ostium may be a challenge if located laterally to the superior turbinate and the lateral extent of the spheno-ethmoidal recess plays a significant role in locating the ostium (Nomura et al., 2013; Lund et al., 2014).

The purpose of this study was to document the sphenoid sinus classification by assessing the degree of pneumatisation of the sinus in relation to the ST, to document the relationship between the sphenoid sinus and the neurovascular structures surrounding it (viz. ICA, ON, MN, VN and other structures), including shape of the ICA related to the sphenoid sinus. It was also to document the morphology (shape and location) of the sphenoid ostium and to estimate the distance from the ostium to the anterior nasal spine (ANS).

MATERIALS AND METHODS

Twenty-five formaldehyde-fixed embalmed cadaveric head specimens (female n=6; male n=19) were used for this study and were obtained from the Discipline of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, College of Health Sciences, Westville and Nelson R Mandela School of Medicine campuses, University of KwaZulu Natal. Ethical clearance was obtained from the Biomedical Research Ethics Committee (BREC), UKZN (Clearance number: BE478/17). The age range for the specimens was 22-97 years of age, with an average of 70 years of age.

To investigate the extent of pneumatisation, neurovascular relations, shape of the ICA (straight when artery had no curvatures, kinking when artery had S-shaped curves present, coiling when artery had C-shaped curves) and the ostium of the sphenoid sinus, the cadaveric heads were cut in mid-sagittal sections using a bandsaw. The lateral walls of the sphenoid sinus were carefully removed to expose the structures bulging into the sinus with the use of a solid forged scalpel, hammer, probe and forceps. The measurements were done using a digital calliper (in millimetres), the first lower (or external) jaw of the calliper was placed on the centre of the sinus ostium and the second lower jaw was extended to the most prominent point of the ANS. Digital images of all observations were captured using the Sony ES30 digital camera (12.2 mega pixel).

Statistical analysis

Categorical variables were summarised using SPSS (Statistical Package for Social Sciences) version 25.0 (IBM® SPSS Inc., Chicago, Illinois, USA) for frequency tables and percentages. Chi-square test was used to test the association between sphenoid sinus classification and the side of location (left/right) separately in male and female specimens. All measurements were done three times and the average distances from sphenoid sinus ostium to the ANS in male and female specimens were compared using the independent t-test, while this distance was compared between right and left sides using paired t-test. A p-value of < 0.05 was considered to be statistically significant. Intra-observer variability and the confidence intervals were included, for more reliable results. Intra-class correlation coefficient (ICC) test for the distance from the ostium to the ANS yielded ICC of 0.999 (95% CI: 0.999-0.999).

RESULTS

Classification

The sphenoid sinus was classified according to

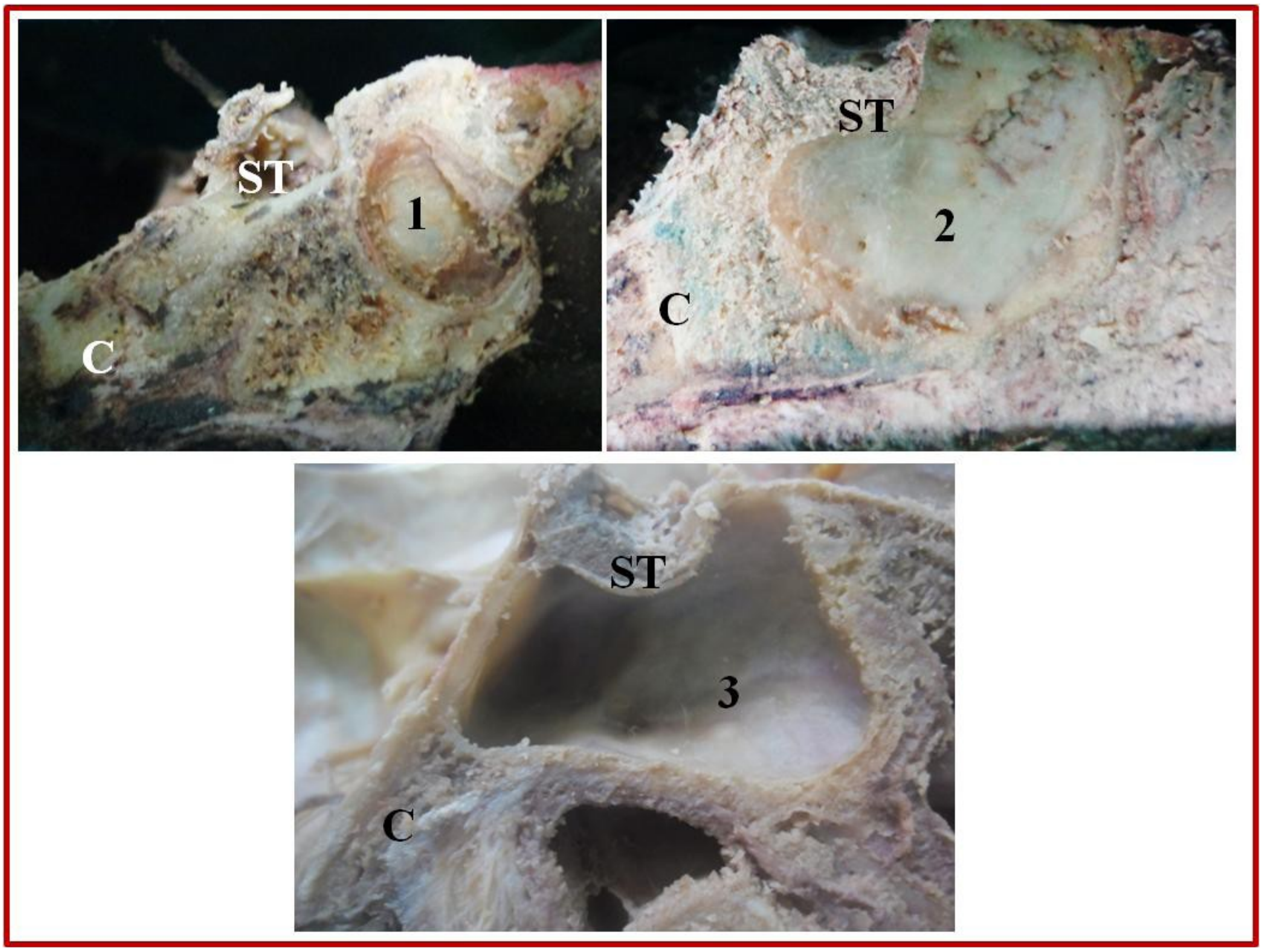


Fig 1. Sphenoidal sinus types (mid-sagittal sections). Pre-sellar (1); Sellar (2); Post-sellar (3); Anterior (**A**); Posterior (**P**); Superior (**S**); Inferior (**I**); Sella Turcica (**ST**); Clivus (**C**).

the Lang (1989) classification, which categorizes the sinus into 4 types, viz.: conchal, pre-sellar, sellar and the post-sellar types. No cases of the conchal sphenoid sinus type were observed in this study. The pre-sellar type was observed in 16% (n=8/50) of cases, and the sellar and post-sellar types were observed in 36% (n=18/50) and 48% (n=24/50) of cases, respectively (Fig. 1). In females, the pre-sellar type was observed in 33.33% (n=4/12) of cases (n=2 on both the left and right sides), the sellar type was observed in 41.67% (n=5/12) of cases (n=3 on the left, n=2 on the right), and the post-sellar type was observed in 25% (n=3/12) of cases (n=1 on the left, n=2 on the right). In males, the pre- sellar type was observed in 10.53% (n=4/38) of cases (n=2 on both the left and right sides), the sellar type was observed in 34.21% (n=13/38) of cases (n=6 on the left, n=7 on the right), and the post-sellar type was observed in 55.26% (n=21/38) of cases (n=11 on the left, n=10 on the right) (Table 1). Sphenoid sinus classification was significantly associated with side of location (left/right) (p = 0.010) in females, however, there was no statistical association in males (p = 0.745).

Out of the 25 specimens investigated, 23 had the same sphenoid sinus types bilaterally. The pre-sellar type was observed bilaterally in 17.39%

Table 1. Distribution of the types of the sphenoidal air sinus according to sex and laterality.

Type	Females			Males		
	Left (%)	Right (%)	Bilateral	Left (%)	Right (%)	Bilateral
Pre-sellar	2 (33.33)	2 (33.33)	2 (40)	2 (10.53)	2 (10.53)	2 (11.11)
Sellar	3 (50.00)	2 (33.33)	2 (40)	6 (31.58)	7 (36.84)	6 (33.33)
Post-sellar	1 (16.67)	2 (33.33)	1 (20)	11 (57.89)	10 (52.63)	10 (55.56)
Total	6 (100)	6 (100)	5 (100)	19 (100)	19 (100)	18 (100)
	p-value 0.01359			*p-value 0.74545*		

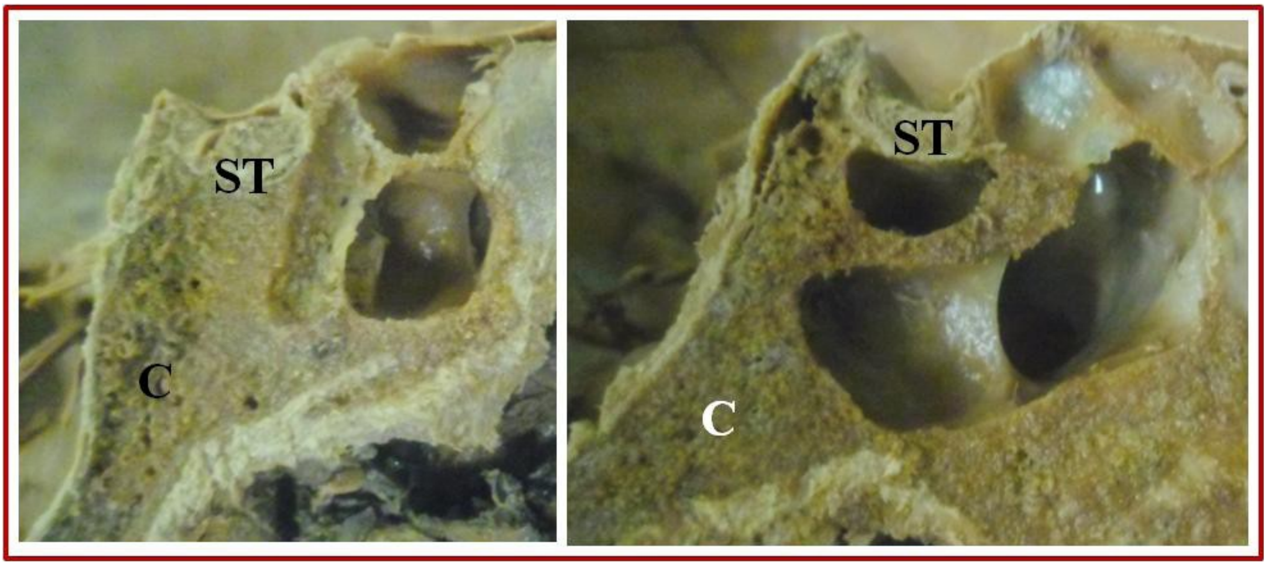
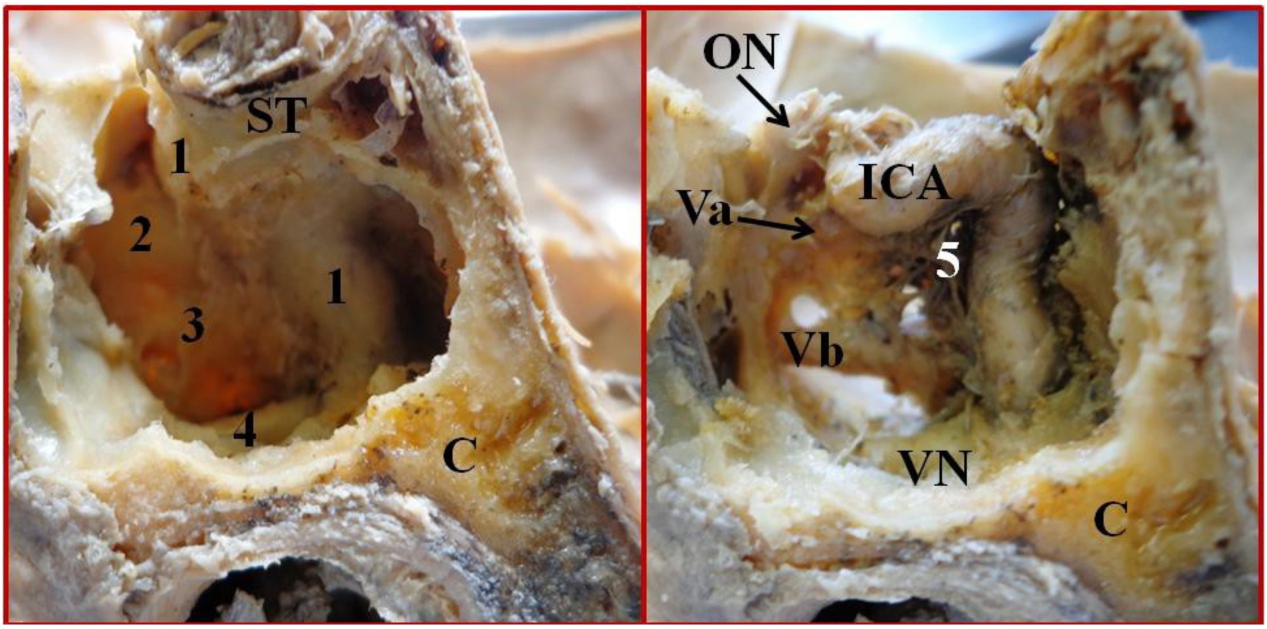


Fig 2. Sphenoidal sinus types still under pneumatisation (mid-sagittal sections). Pre-sellar (**a**); Sellar (**b**); Anterior (**A**); Posterior (**P**); Superior (**S**); Inferior (**I**); Sella Turcica (**ST**); Clivus (**C**).



Bulges (a): internal carotid artery (1); ophthalmic nerve (2); maxillary nerve (3); Vidian nerve (4); sella turcica (ST); clivus (C). **Neurovascular structures (b):** internal carotid artery (ICA); optic nerve (ON); ophthalmic nerve (Va); maxillary nerve (Vb); Vidian nerve (VN); Plexus (5)

Fig 3. Protrusions on the sinus walls and the neurovascular structures causing them (mid-sagittal view). Anterior (**A**); Posterior (**P**); Superior (**S**); Inferior (**I**).

(n=4/23) of cases [females=40% (n=2/5); males=11.11% (n=2/18)], the sellar and post-sellar were observed bilaterally in 34.78% (n=8/23) of cases [females=40% (n=2/5); males=33.33% (n=6/18)] and 47.83% (11/23) of cases [females=20% (n=1/5); males=55.56% (n=10/18)], respectively (Table 1). Two specimens (1 female and 1 male) had different sphenoid sinus types on either side. On the female specimen, the sellar type occurred on the left and the post-sellar type was observed on the right, and on the male specimen, the post-sellar type was observed on the left and the sellar type on the right side. There were no cases observed of the pre-sellar type occurring unilaterally. Sphenoid sinuses with incomplete or partial pneumatisation were observed in 2 male specimens with the pre-sellar and sellar sinus types (Fig. 2).

Neurovascular Relations

The ON, ICA, MN and the VN were the structures found intimately related to the sphenoid air sinus in this study (Fig. 3). In most cases, these structures formed protrusions on the walls (viz.

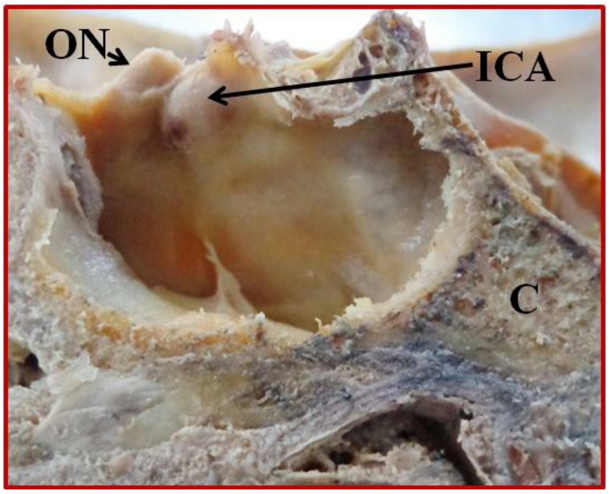


Fig 4. Internal carotid artery dehiscence observed on the right side in a male specimen (mid-sagittal view). Anterior (**A**); Posterior (**P**); Superior (**S**); Inferior (**I**); Clivus (**C**); Internal Carotid Artery (**ICA**); Optic Nerve (**ON**).

anterior, lateral and the floor) of the sphenoid sinus (Fig. 3a), and in some cases a dehiscence was observed (Fig. 4). Dehiscence is when the bone separating a particular structure within the sinus is absent (DeLano et al., 1996; Priyadarshini et al., 2014).

Post-sellar sinuses had the most number of structures protruding into the sinus walls with all of the four abovementioned structures protruding in 4% of cases and in 2% of cases in sellar sinuses. There were no cases of all four structures protruding into the walls of pre-sellar sinuses. Three bulges of the four structures were prevalent in sellar sinuses with 12% compared to 8% in post-sellar and 2% in pre-sellar sinuses. Two protrusions of four were also prevalent in sellar sinuses with 16% of cases and 14% of cases were observed on the post-sellar sinuses. There were no cases where the pre-sellar sinuses had only two bulges on their walls. Single bulging on the post-sellar sinuses was prevalent with 10% of cases, 2% of cases were observed in pre- sellar sinuses and no single bulge was recorded in sellar sinus types. Cases where no protrusions were observed in any of the sinus walls were 6%, 8% and 4% in pre-sellar, sellar and post-sellar sinuses, respectively (Table 2).

Optic Nerve

The protrusion of the ON on the lateral wall of the sinus was observed in 56% (n=28/50) of cases, of which 100% (n=12/12) and 44.74% (n=17/38) of cases were observed in female and male specimens, respectively. In 44% (n=22/50) cases, the ON bulges were bilateral and 6% (n=3/50) were unilateral on each side (left and right, in separate specimens). In total, the optic nerve bulge occurred in 28% (n=14/50) of cases on the left and also on the right side (Table 3). No cases of dehiscence by the ON were observed in this study. All ON protrusions were located more anteriorly and superiorly above the internal carotid artery. In relation to the degree of pneumatisation, the ON bulges were prevalent in post-sellar sinuses [26% (n=13/50) of cases] and in sellar sinuses [24% (n=12/50) of cases]. Pre-sellar sinuses had 6% (n=3/50) of cases of the ON protrusion (Table 4).

Internal Carotid Artery

The ICA protruded or formed a bulge on the lateral wall of the sphenoid sinus in 74% (n=37/50) of cases, 100% (n=12/12) were observed in females and 65.79% (n=25/38) in male specimens. In 60% (n=30/50) of cases, the bugles were bilateral and 6% (n=3/50) were on the left and 8% (n=4/50) were on the right side (Table 3). Dehiscence by this artery was observed in 6% (n=3/50) of cases which were on the right side in male specimens (Fig. 4). In total, the ICA was observed in 36%

Table 2. Number of protrusions by neurovascular structures per sinus wall in relation to the sphenoidal sinus types

Sinus Type	Number of protrusions %				
	Four	Three	Two	One	Zero
Pre-sellar	0	2	6	2	6
Sellar	2	12	16	0	8
Post-sellar	4	8	14	10	4

Table 4. Protrusions of the neurovascular structures on the sinus walls in relation to the sphenoidal sinus types

Sinus Type	Neurovascular Structures (%)			
	ICA	ON	MN	VN
Pre-sellar	5 (10)	3 (6)	2 (4)	0
Sellar	15 (30)	12 (24)	8 (16)	4 (8)
Post-sellar	17 (34)	13 (26)	6 (12)	7 (14

Table 3. Protrusion of the neurovascular structures on the sphenoidal sinus

	Distribution (%)			Total (%)		
Structures	Bilateral	Left	Right	Left	Right	Overall
ICA	30 (60.00)	3 (6.00)	4 (8.00)	18 (32.00)	19 (38.00)	37 (74.00)
ON	22 (44.00)	3 (6.00)	3 (6.00)	14 (28.00)	14 (28.00)	28 (56.00)
MN	6 (12.00)	6 (12.00)	4 (8.00)	9 (18.00)	7 (14.00)	16 (32.00)
VN	4 (8.00)	4 (8.00)	3 (6.00)	6 (12.000	5 (10.00)	11 (22.00)

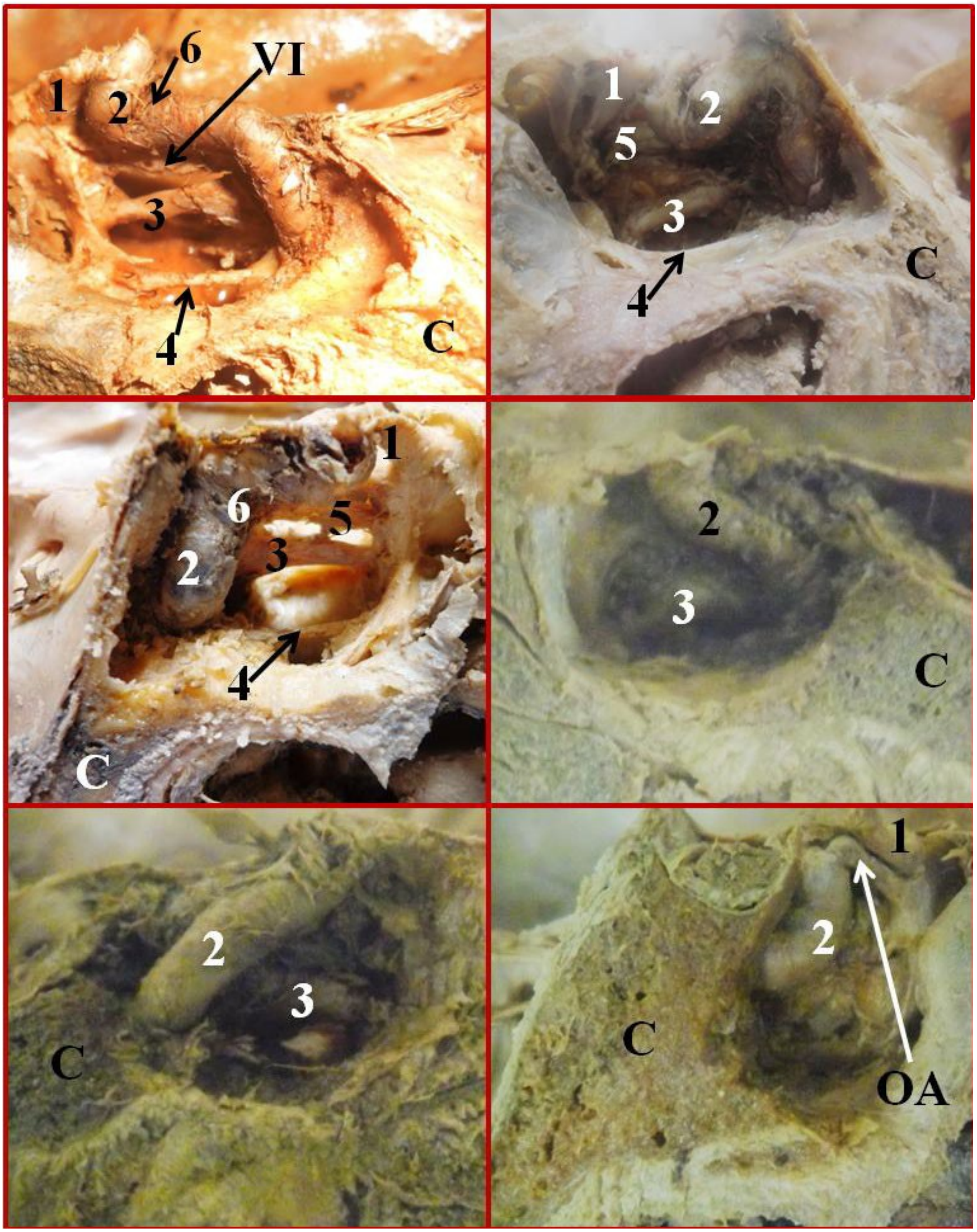


Fig 5. Neurovascular relations of the sphenoidal sinus in relation to sinus types (mid-sagittal sections). Anterior (**A**); Posterior (**P**); Superior (**S**); Inferior (**I**); Clivus (**C**); Optic Nerve (1); Internal Carotid Artery (2); Maxillary Nerve (3); Vidian Nerve (4); Ophthalmic Nerve (5); Cavernous Plexus (6); Abducens Nerve (**VI**); Ophthalmic Artery (**AO**)

(n=18/50) of cases on the left and in 38% (n=19/50) cases on the right side. Internal carotid artery protrusions were prevalent in post-sellar sinuses with 34% (n=17/50). Protrusions by this artery in pre-sellar and sellar sinuses were 10% (n=5/50) and 30% (n=15/30), respectively (Table 4).

It was observed that in pre-sellar sinuses, the sphenoid sinus was related to the cavernous part of the ICA, while in sellar and post-sellar sinuses a

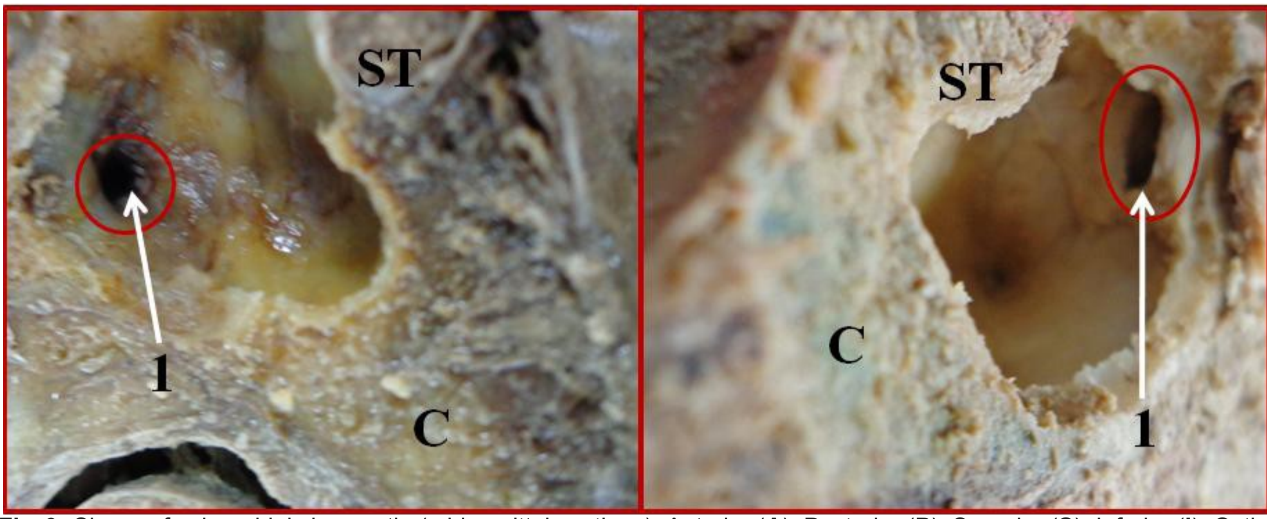


Fig 6. Shape of sphenoidal sinus ostia (mid-sagittal sections). Anterior (**A**); Posterior (**P**); Superior (**S**); Inferior (**I**); Ostium (**1**); Round-shaped (**a**); Oval-shaped (**b**).

longer course of the artery was observed. Out of the 37 ICAs that formed bulges on the lateral wall of the sinus, this artery was observed coiling (Fig. 5b) and kinking (Fig. 5c) in 37.8% and 45.9% of cases, respectively. It was straight (Fig. 5e) in 16.2% of cases. The straight ICA was observed in 25% of females and 12% of males. This artery was observed kinking in 33.3% of females and 52% of males. The ICA was coiling in 41.7% of females and 36% of males (Table 5).

Maxillary Nerve

The protrusion on the sphenoid sinus lateral wall formed by the MN was observed in 32% (n=16/50) of cases, 58.33% (n=7/12) were observed in females and 23.68% (n=9/38) in males. In 12% (n=6/50) of cases, the bulges were bilateral, 8% (n=4/50) were on the right side and 12% (n=6/50) were on the left side. In total, 18% (n=9/50) of cases occurred on the left side and 14% (n=7/50) were observed on the right side (Table 3). No cases of dehiscence by the MN were observed in this study. The MN bulge was prevalent in sellar sinuses with 16% (n=8/50) [post- sellar type 12% (n=6/50) and pre-sellar sinus type 4% (n=2/50), respectively] (Table 4).

Nerve of the pterygoid canal (Vidian nerve)

The VN was observed bulging into the sphenoid sinus floor in 22% (n=11/50) of cases, 25% (n=3/12) in females and 21.05% (n=8/38) in males. In 8% (n=4/50) of cases, VN bulges were bilateral, 6% (n=3/50) were on the right and 8% (n=4/50) were on the left side. In total, 12% (n=6/50) of cases were on the left side and 10% (n=5/50) were on the right side (Table 3). No cases of VN dehiscence were observed in this study. Vidian nerve protrusion was not observed in pre-sellar sinuses, this protrusion was prevalent in post-sellar sinus types with 14% (n=7/50) of cases and it was observed in 8% (n=4/50) of cases in sellar sinuses (Table 4).

Table 5. Shape of the Internal Carotid artery.

ICA Shape	Incidence (%)		
	Female	Male	Total
Straight	3 (25.00)	3 (12.00)	6 (16.21)
Kinking	4 (33.33)	13 (52.00)	17 (45.94)
Coiling	5 (41.67)	9 (36.00)	14 (37.84)
Total	12 (100)	25 (100)	37 (100)

Other Structures

In 8% (n=4/50), the posterior superior alveolar branch of the MN coursed intimately to the sphenoid sinus and formed protrusions on the anterior wall of the sinus laterally (Fig. 5). Although the ophthalmic branch of the trigeminal nerve and the abducent nerve coursed behind the ICA, they were also intimately related to the sphenoid sinus. The meningohypophyseal trunk was found intimately related to the ICA and pituitary gland and this was observed in 2.2% of cases. This makes the meningohypophyseal trunk susceptible to injury during removal of pituitary gland tumours or during other trans-sphenoidal procedures (Fig. 5c-d).

Sphenoid Sinus Ostia

Shape and Location

Out of the 50 sides investigated for this section of the study, 2 ostia were observed on the right side of one of the specimens; therefore, the total number of ostia studied was 51. Two shapes of the sphenoid sinus ostium were observed in this study, viz. oval and round (Fig. 6). Oval- shaped ostia were in 72.55% (n=37/51) of cases and round-shaped ostia were observed in 27.45% (n=14/51) of cases. In 64.71% (n=33/51) and 19.61%

Table 6. Distribution of the shape and location of the sphenoidal sinus ostia

		Females (%)		Males (%)		Overall (%)			
		L	R	L	R	Bilateral	L	R	Total
Shape	Oval	4 (66.67%)	3 (50)	15 (78.95)	15 (75)	33 (66)	19 (76)	18 (69.23)	37 (72.55)
	Round	2 (33.33)	3 (50)	4 (21.05)	5 (25)	10 (20)	6 (24)	8 (30.77)	14 (27.45)
	Total	6 (100)	6 (100)	19 (100)	20 (100)	50 (sides)	26 (100)	26 (100)	51 (100)
Location	Superior	2 (33.33)	2 (33.33)	7 (36.84)	7 (36.84)	18 (36)	9 (36)	9 (36)	18 (35.29)
	Middle	4 (66.67)	4 (66.67)	12 (63.16)	12 (63.16)	30 (60)	16 (64)	16 (64)	32 (62.75)
	Total	6 (100)	6 (100)	19 (100)	19 (100)	50 (sides)	25 (100)	25 (100)	51 (100)

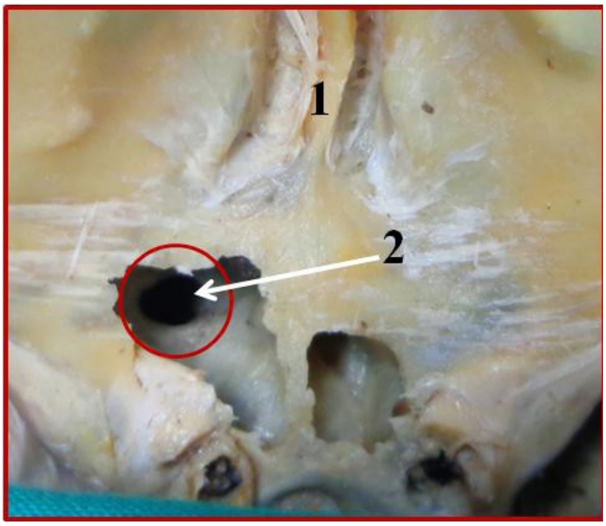


Fig 7. Sphenoidal sinus ostium located on the floor of the sinus (axial view). Anterior (**A**); Posterior (**P**); Lateral (**L**); Medial (**M**); Crista Galli (**1**); Ostium (**2**).

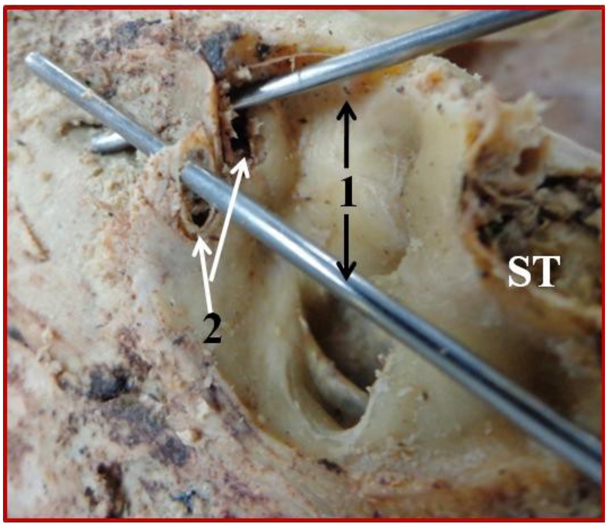


Fig 8. Double oval-shaped ostia on the right side in a male specimen (mid-sagittal section). Anterior (**A**); Posterior (**P**); Superior (**S**); Inferior (**I**); Probes (**1**); Ostia (**2**); Sella Turcica (**ST**).

(n=10/51) of cases, the oval and round ostia occurred bilaterally, respectively (Table 6). Combination of round and oval ostia occurred in 7.84% (n=4/51) of cases. The sphenoid sinus ostia were found located behind the superior or middle nasal conchae. The ostium location was categorized into superior (behind the superior nasal concha and close to the roof of the sinus) and middle (behind the middle nasal concha) (Fig. 8). In 35.29% (n=18/51) of cases, the ostia were located superior, whilst in 62.75% (n=32/51) of cases they were located in the middle along the anterior wall of the sphenoid air sinus. In one case the ostium was located on the floor of the sinus (Fig. 7). Double ostia were observed on the right side in a male specimen, one ostium in the middle and the other located superiorly (Fig. 8) (Table 6).

Measurements from the ostium to the ANS

The average distance from the sphenoid sinus ostium to the anterior nasal spine (ANS) was found to be 53.54±5.04 mm on the left side and 57.17±3.88 mm on the right side. There was no significant differences in the average distance from the sphenoid sinus ostium to ANS, between the right and left sides (p = 0.069). The measurement data was normally distributed. In males, the distance from the ostium to the ANS was 58.08±4.57 mm and in females it was 57.09±4.35 mm. The average distance from the ostium to the ANS was 54.54±5.19 mm in pre-sellar sinuses, this distance was 58.11±4.03 mm and 58.72±4.35 mm in sellar and post-sellar sinuses, respectively.

DISCUSSION

The sphenoid air sinus is a highly variable cavity at the base of the skull and is a significant landmark when hypophyseal surgical procedures and other trans-sphenoidal approaches are concerned (Kayalioglu et al., 2005; Emirzeoglu et al., 2007). Its relation to delicate vascular and neural structures makes access to the sinus a great challenge. According to Budu et al. (2013), the relationship between the sphenoid sinus and the neurovascular structures (viz. internal carotid artery, optic, maxillary and Vidian nerves) depends on the size or the extent of pneumatisation of the sinus.

According to most authors, the sellar type of sphenoid sinus is the most common type (Table 7). In the current study, the post-sellar sinus was the most prevalent type (48%) followed by sellar

Table 7. Sphenoidal air sinus classification reported by various authors

Author (year)	Modality	Sample size	Population	Sinus Classification (%) Conchal	Pre-sellar	Sellar	Post-sellar
Hammer and Radberg (1961)	Anatomical	120	-	2.5	11	86	-
Kayalioglu et al. (2005)	Mixed	257	Turkish	1.9	9	52.9	36.2
Sareen et al. (2005)	Cadaveric	20	Indian	-	25	-	75
Madiha and Raouf (2007)	Mixed	-	Egyptian	0	76	24	-
Tan and Ong (2007)	Cadaveric	-	Asian	-	17	55	-
Hamid et al. (2008)	Radiological	296	Egyptian	2	21	45.7	22.3
Cho et al. (2010)	Cadaveric	-	Korean	1	9	90	-
Wang et al. (2010)	Radiological	100	Asian	0	2	98	-
Baldea and Sandu (2012)	Radiological	50	Romanian	7.14	44	82	2
Chougule andDixit (2014)	Radiological	30	Indian	-	13.33	23.33	61.67
Chougule and Dixit (2014)	Cadaveric	30	Indian	-	20	14	66
Awadalla et al. (2015)	Anatomical	25	Egyptian	-	12	88	-
Awadalla et al. (2015)	Radioloical	-	Egyptian	1.6	12.6	86	-
Vidya and Raichurkar (2015)	Radiological	80	Indian	0	10	85	5
Current Study	**Cadaveric**	**25 (50)**	**South African**	**0**	**16**	**36**	**48**

(36%) and pre-sellar (16%); these findings were consistent with those reported in a radiological study by Chougule and Dixit, (2014). In Chougule and Dixit's cadaveric study (2014), the post-sellar sphenoid sinus was prevalent followed by the pre-sellar type. Madiha and Raouf (2007) reported a unique case where the pre-sellar sinus was prevalent compared to the sellar type (Table 7).

In the current study, protrusion by the ICA and the ON was common, with 70% and 56% of cases, respectively. This was consistent with the findings by Hewaidi and Omami (2008) with protrusion of the ICA and ON in 41% and 35.6% of cases, respectively. The protrusion of the optic nerve was reported prevalent (65%) compared to that of the ICA (50%) by Mamatha et al. (2010). Dehiscence by the different neurovascular structures varies greatly. Hewaidi and Omami (2008) reported dehiscence of the VN prevalent in 37% of cases; Mamatha et al. (2010) reported prevalent ON dehiscence in 50% of cases; and Priyadarshini et al. (2014) reported prevalence of the ICA dehiscence in 33% of cases. The current study reported no cases of dehiscence of other structures but of the ICA (6%) (Table 8).

It was noted that, even though the structures may not always form protrusions on the sinus walls, they were however always intimately related to the sinus, and are always found immediately on the walls of the sinus. Therefore, all neurovascular structures surrounding the sphenoid sinus walls are susceptible to injury during surgery. The protrusions caused by these structures on the sinus walls may serve as clues of where exactly the structures course in relation to the sphenoid sinus (Li et al., 2014). Complications concerning these structures may then be easily avoided. In addition, the most posterior ethmoidal cells have an important relationship with the sphenoid air sinus. Some of these cells lie superior to the sinus and may contain the optic nerve; these are known as sphenoethmoidal cells or Onodi cells. Access to the sphenoid air sinus is known via the sphenoethmoidal recess route but reliable landmarks have not been established utilising the posterior ethmoidal cells. Hence, surgeons need to be aware of these cells and their relationship to the optic nerve and the internal carotid artery, which form bulges

Table 8. Sphenoidal sinus neurovascular relations reported by various authors

Author (year)	Modality	Sample size	Protrusion (%)				Dehiscence (%)			
			ICA	ON	MN	VN	ICA	ON	MN	VN
Hewaidi and Omami (2008)	Radiological	300	41	35.6	24.3	27	30	30.6	13	37
Mamatha *et al*. (2010)	Radiological	20	50	65	-	-	45	50	-	-
Priyadarshmi *et al.* (2014)	Radiological	100	-	-	1	18	33	8	20	6
Current Study	**Cadaveric**	**25 (50)**	**70**	**56**	**32**	**22**	**6**	**0**	**0**	**0**

Table 9. Shape of the sphenoidal sinus ostium reported by various authors

Author (year)	Modality	Sample size	Shape (%)	
			Oval	Round
Elwany et al. (1999)	Cadaveric	186	28	72
Sethi et al. (1995)	Cadaveric	30	40	47
Chougule and Dixit (2014)	Cadaveric	30	46	53
Current Study	**Cadaveric**	**50**	**72.55**	**27.45**

on the supero-lateral wall of the sinus. The focus of the current study was to investigate the pneumatisation patterns of the sphenoid sinus and its relationship to neurovascular structures within a South African population, which have not been previously recorded. It is recommended that landmarks for the posterior ethmoidal cells as well as the incidence of the Onodi cells be investigated within this population for future studies (Cho et al., 2010).

The sphenoid ostium serves as a natural portal to access the sphenoid sinus in order to perform cranial base surgeries. The ostium is highly variable in its shape and location within the sinus walls. The current study reported the oval-shaped ostia prevalent compared to round-shaped, with 72.55% and 27.45%, respectively. However, other authors reported round-shaped ostia prevalent compared to the oval-shaped ostia (Sethi et al., 1995; Elwany et al., 1999; Chougule and Dixit, 2014). Round-shaped and oval-shaped ostia were found in 47% and 40% (Sethi et al., 1995), 72% and 28% (Elwany et al., 1999), 53% and 46% (Chougule and Dixit, 2014), of studies respectively (Table 9). The estimated average distance between the sphenoid ostium and the anterior nasal spine was found to be 58.56±5.05 mm on the left and 57.84±4.52 mm on the right side. This distance was measured to be 58.08±4.57 mm in females and 57.09±4.35 mm in males.

The sphenoid sinus is a highly complex cavity at the base of the skull. Knowledge on the anatomy of this sinus and its variations requires major attention prior to endoscopic trans-sphenoid approaches. Failure to understand the sphenoid sinus anatomy, its varying relationship between the sinus and significant neurovascular structures and the location of the sinus ostium may make surgical procedures related to the sinus difficult. This study updates knowledge on the anatomy and variations of the sphenoid air sinus in a select South African population.

Due to the limited sample size (shortage of cadaveric material), precise estimation of the incidences of certain variations of the sphenoid sinus may not be provided in this current study. For future studies, the posterior ethmoidal air sinus needs to be determined, and the relationship to the spheno-ethmoidal or Onodi cells also needs to be investigated since they may contain the optic nerve and the internal carotid artery. The superior turbinate plays a significant role regarding the location of the sphenoid sinus ostium as reported by Lund et al. (2014); therefore, it is recommended that future studies investigate further the relationship between the sphenoid sinus ostium and the superior turbinate. It is also recommended that the relationship between the sphenoid sinus ostium and the posterior nasal artery be investigated, as the inferior enlargement of the ostium may damage this artery which crosses the commonly thin anterior wall of the sphenoid sinus (Lund et al., 2014).

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