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CLINICO-ANATOMICAL RELATIONSHIPS BETWEEN THE INTERNAL CAROTID ARTERY AND SPHENOID SINUS USING COMPUTED TOMOGRAPHY

***Abdulhameed Aliu[1], Samuel Abayomi Asala[2]**
1. Department of Anatomy, Faculty of Basic Medical Sciences, College of Health Sciences, Usmanu Danfodiyo University, Sokoto, Nigeria.
2. Department of Anatomical Sciences, Faculty of Basic Medical Sciences, College of Health Sciences, University of Abuja, Abuja, Nigeria.
Corresponding author: Dr. Abdulhameed Aliu. Email: aliu.abdulhameed@udusok.edu.ng. Phone no: +234(0)8062372824

ABSTRACT

Unexpected and sometimes inexplicable massive haemorrhage arising from intracranial injury to the internal carotid artery (ICA) is a life-threatening complication of endoscopic transsphenoidal skull base surgeries. Pre-interventional computed tomography (CT) assessment of the anatomical relationships between the ICA and the sphenoid sinus is necessary to understand and prevent this complication. The aim of this study was to determine the normal anatomical variations between the sphenoid sinus and internal carotid artery using CT and evaluate their relationship with sinus dimensions. The CT scans of 323 sphenoid sinuses of patients aged 18 to 80 years were retrospectively studied. The images were taken with a GE Bright Speed Multi detector Helical CT Scanner and viewed using the Digital Imaging and Communication in Medicine (DICOM) viewer. The anteroposterior, craniocaudal and transverse diameters were measured and used to determine sinus volume. Protrusion of the ICA into the sinus cavity, dehiscence, and presence of septal attachments to the sinus walls bordering the ICA were studied. The prevalence of ICA protrusion, dehiscence of sinus wall, and septal attachment were 28.48%, 17.34% and 13.93% respectively. There was a statistically significant relationship between protrusion of ICA and the anteroposterior and transverse sinus diameters. The relationship between dehiscence of the wall over the ICA and sinus volume as well as the transverse diameter was statistically significant. A careful CT identification of these normal but potentially dangerous variations between the ICA and the wall of the sphenoid sinus prior to surgery is essential for a safe cranial base endoscopic transsphenoidal procedure.

Key words: *Anatomical relations, CT sphenoid sinus, internal carotid artery, protrusion dehiscence*
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INTRODUCTION

The internal carotid artery is intimately related to the lateral wall of the sphenoid sinus. This segment of the ICA is evident as a distinct groove on the body of the sphenoid bone called the carotid sulcus (Williams et al., 1995; Sinnatamby, 2005). This groove could become more prominent as a result of increased sinus expansion due to pneumatisation or from bone resorption, consequently allowing protrusion of the ICA into the cavity of the sphenoid sinus (Rhoton et al., 1977; Harris and Rhoton, 1979). Cases of skull base haemorrhages following endoscopic transsphenoidal cranial base surgeries have been attributed to injuries to the ICA in the neighborhood of the sella (Fujii et al., 1979). Protrusion of the ICA through the thin sinus wall into the cavity increases the chances of vascular injury to the ICA during endoscopic transsphenoidal procedures. This is particularly so when the bony wall adjacent to the ICA is dehiscent (incomplete and so bare) or, a sinus septum that obscures and obstructs the procedure is attached to the sinus wall bordering the site of the blood vessel. Chances of ICA injury increases when these structures lie in the field of operation, especially with the avulsion of a sinus septum to enhance visibility. This could explain the occurrence of unexpected massive cranial base haemorrhages following transsphenoidal surgical approaches (Renn and Rhoton, 1975). Therefore, in order to understand, control or prevent these complications pre-interventional computed tomography (CT) assessment of minute anatomical details of the sphenoid sinus and variations in its side walls in relation to the internal carotid artery is necessary. According to Tomovic et al., (2013), the overall prevalence of ICA protrusion was 28.2% in the general American population, 24.6% in African Americans, 26.1% in Hispanics, 50.0% in Asians, and 49.1% in Caucasians. The prevalence of dehiscence was 4.6% among African Americans, 2.7% in Hispanics, 8.3% in Asians, and 0% among Caucasians (Tomovic et al., 2013). There is a general paucity of CT-based data concerning the normal anatomical variations between the ICA and the side walls of the sphenoid sinus. Injury to the ICA emanating from inadequate knowledge of these variations could lead to severe life-threatening surgical complications. The aim of this study is to determine the variations between the ICA and the sphenoid sinus via CT and evaluate their relationship with sinus dimensions.

MATERIALS AND METHODS

Computed Tomography images of 323 sphenoid sinuses of patients aged 18 - 80 years (mean age, 41.4 years ± 17.8) over a five-year period (April 2016 to March 2021) were retrospectively studied at the departments of Anatomy and Radiology. This study was conducted in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards after an ethical approval was granted by the Human Research Ethics Committee. The CT scan images were obtained from the hospital database and CT library. Images were taken with a GE Bright Speed Multi detector, 4 Slice Helical CT (GE Healthcare, USA, 2005) Scanner, at 200 mAs, 120 KVp, 15 cm Field of View, slice thickness of 2.5 mm, 512 X 512 matrix and a standard reconstruction algorithm. The CT images with evidence of sinus disease, craniofacial anomalies, skull base trauma and intracranial pathologies were excluded from the study. The images were viewed on the computer aided Digital Imaging and Communication in Medicine (DICOM) viewer, powered by the RadiAnt Version 4.2 software. The ages of subjects in years were clustered into seven groups of equal intervals in order to assess age related changes in the sphenoid sinus in relation to the ICA. With the aid of the distance measuring tool (ruler) provided by the software, the anteroposterior, craniocaudal and transverse diameters of the sphenoid sinus were measured on sagittal reformatted, axial and coronal reconstructed CT images, while the sinus volume was calculated using the ellipsoid formula: Sinus Volume = 4/3 x π x A x B x C/23 according to Barghouth et al., (2002); where A, B, and C are the ellipsoid diameters corresponding to anteroposterior (AP) transverse (TR), and craniocaudal (CC), diameters, respectively. Three anatomical features namely: ICA protrusions, incomplete or dehiscent sinus wall over the ICA and attachment of septum to the sinus wall bordering the site of the ICA (Figure 1 - 4) were studied on axial and coronal reconstructed images. IBM SPSS Statistics Version 22 was used for data analysis. Comparison of mean values in relation to sex and age distribution of the subjects was carried out using One-way analysis of variance (ANOVA), and proportions were compared using chi-square test. Logistic regression was done to assess the relationship between sinus dimensions and ICA protrusion or dehiscence.

RESULTS

Study outcome of sample images in Figures 1-4 demonstrated the presence of protrusion of ICA into the sphenoid sinus, dehiscence of sinus walls over the ICA and attachment of sinus septa to the sinus wall bordering the ICA.

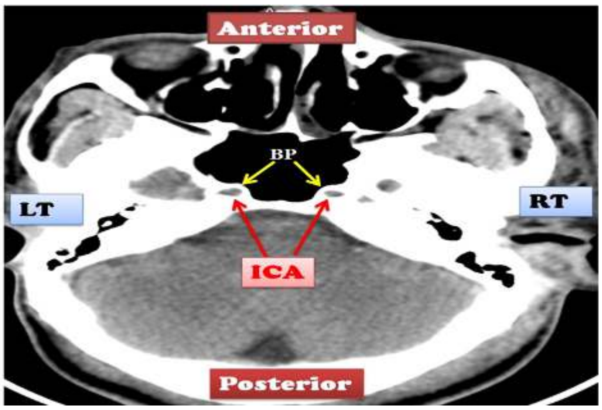

Figure 1 Axial CT of the sphenoid sinus with bilateral protrusions (BP) of the internal carotid arteries (ICA), with no dehiscence of its walls, and no septal attachment. RT = Right Side, LT = Left Side

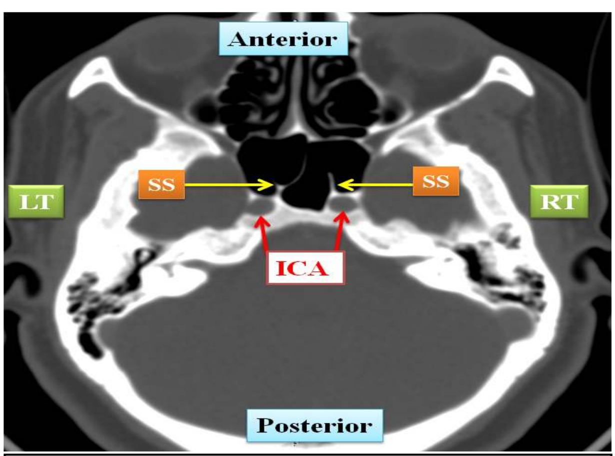

Figure 2 Axial CT of the sphenoid sinus with bilateral attachment of sinus septae (SS) to the walls of bilaterally protruding internal carotid arteries (ICA). RT = Right Side, LT = Left Side

Variations in the anatomic relationship between the ICA and the sphenoid sinus

The prevalence of ICA protrusion, dehiscence, and septal attachment to the sinus walls at the site of the ICA, were 28.48%, 17.34% and 13.93% respectively. The ICA protruded into the sinus cavity more on the right side (41 subjects, 12.7%), than on the left side (15 subjects, 4.7%). Bilateral ICA protrusions were found in 36 (11.2%) of subjects. (Figure 1, 2. Table 1). Within age groups, the highest incidence of ICA protrusions was 36% in age group 45-53 while the maximum incidence of bilateral ICA protrusion was 25% in 54-62 years age group (Table 1).

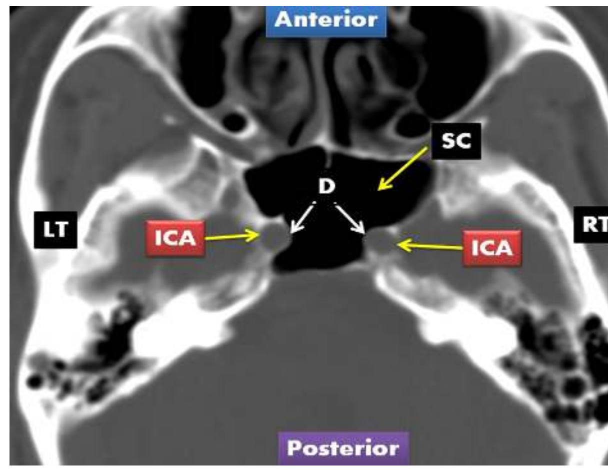

Figure 3. Axial CT of the sphenoid sinus demonstrating dehiscence (D) of the walls of bilaterally protruding internal carotid arteries (ICA). SC = Sinus Cavity; RT = Right Side, LT = Left Side

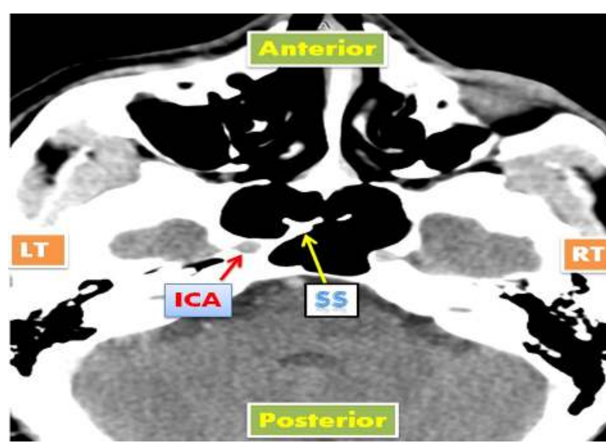

Figure 4 Axial CT of the sphenoid sinus showing attachment of a sinus septum (SS) to the wall of the left internal carotid artery (ICA). RT = Right Side, LT = Left Side.

Relationship between internal carotid artery protrusion, dehiscence and septal attachments and age or sex of subjects

There was no statistically significant relationship between age of subjects and protrusion, dehiscence of the ICA and septal attachments (Table 1). There was no statistically significant relationship between sex of subjects and protrusion of the internal carotid artery, dehiscence or septal attachment. (Table 1, 2).

Logistic regression: Test of association between ICA protrusion and dimensions of the sphenoidal sinus

In Table 3, there was a strong statistically significant relationship between protrusion of the ICA and the anteroposterior (p = 0.001), and transverse (p = 0.001) diameters of the sphenoid sinus. The dehiscence of the adjoining sinus wall of the ICA had a statistically significant association with the transverse diameter (p = 0.001) and volume (p = 0.001) of the sphenoid sinus.

Table 1. Septal attachment and protrusion of the Internal Carotid Artery

Age Group (Years)	No of Subjects per group	Internal Carotid Artery-Related Features							
		Septal Attachment		Protrusion of Internal Carotid Artery					
				Right		Left		Bilateral	
		No	%	No	%	No	%	No	%
18-26	88	10	11.4	8	9.1	4	4.6	5	6.7
27-35	58	8	13.8	8	13.8	3	5.2	6	10.3
36-44	40	1	2.5	8	20.0	3	7.5	1	2.5
45-53	50	8	16.0	9	18.0	3	6.0	6	12.0
54-62	36	11	30.6	3	8.3	0	0.0	9	25.0
63-71	31	4	12.9	3	9.7	1	3.2	4	12.9
72-80	20	3	1.5	2	10.0	1	5.0	5	25.0
Total	323	45	13.9	41	12.7	15	4.7	36	11.2

$\chi 2$ = 0.112, df = 18. (Protrusion of Internal Carotid Artery). $\chi 2$ = 0.186, df = 18. (Septal attachments). Data is expressed as number (No) and percentages (%) of internal carotid arteries with septal attachments, and protrusion across age groups.

Table 2: Sex differences in prevalence of internal carotid artery protrusion, dehiscence and septal attachment to sinus walls

ICA Features	Sex	No of subjects	Right		Left		Bilateral		Total (%)	
			No	%	No	%	No	%	No	%
Protrusion	Male	216	33	15.3	8	3.7	28	13	69	31.9
	Female	107	8	7.5	7	6.5	8	7.5	23	21.5
Septal Attachment	Male	216	15	6.9	12	5.6	3	1.4	30	13.9
	Female	107	6	5.6	7	6.5	2	1.9	15	14.0
Dehiscence	Male	216	12	5.6	9	4.2	16	7.1	37	17.1
	Female	107	7	6.5	5	4.7	7	6.5	19	17.8

χ^2 = 0.61, df = 3 for ICA (Internal Carotid Artery). χ^2 = 0.937, df = 3 for septal attachment. χ^2 = 0.365, df = 3 for dehiscence. Data is expressed as number (No) and percentages (%) of internal carotid arteries with septal attachments and protrusion of its walls, among gender groups.

Table 3: Test of association between ICA Protrusion/Dehiscence and dimensions of the sphenoidal sinus

Sinus dimensions	Mean ± SD	*P* value (Protrusion)	*P* value (Dehiscence)
AP (cm)	26.9 ± 6.431	0.001*	0.040*
CC(cm)	24.6 ± 4.304	0.125	0.317
TR(cm)	34.0 ± 5.947	0.001*	0.001*
VOL(cm²)	11.9 ± 5.491	0.047	0.001*

Logistic regression: * statistically significant at $p < 0.05$. AP = Anteroposterior, CC = Craniocaudal, TR = Transverse, VOL = Volume.

DISCUSSION

The expanded endoscopic endonasal trans-sphenoidal access to the pituitary gland and neighbouring skull base structures is less traumatic, evades retraction of the brain and offers a better visualization of the operation field. It has become the standard approach for the surgical removal of pituitary adenoma due to its lower postoperative morbidity and mortality in contrast with the transcranial route (Tomovic et al., 2013). However, potentially severe complications can be encountered in the presence of a poor understanding of the complex anatomy of the sphenoid sinus and the inherent variations in its relationship with the ICA on its sidewalls. When the ICA projects into the cavity of the sphenoid sinus, it is either fully or partially covered by a thin shell of bone, or the covering is completely dehiscent, making the artery bare and prone to inadvertent surgical injuries with consequent haemorrhage that could be difficult to control. Head and neck surgeons are therefore expected to be watchful of these variations.

The use of CT with multiplanar and three-dimensional reconstruction abilities has improved the quality and the quantity of information obtainable from evaluation of bony structures on the cranial base. This allows for accurate determination and localization of structures and their relationship with the surroundings (Cavalcanti and Vannier, 1998; Cesarani et al., 2003).

In this study, the prevalence of ICA protrusion was higher than the respective 24.6% and 4.6% among African Americans, 26.1% and 2.7% among Hispanics (Tomovic et al., 2013), 27.3%, and 10.9%, (Fasunla et al., 2012), as well as the findings of Li et al., (2014). However, values obtained among Asians (50.0%) and Caucasians (49.1%) according to Tomovic et al., (2013) and the 85% in the report of Fernandez-Miranda et al., (2009), were higher than the outcome of the current study.

In agreement with the report of other studies (Şirikci et al., 2000; Unal et al., 2006; Li et al., 2014; Ramalho et al., 2017), ICA protrusion and sinus wall dehiscence are associated with anteroposterior diameter which is an indication of the extent of pneumatisation of the sphenoid sinus (Wiebracht and Zimmer 2014).

Sphenoid sinus septae are highly variable intrasinus bony crests that extend from the floor to the roof and side walls, dividing the sinus cavity into compartments (Güldner et al., 2012). This study considered only intrasinus septae attached to the sinus wall adjoining the ICA due to its clinical implications during endoscopic transphenoidal surgical procedures. An attempt to resect or pluck off a sinus septum that is attached to the site adjoining the wall of the ICA, either inadvertently or deliberately to improve visibility within the field of operation could tear or rupture the ICA leading to massive haemorrhage on the skull base (Renn and Rhoton, 1975; Fujii et al., 1979). The current study found a higher prevalence of septal attachment to the adjoining sinus wall of the ICA compared with the outcome of similar studies (Fasunla et al., 2012; Hamid et al., 2008), but lower than the report of Mutlu et al., (2001) among Italians (14.50%), Lupascu et al., (2014), among Romanians (32%), Kapoor et al., (2017) in Bosnia and Herzegovina (26.42%), and Jaworek-Troć et al., (2020) in Poland (30.07%). Jaworek-Troć et al., (2020), reported double and triple septal attachment to an ICA in 4.39% and 0.34% of subjects respectively. This study found that females had higher incidence of septal attachments to the sinus wall bordering the ICA than males, contrary to the report of Idowu et al., (2009) who found no gender differences in the attachment of the sinus septae. In this study, the prevalence of right and left septal attachments were lower than values reported by Abdullah et al., (2001), in Malaysia and Wiebracht and Zimmer, (2014), in Cincinnati. The reasons for the differences between the findings of these studies are not clear, however, modifications in methodology (use of dried skulls, cadaver, CT or MRI), genetic, ethnic, racial, and environmental factors may have accounted for these differences. Hence, in populations with high prevalence of these potentially dangerous anatomical variations, it is important for otorhinolaryngologists, head and neck surgeons to consider the higher risk of iatrogenic injuries to the ICA during transsphenoidal procedures.

CONCLUSION

The prevalence of normal anatomical variations of protrusion of the internal carotid artery and dehiscence of its adjoining sinus wall is noteworthy. A pre interventional CT assessment for the identification of these potentially dangerous patterns of relationship is essential for a safe cranial base transsphenoidal procedure.

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