Exposure of the Petrous Segment of the Internal Carotid Artery Through the Extradural Subtemporal Middle Cranial Fossa Approach: A Systematic Anatomical Study

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ABSTRACT

The relationships between the horizontal segment of the internal carotid artery (ICA) and other petrous apex structures was studied in 14 anatomical specimens obtained from routine autopsies and on 10 magnetic resonance images obtained from healthy volunteers. The dissection was performed under an operating microscope using the middle fossa transpetrous approach. A pentagon-shaped area of 67.91 mm² posterior to the trigeminal nerve and bordered by anatomical structures was identified inside the petrous apex. The results suggest a method for exposing the ICA when the artery is not visible after dural elevation.

KEYWORDS: Carotid artery, skull base, transpetrous approach, temporal bone anatomy

The horizontal segment of the petrous internal carotid artery (ICA) can be exposed through the extradural subtemporal middle cranial fossa approach,¹⁻¹⁶ which requires good knowledge of the anatomy of the petrous apex.^{1,2,5-8,10,12-15,17} In par-

ticular, the relationship among the structures of the petrous apex must be understood. We performed a systematic anatomical study to determine a safe and effective method for exposing the ICA through the above approach.

MATERIALS AND METHODS

During routine autopsies 14 tissue blocks (7 right and 7 left) were removed from cadavers with no history of diseases involving the central nervous system or skull base. There were six males and eight females aged 54 to 94 years [mean, 71.2 years; standard deviation (SD), 14.3 years].

During exposure of the cranial base, cranial nerves III to XII were preserved. Each anatomical specimen included the following structures: the temporal bone, sella turcica with pituitary gland, cavernous sinus, superior orbital fissure, dura mater covering the endocranial surface of the skull base, the muscles of the infratemporal fossa inserted on the lateral cranial base, and the ascending branch of the mandible.

The ICA and the jugular vein (JV) were washed with a saline solution and injected with a gelatin-dye compound: red for the ICA and blue for the JV. Each tissue block was placed at -4°C for 15 minutes to harden the gelatin. The blocks were preserved in a 10% formalin solution for 48 hours before being dissected.

The tissue blocks were placed in the surgical position used for the extradural subtemporal middle cranial fossa approach. The dissection and the

measurements were made under an operating microscope (Leica MS, Switzerland): first the surface structures and then the deeper ones evident after bone removal. Linear measurements were made with a microcaliper whereas angular measurements were made with a goniometer.

The temporalis squama was removed. The dura mater of the middle cranial fossa was dissected from the bone and elevated from the arcuate eminence to the gasserian ganglion (GaG) after the meningeal artery was sectioned at the foramen spinosum. The bone was drilled in the area bordered by the internal auditory canal (IAC), the superior petrosal sinus (SPS), the GaG, the horizontal segment of the ICA, and the cochlea (Fig. 1). The petrous segment of the ICA under the GaG was exposed in three steps. First, the third trigeminal branch (V_3) was retracted anteriorly (Fig. 2A). Next, after the trigeminal nerve was retracted, V_3 and the second trigeminal branch (V_2) were decompressed to enlarge the foramen ovale and rotundum by drilling (Fig. 2B). Finally, V_3 was sectioned (Fig. 2C). After each step the length of the exposed ICA was measured.

Our anatomic material was unsuitable to study the relationship between the stato-acoustic-

Figure 1 Schematic drawing of the structures exposed during the extended middle cranial fossa approach. ICA, internal carotid artery; GSPN, greater superficial petrosal nerve; GG, geniculate ganglion; GaG, gasserian ganglion; IAM, internal auditory meatus; IAC, internal auditory canal; SPS, superior petrosal sinus.

Figure 2 (A) Schematic drawing of the internal carotid artery (ICA) exposed by retraction of V3 during the extended middle cranial fossa approach. (B) Schematic drawing of the extent of the ICA exposed by retraction of V3 after decompression of V2 and V3 at the foramina ovale and rotundum. (C) Schematic drawing of the extent of the ICA exposed by sectioning V3. GSPN, greater superficial petrosal nerve; GG, geniculate ganglion; GaG, gasserian ganglion; IAM, internal auditory meatus; IAC, internal auditory canal; SPS, superior petrosal sinus.

facial bundle and the internal auditory meatus (IAM). Therefore, we measured the distance between the anterior border of the IAM and the cranial nerves VII to VIII on the magnetic resonance images (MRIs) of 10 healthy volunteers aged 18 to 68 years (mean, 35.3 years; SD, 18.9 years). The examinations were conducted on axial 3DFT-CISS (0.7 mm, gradient-echo images) sequences (CISS, Constructive Interference in Steady State) using a 1.5 T supraconductive magnet (Siemens Vision, Germany). The sequences adopted for the study of the cerebellopontine cystern and the intralabyrinthine fluid spaces were the same as described elsewhere (TR/TE12.2/5.1/1, acquisitions 2, 192 x 512 matrix; 150 x 200 field of view) (Fig. 3).¹⁸⁻²⁰

The mean (X_M), SD, range, and 95% confidence limits (CL) were calculated for all measurements. The latter is defined as the range within which a 95% probability of finding the real mean of the population (μ) is found. These limits were obtained by the *t* distribution with ($n - 1$) degrees of freedom, where *n* represents the number of tissue blocks using the following formula:

$$\text{confidence limits } 95\% = X_M \pm t_{n-1, 0.05} \cdot \text{SD}/\sqrt{n}$$

where $t_{n-1, 0.05} = 2.201$ as reported in the two-tails *t* distribution table with ($n - 1$) degrees of freedom. Areas were calculated by dividing them into triangles and applying Carnot's theorem ($a^2 = b^2 + c^2 - 2bc \cos \alpha$ where *a*, *b*, *c* are the sides and α is the angle opposite *a*).

Figure 3 MRI of a healthy volunteer; the anterior border of the internal auditory canal (IAC) is not in contact with the acoustic-facial bundle.

RESULTS

There were no significant differences between any of the measurements on the right and left sides (Tables 1–6).

Structures Around the ICA

In 63% of the specimens, the petrous segment was visible behind V_3 after dural elevation. The mean length of the exposed portion was 2.5 mm (SD, 1.85; Table 1). In the remaining tissue blocks the ICA was covered by a bony shell whose thickness varied from a few fractions of a millimeter to 1.5 mm. In 43% of these specimens the artery could be identified after simple retraction of V_3 . In the other 57% of specimens a thin bony shell (43%) or a thick bony leaf (14%) were interposed between the artery and the undersurface of the GaG (Table 1).

In 14% of the specimens, the geniculate ganglion (GG) was totally or partially uncovered by bone (Table 1). The mean distance between the posterior root of the zygomatic arch and the GG was 25.16 mm (SD, 1.64 mm).

In all our specimens, the tensor tympani muscle was covered by bone. The muscle was lo-

Table 1 Morphologic Features of Surface Structures in 14 Tissue Blocks

	Tissue Blocks No. (%)
<i>Length of ICA not covered by bone</i>	
Not visible	5 (37%)
6 mm	1 (7%)
4 mm	2 (14%)
2 mm	1 (7%)
1.5 mm	2 (14%)
1 mm	2 (14%)
0.5 mm	1 (7%)
<i>Tissue interposed between ICA and GaG</i>	
None	6 (43%)
Subtle bony leaf	6 (43%)
Thick bony leaf	2 (14%)
<i>Tissue interposed between GG and dura</i>	
Bone	12 (86%)
GG partially covered by bone	1 (7%)
Uncovered	1 (7%)

ICA, internal carotid artery; GaG, gasserian ganglion; GG, geniculate ganglion

cated above the Eustachian tube, lateral and parallel to the horizontal portion of the carotid canal.

The mean length of the greater superficial petrosal nerve (GSPN) was 14.68 mm (SD, 1.78 mm) from its origin at the GG to the GaG (Table 2). The nerve courses under the dura and forms an angle of 89.25 degrees (SD, 19.64 degrees) with V_3 (Table 3). In all specimens the GSPN was identified above the roof of the lateral half of the carotid canal forming an angle of 15.08 degrees (SD, 6.39 degrees) with the axis of the ICA (Table 3).

The foramen ovale was anteromedial to the foramen spinosum. The latter was located 21.5 mm (SD, 1.88) from the inner table of the temporalis squama at the level of the posterior root of the zygoma. These foramina are separated by a distance of 3.16 mm (SD, 1.03). The distance between the foramen ovale and the foramen rotundum was 8.33 mm (SD, 2.88; range, 3 to 13 mm). These two foramina were located, respectively, at 6.04 mm

Table 2 Distance Between Structures After Bone Removal and Related Parameters

Structures	Mean Total Values (mm)	SD (mm)	Range (mm)	95% Confidence Limits (mm)
Posterior zygomatic root to GG	25.16	1.64	23–29	24.11–26.2
Junction of the GSPN with V ₃ to GG	14.68	1.78	12–17	13.63–15.72
Depth of cochlea from surface of middle cranial fossa (point of reference: tip of arcuate eminence)	5.5	2.12	3–9	4.15–6.84
Diameter of IAM	5.68	1.29	3.5–7	4.92–6.43

SD, standard deviation; GG, geniculate ganglion; GSPN, greater superficial petrosal nerve; IAM, internal auditory meatus

(SD, 2.33) and 16.79 mm (SD, 2.96) from the junction of V₃ and GSPN (Table 4).

The angle between V₂ and V₃ was 65.91 degrees (SD, 22.66 degrees); the posterior border of GaG described an angle of 101.66 degrees (SD, 9.33 degrees). SpS defined an angle of 128.5 degrees (SD, 5.99 degrees) with the anterior wall of the IAC (Table 3). Along its anterior dural wall, the cochlea was exposed to a depth of 5.5 mm (SD, 2.12) from the surface of the temporal bone at the tip of the arcuate eminence. The mean diameter of the IAM was 5.68 mm (SD, 1.29 mm) (Table 2), and the distance on the MRI from its anterior border to the VII-VIII cranial nerve complex was 3.51 mm (SD, 2.60 mm; range, 2.0 to 4.0 mm; 95% CL 1.70 to 5.31 mm; Fig. 3).

Horizontal Segment of the ICA

The horizontal segment of the ICA began at the posterior loop, which was 3 mm (SD, 1.06 mm) anterolateral to the tip of the cochlea and 6.0 mm to the GG (SD, 1.9 mm). Its lateral surface was located at 5.04 mm (SD, 1.38 mm) from the foramen spinosum and 5.95 mm (SD, 1.69 mm) from the foramen ovale (Table 5).

The ICA described an angle of 19.25 degrees (SD, 2.71 degrees; range, 15 to 25 degrees; CL, 17.65 to 20.84 degrees) with the SpS and an angle of 38.54 degrees (SD, 5.56 degrees; range, 31 to 50 degrees; CL, 35 to 42.07 degrees) with the IAC (Table 3). The diameter of the ICA was quite constant (mean, 5.25 mm; SD, 0.54 mm), and its

Table 3 Angular Measurements of Relationships Among Structures

Structures	Mean Angle (Degrees)	SD (Degrees)	Range (Degrees)	95% Confidence Limits (Degrees)
GSPN and V ₃	89.25	19.64	60–115	76.8–101.72
GSPN and axis of the carotid canal	15.08	6.39	0–35	11.32–18.83
V ₂ and V ₃	65.91	22.66	29–112	52.58–79.23
SpS and GaG	101.66	9.33	90–119	95.73–107
IAC (anterior wall) and SPS	128.5	5.99	118–140	124.9–137
ICA and SpS	19.25	2.71	12–25	17.65–20.84
ICA and IAC	38.54	5.56	31–50	35–42.07

SD, standard deviation; GSPN, great superficial petrosal nerve; SPS, superior petrosal sinus; GaG, gasserian ganglion; IAC, internal auditory canal; ICA, internal carotid artery

Table 4 Distance Between Surface Structures

Structures	Distance Total Values (mm)	SD (mm)	Range (mm)	95% Confidence Limits (mm)
Foramen spinosum to temporalis squama at posterior root of zygoma	21.5	1.88	19–25	20.3–22.69
Foramen spinosum to lateral border of the foramen ovale	3.16	1.03	1–5	2.5–3.81
Medial border of foramen ovale to foramen rotundum	8.33	2.88	3–13	6.5–10.16
Junction of GSPN with V_3 to foramen ovale	6.04	2.33	3–11.5	4.55–7.52
Junction of GSPN with V_3 to foramen rotundum	16.79	2.96	12.5–21	14.9–18.67

GSPN, greater superficial petrosal nerve

mean length from the posterior loop to V_3 was 8.33 mm (SD, 1.47 mm; Table 5).

Three different degrees of exposure of the ICA were obtained after a progressive mobilization of the trigeminal nerve. Simple retraction of V_3 exposed the ICA 3.91 mm (SD, 1.14 mm; Fig. 2A). This value increased by 6.08 mm (SD, 1.01 mm)

when V_3 and V_2 were decompressed from their bony canals (Fig. 2B) and by 9.16 mm (SD, 1.38 mm) after V_3 was cut at the foramen ovale and then retracted (Fig. 2C, Table 5).

Between the carotid segment and the trigeminal complex in all specimens, a thick fibrous tissue formed by the inferior layer of the GaG

Table 5 Distance Between ICA and Surrounding Structures and Extent of Exposure

Structures	Mean Distance Values (mm)	SD (mm)	Range (mm)	95% Confidence Limits (mm)
Tip of cochlea to posterior loop of ICA	3	1.06	2–5.5	2.32–3.67
GG to posterior loop of ICA	6	1.9	3–8.5	4.88–7.11
Foramen spinosum to lateral wall of ICA	5.04	1.38	3–7	4.16–5.91
Foramen ovale to lateral wall of ICA	5.95	1.69	3–9	4.27–7.02
Diameter of ICA	5.25	0.54	4.5–6	4.9–5.59
Length of horizontal segment of ICA	8.33	1.47	6.5–11.5	7.46–9.19
Exposure of ICA after retraction of V_3	3.91	1.14	2.5–6.5	3.18–4.63
Exposure of ICA after trigeminal retraction and decompression of V_3 and V_2	6.08	1.01	4–8	5.48–6.67
Exposure of ICA after section and retraction of V_3	9.16	1.38	6–11	8.28–10.03

SD, standard deviation; ICA, internal carotid artery; GG, geniculate ganglion

dural sleeve was firmly adherent to the arterial adventitia and to the epineurium of the inferior surface of the ganglion.

Post-trigeminal Area

A pentagon-shaped bony surface posterior to the GaG (Fig. 4) was named the "pentagonal post-trigeminal area" (PPTA). The area represents the anterior aspect of Kawase's triangle^{9,11} anterior to the IAC. Its sides were defined by the lines traced between the junction points (P1 to P₅) at the vertices of the pentagon (see Table 6 for explanations). The mean PPTA surface was 67.91 mm² (SD, 10.5; range, 47.5 to 85.7 mm²; CL, 61.73 to 74.08 mm²; Table 6).

DISCUSSION

The intent of this morphometric study was to systematically define the anatomic relationships among recognizable landmarks of the petrous apex. The data helped to safely expose the petrous segment of the ICA in cadavers during the extradural middle cranial fossa approach.

In 14 to 16% of cases the GG is totally free of or only partially covered by bone.^{13,14} This condition increases the risk of injury during dural elevation. In our material the GG was located 21.5 mm (SD, 1.88 mm) from the inner table of the middle cranial fossa at the posterior root of the zygomatic arch and was totally uncovered in 7% of the specimens.

After dural elevation the ICA has been reported to be visible just behind the posterior border of V₃ in 68% of cases;¹³ in our material it was visible in 63% of the specimens.

Clinically, V₃ can be divided. It causes immediate postoperative anesthesia of the lower face and tongue. Typically, sensitivity reappears in both regions after 9 to 12 months. Permanent anesthesia or pain (anesthesia dolorosa) is unusual.^{4,6,21}

We called the surface behind the posterior loop of the ICA the "forbidden zone" (FZ). Anteriorly, it is bordered by a vertical plane tangent to its posterior loop. This area should not be drilled to avoid injuring the cochlea (Fig. 5).

When the ICA is visible after dural elevation or can be identified by retracting V₃, the carotid canal can be unroofed using intracranial palpation. This technique was suitable to expose the ICA in 79% of our specimens. When this tech-

Figure 4 (A) An anatomical specimen dissected through the subtemporal middle cranial fossa approach. The pentagonal post-trigeminal area (PPTA) is evident. (B) Schematic drawing of the extended middle cranial fossa approach showing the PPTA. ICA, internal carotid artery; GSPN, greater superficial petrosal nerve; GG, geniculate ganglion; GaG, gasserian ganglion; IAM, internal auditory meatus; IAC, internal auditory canal; SPS, superior petrosal sinus.

Table 6 Length of the Borders of the Pentagonal Post-Trigeminal Area

Borders	Mean Length Values (mm)	SD (mm)	Range (mm)	95% Confidence Limits (mm)
P ₁ -P ₂	3.13	1.16	2-5	2.44-3.81
P ₂ -P ₃	8.54	2.09	6-13	7.31-9.76
P ₃ -P ₄	5.36	0.86	4-6.5	4.85-5.86
P ₄ -P ₅	6.64	0.92	5-8	6.09-7.18
P ₅ -P ₁	8.55	1.35	9-14	7.75-9.34
Area	67.91 mm ²	10.5 mm ²	47.5-85.7 mm ²	61.73-74.08 mm ²

SD; standard deviation

P₁, junction of the posterior border of the gasserian ganglion and the superior petrosal sinus; P₂, junction of SPS and a straight line projected along the anterior border of the internal auditory canal from P₃; P₃, junction of cochlea and the anterior border of the internal auditory canal; P₄, junction of a tangent line to the cochlea from P₃ and the internal auditory canal in its most medial part; P₅, junction of the medial border of the horizontal part of the internal carotid artery and the posterior margin of V₃

nique is unsuitable, different techniques of ICA exposure can be adopted.

Sekhar et al.¹⁵ proposed that drilling should begin over the roof of the carotid canal medial to the GSPN at its junction with the posterior border of V₃. The ICA axis describes an angle with the

GSPN of about 15 degrees opened toward V₃. This angle permits the larger ICA surface further from the cochlea to be exposed. That this method is based on well-defined landmarks such as the GSPN and V₃ is an advantage. According to Paullus et al.,¹³ the GSPN is located directly above the lateral border of the carotid canal in 66% of cases and laterally to it in 20% of cases. In all our specimens, the GSPN was located over the roof of the lateral half of the carotid canal making rapid identification of the ICA possible. When this method is used, the variable thickness of the bone must be considered to avoid damaging the ICA.

Others^{3,16} have suggested unroofing the carotid canal by drilling 10 mm medially to a line connecting the centers of the foramina ovale and spinosum. In our study, the distances from these foramina and the lateral border of the carotid canal were quite constant. When using this method, the variable thickness of the canal roof should be considered. Velut and Jan¹⁶ described a *zone interdite*, medial and posterior to the ICA, which should be avoided during drilling. According to our results, their zone interdite does not include the entire cochlea. In contrast, the forbidden zone described here does include the entire cochlea.

Figure 5 Schematic drawing of the extended middle cranial fossa approach showing the forbidden zone (FZ), which should be avoided during drilling. The "key point" at which drilling starts is marked by the black triangle. ICA, internal carotid artery; GSPN, greater superficial petrosal nerve; GG, geniculate ganglion; GaG, gasserian ganglion; IAM, internal auditory meatus; IAC, internal auditory canal; SPS, superior petrosal sinus.

Dolenc et al.^{22,23} suggested that drilling should start 5 to 8 mm medial to the foramen spinosum and posterior to V_3 . With this approach, the tensor tympani muscle is the first structure identified to determine the correct position of the underlying Eustachian tube and ICA. However, the muscle cannot be seen because it is covered by bone as found in all our specimens; consequently, the risk of damaging it should be considered.

The advantage of drilling inside Glasscock's triangle (bordered laterally by a line from the foramen spinosum to the facial hiatus, medially by the GSPN, and anteriorly by the mandibular division of the trigeminal nerve)^{7,8,11,24} is that the ICA can be approached quickly in a lateromedial direction. However, the tensor tympani muscle and the Eustachian tube can still be injured while approaching the carotid canal.

One study focused on exposing the IAC defined an area of removable bone anterior to the IAC and medial to the ICA.¹² The key point of the procedure was to identify the IAC by tracing an imaginary 45-degree angle from the SpS to the intersection of the lines traced along the GSPN and the arcuate eminence. In our material the 128.5-degree angle between the anterior border of the IAC and the SpS was quite constant (SD, 5.99 degrees). If this angle can be identified intraoperatively, identifying the arcuate eminence could be unnecessary when exposing the IAC.

According to our data, V_3 and GSPN are the landmarks most evident during exposure of the ICA. During dissections, both the ICA and IAC were considered the important structures to identify before bone was removed between them. The length of the second border (P_2-P_3) of the PPTA was quite constant (mean, 8.54 mm; SD, 2.09) as was the 38.54-degree angle described by the IAC and ICA (SD, 5.56 degrees; 95% CL, 35 to 42.07 degrees).

The "key point" (Fig. 5) from which to start drilling was the junction of the posterior border of the GaG and SpS. Drilling was continued along the first border of the PPTA to expose the anterior border of the IAM. This maneuver was safe be-

cause the VII-VIII cranial nerve complex did not adhere to the anterior border of the IAM as shown by the MRIs from the healthy volunteers. At that point the anterior wall of IAC was exposed no more than 5 mm from the IAM to avoid opening the cochlea. This maneuver made it possible to define the axis of the IAC and consequently the expected axis of the ICA. The bone was then removed along the posterior border of the GaG approaching the ICA segment. Using a wide-diameter diamond burr under continuous suction-irrigation, the carotid canal was reached without risk of damaging the vessel.

After the medial border of the carotid canal was unroofed just behind V_3 , the drilling continued. The IAC was palpated from inside with a smooth microdissector to identify the vertical segment of the ICA just anterior to the tip of the cochlea.

If necessary, bone removal was extended inside the PPTA to reach the dura of the petrous apex below the SpS to approach the posterior fossa.

When this method was used to expose the ICA, neither the ICA, IAC dura, nor cochlea was damaged in any specimens.

In our experience, the "key point" is the safest point from which to start drilling because it is the farthest away from the ICA, IAC, and cochlea.

This method of exposing the ICA differs in two ways from those previously described.^{3,7,12,15,16,22} First, drilling starts at the most medial part of the petrous apex and proceeds laterally toward the ICA. Second, the IAC is exposed without identifying the arcuate eminence.

CONCLUSION

A systematic anatomical study using the subtemporal middle cranial fossa approach was conducted on cadaveric specimens. MRIs from volunteers showed that the acoustic-facial bundle did not adhere to the anterior border of the IAM. Inside a structureless zone called "the pentagonal-post-trigeminal area"

immediately posterior to the GaG and lateral to the SpS, we identified a safe point to start drilling to expose the horizontal segment of the ICA. Moreover a "forbidden zone" that should be avoided during drilling was identified posterior to the ICA loop. This zone includes the entire cochlea.

COMMENTS FOR PUBLICATION

This detailed morphometric study of the surgical anatomy of the middle fossa describes relationships among extradural structures. The critical structures were measured accurately in 14 adult skull base blocks. These measurements are useful for practicing surgeons and for residents early in their experience and should be studied carefully.

There are several ways to expose the petrous segment of the ICA in the temporal bone, depending on how much of the artery needs to be exposed. I prefer to preserve the GSPN by sharply incising a layer of the periosteal dura, which is left with the nerve and used to elevate the rest of the middle fossa dura from the bone. The artery is often devoid of a bony cover and can be found underneath the nerve. Otherwise, the bone under the GSPN is drilled away carefully with a diamond burr until the horizontal segment of the ICA is exposed. It is important to recognize the location of the Eustachian tube immediately lateral to the artery. If it is opened inadvertently, a cerebrospinal fluid fistula can result. The artery is then separated from the bony canal by developing a subperiosteal plane with a dissector. Proximal control of the artery can be obtained by establishing the subperiosteal plane and by using a no. 2 or no. 3 Fogarty balloon catheter. Inflating the balloon compresses the artery in its bony canal temporarily occluding the vessel. This technique is preferable to using an aneurysm clip.

This important information should be studied personally in cadaveric dissections by all surgeons working in this area.

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