Computed Tomography Evaluation of the Correspondence Between the Arcuate Eminence and the Superior Semicircular Canal

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■ BACKGROUND: **The arcuate eminence (AE) has been traditionally used in middle cranial fossa (MCF) surgery as a guide to accurate location of the superior semicircular canal (SSC) deep within the temporal bone. However, the anatomic relationship between the AE and SSC is controversial. We evaluated the anatomic coincidence between the AE and the SSC in the MCF surface. Distances between the most relevant anatomic structures in the MCF and prevalence of SSC dehiscence were measured.**

■ METHODS: **We analyzed 75 (150 sides) 0.75-mm slice thickness temporal bone computed tomography scans and classified the AE and SSC relationship as coincident and noncoincident. Radiologic findings were reported independently in a blind fashion by 2 authors. Data were presented as mean ± SD or frequency and percentage. Student *t* test or an unequal variance *t* test was used. Interobserver agreement among readings was assessed using κ statistic for categorical variables and intraclass Kendall tau-a correlations for continuous measures. *P* < 0.05 was considered to indicate statistical significance.**

■ RESULTS: **The AE matched the SSC in only 31.3% of cases. The AE could be localized as lateral as 11.6 mm from the SSC. It was impossible to identify the AE in 33 scans (22.0%). SSC dehiscence was found in 5 cases (3.3%). A few millimeters separated most analyzed landmarks, and a wide variability in secondary measurements was observed.**

■ CONCLUSIONS: **The AE does not systematically overlie the SSC and should not be routinely used as a reference to reach this structure in MCF surgery.**

INTRODUCTION

During the past 100 years, the middle fossa approach has been used for treatment of different neoplastic and non-neoplastic conditions involving the temporal bone and adjacent structures.[1,2] Among the various surgical techniques, different anatomic landmarks have been proposed for identification and dissection of the petrous bone contents.[3-6] The arcuate eminence (AE) has been traditionally described as a bone bulge resulting from the superior semicircular canal (SSC) protrusion toward the floor of the middle cranial fossa (MCF). The presumable topographic correspondence of the AE and SSC has continued to support the use of the AE as a guide to accurate location of the SSC deep within the temporal bone.[4,7,8] Studies have raised questions about the exact association between these structures,[9-11] and the lack of consensual agreement about the coincidence between the AE and SSC in the MCF can be seen in neurosurgery and otorhinolaryngology textbooks, which have described AE as a major landmark to reach SSC.[12,13] The purpose of this study was to evaluate the anatomic relationship between the AE and the SSC in the MCF surface. Distances between the most applicable anatomic structures in MCF surgery and prevalence of SSC dehiscence were also studied.

Key words
- Arcuate eminence
- Middle fossa anatomy
- Middle fossa approach
- Superior semicircular canal
- Surgery
- Temporal bone

Abbreviations and Acronyms
AE: Arcuate eminence
CI: Confidence interval
CT: Computed tomography
IAC: Internal auditory canal
MCF: Middle cranial fossa
SSC: Superior semicircular canal

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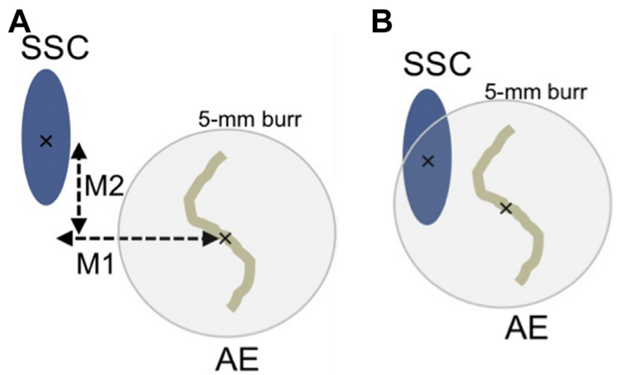

Figure 1. A noncoincident (**A**) and a coincident (**B**) case. The gray circle corresponds to the drill bit. Measurement 1 (M1) and measurement 2 (M2) indicate the distances separating the arcuate eminence (AE) and superior semicircular canal (SSC). If the drill bit includes the SSC dome (**B**), the structures are considered as coincident.

MATERIALS AND METHODS

This cross-sectional descriptive study was developed in the radiology department of a tertiary referral hospital and was approved by the Research Ethics Committee of this institution (protocol number 903.389). Data were collected between June and September 2016. Seventy-five consecutive patients who underwent a bilateral high-resolution temporal bone computed tomography (CT) scan between September 2015 and June 2016 were studied (150 sides). For each patient, measurements were obtained bilaterally. As evidence[14] shows that in chronic otitis media the contralateral ear often demonstrates radiologic abnormalities, we carefully included only healthy bilateral cases. All patients included in this study had no evidence of temporal bone disease or malformation. Exclusion criteria were radiologic evidence of ear disease, evidence of otologic or middle fossa surgery, and CT scans that did not meet the minimum image acquisition criteria specified later in this section.

Imaging Acquisition and Analysis

CT scans were performed using multidetector scanners (Philips Brilliance 16 Power model, software version 2.3.0 [Philips Medical Systems, Best, The Netherlands]; GE Brightspeed S8, software release 10 BW 27.7 [Chicago, Illinois, USA]). The images were analyzed using IMPAX software, version 6.6 (AGFA Healthcare, Mortsel, Belgium). Acquisition was in the axial plane at 0.75-mm slice thickness, and the images were reconstructed and analyzed using IMPAX Volume Viewing 3D software, version 3.1 (AGFA Healthcare), on a workstation. To avoid bias, radiologic findings were reported independently in a blind fashion by 2 authors (F.P.S., an otolaryngologist and M.G.L., a neuroradiologist), and disagreements were discussed in a consensus conference.

Measurements

The primary outcome of this study was the correspondence between the AE and the SSC. Drilling the bone of the AE is the strategy for SSC exposition. The size of drill bits determines the extent of the initial MCF opening. In our study, we considered the use of a 5-mm burr. If the SSC dome was within the scope of the drill bit (each side approximately 2 mm from the center), the AE could precisely lead to the SSC. Therefore, the structures were classified as coincident if the top of the SSC was found <2 mm of the midpoint of AE, in both the lateromedial and the anteroposterior planes (Figure 1). To resemble the intraoperative setting, the AE was first identified and marked parallel to the MCF surface in the axial plane, as the most superior appearance of the MCF floor (Figure 2A). Next, in the same axial plane,

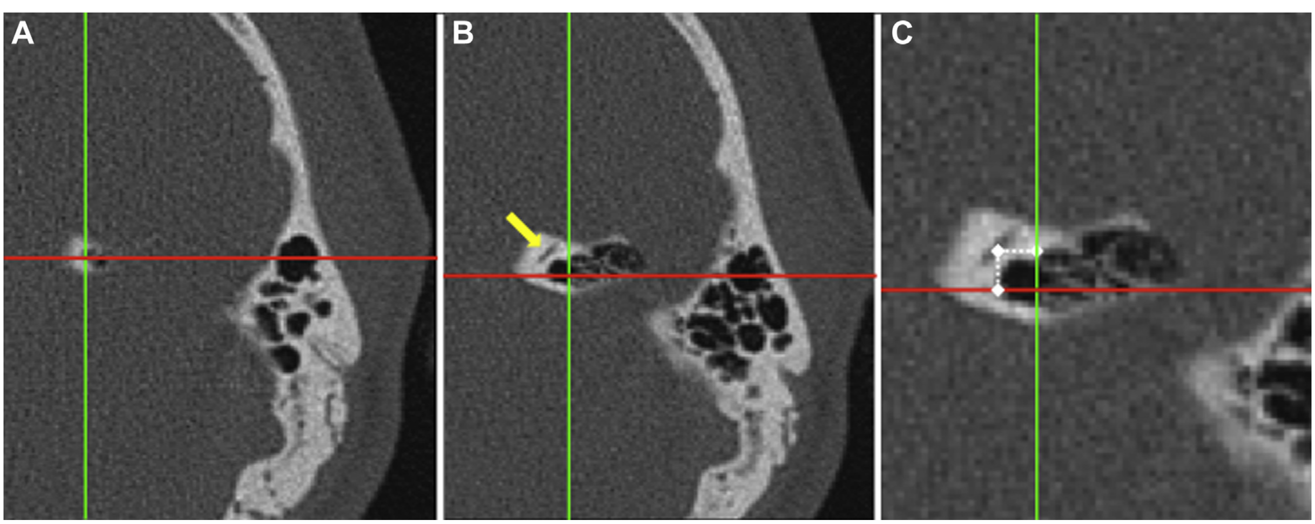

Figure 2. Axial temporal bone computed tomography scan (left side) demonstrates how measurements of the distances between the arcuate eminence and superior semicircular canal were carried out. (**A**) Arcuate eminence was identified. (**B**) Advancing inferiorly, superior semicircular canal (*arrow*) in its most superior appearance. (**C**) Distance in millimeters (*dashed lines*).

Table 1. Abbreviations and Descriptions of Measurements

Abbreviation	Description
M1 (AE—SSC LM)	Distance between AE and SSC in LM plane
M2 (AE—SSC AP)	Distance between AE and SSC in AP plane
M3 (SSC—MCF floor)	Distance between top of SSC and MCF floor in vertical plane
M4 (ZR—AE)	Distance between ZR and AE
M5 (ZR—SSC)	Distance between ZR and SSC
M6 (SSC—post IAC°)	Angle formed between SSC and posterior border of IAC
M7 (SSC—ant IAC°)	Angle formed between SSC and anterior border of IAC
M8 (Co—MCF floor)	Distance between top of cochlea and MCF floor in vertical plane
M9 (Co—SSC LM)	Distance between top of cochlea and SSC in LM plane
M10 (Co—SSC AP)	Distance between top of cochlea and SSC in AP plane
M11 (Co—SSC diag)	Diagonal distance between top of cochlea and SSC
M12 (IAC length)	Distance between Bill's bar and line connecting anterior and posterior edges of porus acusticus
M13 (IAC width)	Distance between anterior and posterior edges of IAC at midpoint between Bill's bar and porus acusticus
M14 (IAC roof)	Distance between roof of IAC and MCF floor in vertical plane
M15 (ZR—MH)	Distance between zygomatic root and MH
M16 (MH—Bill's bar)	Distance between MH and Bill's bar

M1—M16, measurements 1—16; AE, arcuate eminence; SSC, superior semicircular canal; LM, lateromedial; AP, anteroposterior; MCF, middle cranial fossa; ZR, zygomatic root; post, posterior; IAC, internal auditory canal; °, angle in degrees; ant, anterior; Co, cochlea; diag, diagonal; MH, malleus head.

advancing in a superior-to-inferior fashion, the SSC was marked in the first section its dome could be verified (Figure 2B). Next, distance in millimeters was obtained (Figure 2C).

Secondary outcomes included the measurements described in Table 1. Except for measurements 3, 8, and 14, which were obtained in a coronal plane, the remaining structures were also marked and measured in a similar fashion.

Sample Size Calculation and Statistical Analysis

Sample size was calculated according to the literature[15] using the following parameters: a confidence level (CI) of 0.95, an expected proportion of 0.3,[10,11,16] and a total width of the CI of 0.15. These figures yielded a sample size of at least 143 cases. Data were presented as mean ± SD or frequency and percentage. For comparing continuous variables, a Student t test or an unequal variance t test was used. Interobserver agreement among readings was assessed using the κ statistic for categorical variables and intra-class Kendall tau-a correlations for continuous measures. A P value <0.05 was considered to indicate statistical significance. All statistical analyses were performed using SPSS Version 18 (SPSS, Inc., Chicago, Illinois, USA).

RESULTS

Bilateral high-resolution temporal bone CT scans were performed in 75 patients (150 sides), including 40 women (53.3%), with a mean age of 51.1 ± 16.8 years. The anatomic relationship between the AE and the SSC in the MCF surface was classified as coincident in 47 cases (31.3%) and noncoincident in 70 cases (46.7%). In the remaining 33 of 150 cases (22.0%), the AE was not identified (Figure 3). The AE could be localized as lateral as 11.6 mm from the SSC. The maximal anteroposterior distance between these structures was 8.2 mm (Table 2). The AE was medial to the SSC in 10 temporal bones (6.7%) and anterior in only 1 case (0.67%). SSC dehiscence was found in 5 cases (3.3%). The average angle between the lumen of the SSC and the posterior and anterior borders of the internal auditory canal (IAC) was 28.8° and 46.0°, respectively. In 5 cases (3.3%), the latter angle was >60°. The distance between the zygomatic root and Bill's bar was 25.4 mm on average. The mean distance between the malleus head and the IAC fundus (Bill's bar) was 7.7 mm. Distances between the remaining structures are summarized in Table 3.

The inter-reader reproducibility for measurement 1 and measurement 2 was substantial, with agreement 82.7%, κ 0.654 (95% CI 0.533—0.774, P < 0.0001) and agreement 82.7%, κ 0.653 (95% CI 0.508—0.762, P < 0.0001), respectively. For the anatomic relationship between the AE and the SSC in the MCF surface, it was moderate, with agreement 82%, κ 0.569 (95% CI 0.425—0.713, P < 0.0001). Inter-reader reproducibility for the continuous measurements was poor in 2 areas (measurement 6 and measurement 13); however, the other areas showed good and excellent concordance (P < 0.0001). There was no statistically significant difference in measurements between sides and sexes.

DISCUSSION

For a long time, the AE has been used as a key reference to location of the SSC beneath the MCF surface; however, the real anatomic relationship remains controversial. Although some studies have reported a strict correspondence between these structures,[4,8,17] others have failed to demonstrate a prominent AE and SSC coincidence.[10,11,16,18,19] Our study showed a weak anatomic correspondence between the 2 structures, with the AE exactly matching the SSC in less than one third of cases. The AE could be found both laterally and medially to the SSC and located as far as 11.6 mm from the latter (Figure 4). Furthermore, the AE could not be recognized in a substantial proportion of patients. A few millimeters separated most of the analyzed landmarks, and a wide range for minimum and maximum values in the secondary measurements could be observed.

Although we have obtained reliable results regarding agreement between readers for the primary outcome and for most secondary measurements, measurement 6 and measurement 13 should be carefully interpreted, as they showed poor concordance. The angulated and sinuous shape of the posterior border of the IAC may have imposed technical difficulties on observers, resulting in disparate measurements. We think that observers could not precisely determine the exact IAC point to be marked and measured posteriorly. Thus, small shifts in the lateromedial plane may have resulted in wide variation in angles and distances. However, a

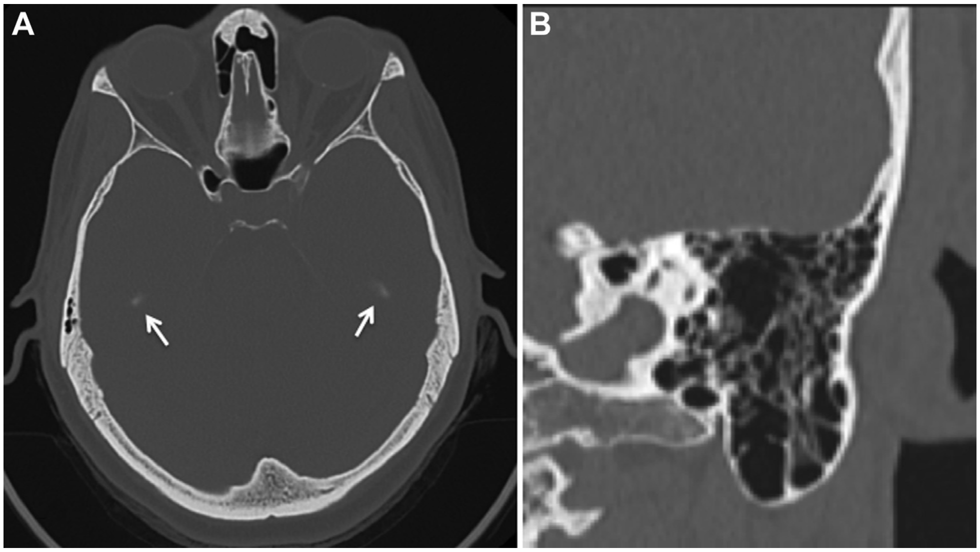

Figure 3. Temporal bone computed tomography (CT) scans illustrate examples of arcuate eminence (AE). (**A**) Axial CT scan shows a bilaterally obvious prominent AE (*arrows*). (**B**) Coronal CT image shows an undetectable AE. Note the flat middle cranial fossa surface.

single study on the AE and SSC relationship presented results from >1 examiner (CT slice thickness of 1.25 mm),[11] and, up to this time, no study had evaluated the interobserver agreement. Regarding technical issues of CT measurements, with the intention of resembling the surgical technique, we started with AE instead of SSC localization. In addition, it is reasonable to recognize that comparing radiologic and dissection measurements—as studied by Sennaroglu and Slattery[20]—should provide more substantial results.

Our results are in agreement with those of previously reported studies that found a poor positional association between the AE and the SSC. In 2 sequential studies, Tsunoda et al.[9,19] examined 13 Japanese (26 temporal bones) and 21 caucasian (42 temporal bones) cadavers and showed the AE to be absent in 7.8% and 19% of specimens, respectively. The authors found an 11.5% and 17% coincidence between the structures and suggested that AE is a trace of the occipitotemporal sulcus and did not exactly correspond to the SSC. Faure et al.[10] evaluated 100 CT scans of patients who presented with otologic pathology without pathologic changes in

Table 2. Arcuate Eminence and Superior Semicircular Canal Distances

Measurement	Mean ± SD	Min–Max
M1 (AE–SSC LM)	2.25 ± 2.27	0.0–11.6
M2 (AE–SSC AP)	2.23 ± 1.59	0.0–8.2
M3 (SSC–MCF)	1.07 ± 0.79	0.0–3.8

Distance measurements are in millimeters.
M1–M3, measurements 1–3; Min, minimum; Max, maximum; AE, arcuate eminence; SSC, superior semicircular canal; LM, lateromedial; AP, anteroposterior; MCF, middle cranial fossa.

Table 3. Distances and Angles Between Anatomic Landmarks in Middle Cranial Fossa

Measurement	Mean ± SD	Min–Max
M4 (ZR–AE)	20.1 ± 3.4	14.7–33.4
M5 (ZR–SSC)	21.9 ± 2.6	17.2–30.6
M6 (SSC–post IAC°)	28.8 ± 7.7	11.4–52.0
M7 (SSC–ant IAC°)	46.0 ± 8.1	22.8–66.4
M8 (Co–MCF floor)	3.3 ± 1.4	1.4–7.7
M9 (Co–SSC LM)	5.3 ± 1.1	3.0–7.9
M10 (Co–SSC AP)	5.4 ± 1.0	2.4–8.3
M11 (Co–SSC diag)	7.5 ± 1.3	4.6–10.2
M12 (IAC length)	10.4 ± 1.9	7.3–16.3
M13 (IAC width)	6.9 ± 1.5	4.1–11.1
M14 (IAC roof)	4.6 ± 1.8	1.3–17.0
M15 (ZR–MH)	17.7 ± 2.6	12.9–26.3
M16 (MH–Bill's bar)	7.7 ± 0.9	5.2–10.4

Distance measurements are in millimeters.
M4–M16, measurements 4–16; Min, minimum; Max, maximum; AE, arcuate eminence; SSC, superior semicircular canal; LM, lateromedial; AP, anteroposterior; MCF, middle cranial fossa; ZR, zygomatic root; post, posterior; IAC, internal auditory canal; °, angle in degrees; ant, anterior; Co, cochlea; diag, diagonal; MH, malleus head.

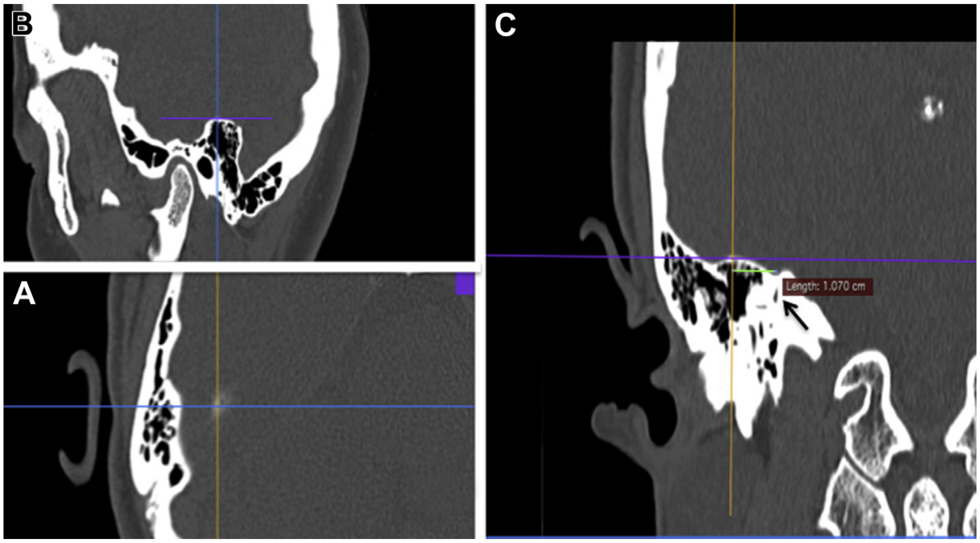

Figure 4. Computed tomography (CT) scans illustrate a lateral arcuate eminence (AE). (**A**) Axial CT scan demonstrating the most superior appearance of the middle cranial fossa floor (AE). (**B**) Corresponding sagittal CT image. (**C**) Coronal CT scan shows the AE lateral to the superior semicircular canal (*arrow*). Note that the midpoint of the AE does not coincide with the top of the superior semicircular canal because the AE has a posterior position.

the petrous bone. In 37 of 100 cases, the AE corresponded to the protrusion/projection/salience of the SSC, and in 15 cases it was impossible to be recognized. Bulsara et al.[21] analyzed 22 temporal bone CT scans and described the average distance separating the SSC and AE as 5.7 mm and the maximal distance as 10.4 mm. Djalilian et al.[11] studied 98 temporal bones on 1.25-mm-thick CT scans and found the AE over the SSC in 20.4%. Seo et al.[18] examined petrous bone scans of 26 Japanese patients scheduled for surgical extirpation of tumor and described the structures as coincident in 17% of cases.

Sennaroglu and Slattery[20] and Pons and Lombard[8] performed combined (CT scans and cadaveric specimens) studies and obtained similar results for radiologic and dissection measurements. Sennaroglu and Slattery[20] reported that the AE does not always coincide with the SSC, as angular measurements (obtained only on dissected specimens) showed divergent angles between the AE and the greater superficial petrosal nerve and the SSC and the greater superficial petrosal nerve. The second study by Pons and Lombard[8] was assisted by an image guidance system and showed that the AE lay directly above the SSC in 100% of their specimens. Several surgical approaches and respective different anatomic landmarks were proposed for IAC dissection.[3-6] **Table 4** summarizes the main distances and angles between remarkable MCF landmarks of previously published series compared with the current study.

Table 4. Previously Reported Distances and Angles Between MCF Landmarks

Series	Cases (Sides)	Method	M4	M5	M6	M7	M12	MH—Bill's bar (M15 and M16)
Bulsara et al., 2006[21]	22	CT	24.3 (18.8—29.6)	25.3 (20.3—30.2)	NR	NR	NR	NR
Djalilian et al., 2007[11]	98	CT	NR	21.1 (17.5—27.9)	42.3° (24—56.9)	60.8° (40.2—73.2)	11.6 (8.5—16.5)	25.7 (20.4—35)
Sennaroglu and Slattery, 2003[20]	10	Dissection	NR	NR	48.1° (42—54)*	NR	11.9 (8—15)	NR
Pons and Lombard, 2009[8]	10	CT	24.4 (23.2—26.3)	NR	NR	NR	NR	29.7 (28.2—31.1)
Current series	150	CT	20.1 (14.7—33.4)	21.9 (17.2—30.6)	28.8° (11.4—52)	46° (22.8—66.4)	10.4 (7.3—16.3)	25.4 (18.1—36.7)

Distance measurements are in millimeters. Minimum—maximum values for all measurements are given in parentheses.
M4, M5, M6, M7, M12, M15, M16, measurements 4—7, 12, 15, 16; MH, malleus head; CT, computed tomography; NR, not reported.
*Angle between superior semicircular canal and internal auditory canal axis, not anterior or posterior border.

The wide range observed in our secondary measurements is verified in the literature (Table 4)[8,11,20,21] and could be related to individual discrepancies of the cranial anatomy and degree of temporal bone pneumatization. We believe that surgeons should not rely on a single technique and/or anatomic reference because we lack a constant and universal landmark for every case. It is crucial to choose and combine inherent advantages of each approach and/or landmark according to the surgical case. A detailed preoperative and intraoperative radiologic assessment could estimate the distances and relationships between these structures and could be helpful in surgical planning.

The findings from our study do not minimize the previous reported usefulness of the AE for SSC location in MCF surgery. However, surgeons should be aware of the frequent lack of association between these structures in the skull base. Moreover, the noticeable variance observed in the secondary measurements suggests that it is critical to be familiar with alternative approaches and diverse external and internal anatomic landmarks to avoid iatrogenic damage to neurovascular structures.

CONCLUSIONS

The AE does not systematically overlie the SSC. Therefore, regular use of the AE as a reference to reach the SSC in MCF surgery could be dangerous, as the AE was absent in 22% of our cases and matched the SSC in less than one third of cases.

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