Petrous Carotid Exposure with Eustachian Tube Preservation: A Morphometric Elucidation

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ABSTRACT

Inadvertent injury to eustachian tube leading to cerebrospinal fluid rhinorrhea is a known complication associated with drilling of Glasscock's triangle to expose the horizontal petrous internal carotid artery (ICA) for management of difficult tumors (especially malignant) or aneurysms at the cranial base. Contrary to the usual approach, we hypothesize that a "medial-to-lateral" approach to Glasscock's triangle drilling will minimize eustachian tube injury. Four formalin-fixed human cadaveric heads were dissected, and underwent appropriate morphometric analysis; yielding a total of eight datasets. The diameter of the horizontal petrous ICA exposed was 4.7 ± 0.9 mm (range, 3.8 to 5.6 mm). The mean distance from the medial carotid wall midpoint to the medial-most point on the eustachian tube was 6.35 ± 0.58 mm (range, 5.4 to 7.1 mm), yielding a "safety zone" for eustachian tube, ranging 0.2 to 1.9 mm lateral to the lateral carotid wall. With the medial-to-lateral approach, the eustachian tube remained preserved in all the specimens. The results of our study provide a practical, consistent, and safe method of maximizing horizontal petrous carotid artery exposure while minimizing the eustachian tube injury.

KEYWORDS: Petrous, carotid, eustachian tube, morphometric

The last two decades have seen tremendous evolution in skull base surgery. Even though skull base surgical techniques have evolved over time, the post-operative morbidity and mortality associated with them are a major area of concern for the surgeon considering quality of life as an important outcome parameter gauging the operative success.

Surgical management of complex aneurysms, vascular lesions, and tumors encasing or invading the internal carotid artery (ICA) located at the skull base necessitates the exposure of the horizontal segment of the ICA located in the petrous bone. The most popular approach described to achieve the latter is the middle fossa approach or its variants.¹⁻⁵ The complex anatomy

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of the neighboring neurovascular structures makes the adequate exposure of the petrous carotid challenging. Cerebrospinal fluid (CSF) rhinorrhea is one of the complications frequently encountered while exposing the same. It results from the inadvertent injury caused to the eustachian tube while drilling in the anterior middle fossa, attributable to the close proximity of the eustachian tube to the lateral wall of ICA.⁶⁻⁹

Two major geometrical figures described to approach the lesions through middle fossa approach are the Glasscock's triangle and middle fossa rhomboid.^{4,10} The standard approach where 270 degree exposure of the horizontal petrous carotid is achieved through middle fossa approach involves the drilling over the Glasscock's triangle, proceeding to the anteromedial part of middle fossa rhomboid.^{4,11-13} The trajectory for this particular type of drilling is "lateral" to "medial" middle fossa orientation. The higher probability of damaging the eustachian tube associated with the standard technique and the lack of anatomical studies to validate the safety of the alternative medial-to-lateral approach prompted us to do a morphometric analytical study.

MATERIALS AND METHODS

Four formalin-fixed human cadaveric heads were dissected, yielding a total of eight datasets. In each specimen, the standard extended middle cranial fossa (MCF) approach was performed. Under a Zeiss operating microscope, drilling of the cranial base was commenced in the "middle-fossa rhomboid," medial to the greater superficial petrosal nerve (GSPN), and then continued lateral into the Glasscock's triangle. The medial carotid wall, the horizontal petrous carotid, the lateral carotid wall, and the eustachian tube draped by tensor tympani fibers were exposed in that order. The distances from the medial carotid wall midpoint to the eustachian tube were measured using calipers that were then compared with a template calibrated to the nearest 1/25 (0.04) mm.

RESULTS

In all our dissections, the eustachian tube remained preserved during the 270 degree exposure of the horizontal petrous carotid. The diameter of the horizontal petrous ICA exposed was 4.7 ± 0.9 mm (range, 3.8 to 5.6 mm). The mean distance from the medial carotid wall midpoint to the medial-most point on the eustachian tube was 6.35 ± 0.58 mm (range, 5.4 to 7.1 mm) (Table 1), yielding a "safety zone" ranging 0.2 to 1.9 mm lateral to the lateral carotid wall. We further noted that a "triangular area" of MCF base (bounded by the foramen spinosum, the foramen ovale and the arcuate eminence), corresponding to the "safety zone for eustachian tube," transgressed the Glasscock's triangle which

Table 1 Mean Distance from the Medial Carotid Wall Midpoint to the Medial-Most Point on the Eustachian Tube

Serial Number	Distance (in mm)
1	R = 6.2
1	L = 5.7
2	R = 5.4
2	L = 6.9
3	R = 6.7
3	L = 6.3
4	R = 7.1
4	L = 6.5
Mean $\pm$ SD	6.35 $\pm$ 0.58 mm (Mean R = 6.35 $\pm$ 0.73 mm; Mean L = 6.35 $\pm$ 0.50 mm)

L, left side; R, right side; SD, standard deviation.

need not be subjected to drilling for adequate horizontal petrous carotid exposure; thus minimizing eustachian tube injury. Figs. 1 to 3 illustrate our hypothesis.

DISCUSSION

Historical Perspective

The concept of exposing the petrous ICA in treating skull base lesions was described by Glasscock¹⁰ in 1969. Expanding on this platform, the team of Paullus et al in 1977 did a morphometric analytical study on cadaveric heads exposing 50 petrous ICAs.¹ This was an attempt to find a better alternative site for bypass vein graft in the management of occluded cervical portion of ICA, which was originally treated by a vein graft bypass from the common carotid to the supraclinoid segment of the ICA. The next two decades saw numerous innovations of the technique which mostly involved the extradural exposure of the horizontal segment of the petrous carotid. Washer et al in 1993 published an alternative transdural route to the same, as opposed to the classical extradural.¹²

Indications

The most common indications for exposing the petrous carotid can be broadly classified into four categories^{1,14}: (1) aneurysm, (2) tumor, (3) atherosclerosis, and (4) traumatic.

The major etiological factors for consideration in the aneurysms of petrous carotid are congenital, traumatic, atherosclerotic, or of postinfectious origin. Cerebral revascularization as a management for petrous carotid aneurysms is well documented.^{2,15-17}

Some skull base and cavernous sinus tumors encasing or invading the carotid which demand tumor

Figure 1 Cadaveric dissection showing the important surgical landmarks via the middle fossa approach. F.O., foramen ovale; F.S., foramen spinosum; gspn, greater superficial petrosal nerve; MCF Rhom, middle cranial fossa rhomboid; V3, third division of trigeminal nerve.

resection, a high flow bypass strategy (petrous-to-supraclinoid ICA) might be a necessary to achieve carotid occlusion in them.^{2,16} Tumors in the cavernous sinus sometimes require proximal ICA control, which is achieved by exposing the horizontal segment of the petrous ICA.

Atherosclerosis not only has a role in the development of an aneurysm, but also can result in major vessel stenosis, thereby mandating cerebral revascularization in selected cases.¹

Lastly, trauma cases involving skull base injuries can cause carotid intimal dissection which might require an open repair.¹⁴

Surgical Approaches

Although the exact location and type of pathology dictates the type of approach a surgeon undertakes, the most widely accepted approach used to expose the horizontal portion of the petrous ICA is the extended middle fossa approach. This was described for the first time in 1985 by Kawase et al to approach sphenopetroclival meningiomas and midlower basilar trunk aneurysms.^{18,19} But the ideology of removing the zygomatic bone which is critical to improve the surgical corridor and exposure of the petrous ICA was introduced by Fisch and Pillsbury in 1979.²⁰ Their technique was then refined in 1990 by al-Mefty and Anand, which

Figure 2 Drilling of the middle cranial fossa (MCF) rhomboid is initiated first and is continued along the direction of greater superficial petrosal nerve (GSPN) in front to back fashion. A.E., arcuate eminence; F.O., foramen ovale; F.S., foramen spinosum; gspn, greater superficial petrosal nerve; V3, third division of trigeminal nerve.

Figure 3 After drilling the MCF rhomboid, Glasscock's triangle is drilled and horizontal petrous carotid is exposed. Eustachian tube draped by tensor tympani is preserved. A.E., arcuate eminence; gspn, greater superficial petrosal nerve; ICA, internal carotid artery; MCF Rhom, middle cranial fossa rhomboid; V3, third division of trigeminal nerve.

considerably decreased the morbidity and increased the surgical access to skull base.²¹ The contributions made to define the geometrical constructs of the middle fossa floor are invaluable.⁴ The triangular area bordered by V3, GSPN, and the line joining foramen spinosum to arcuate eminence, was originally described by Glasscock in 1969, known as the Glasscock's triangle.¹⁰ This area served as the most popular geometrical landmark for initiating the exposure of the horizontal segment of the petrous ICA.^{4,11–13} Additionally, the anatomical knowledge of the middle fossa floor was advanced by various microanatomical studies.^{4,22,23} Defining the rhomboid construct made the 270 degree circumferential exposure of the petrous carotid possible.

Glasscock to Rhomboid or Rhomboid to Glasscock?

The standard approach for an adequate exposure to the petrous ICA includes the extended middle fossa approach. The key steps for this approach involve a question mark-shaped preauricular incision, a frontotemporal craniotomy followed by zygomatic osteotomy, an extradural exposure of the middle fossa for location of the arcuate eminence and identification of foramen spinosum. To note, the arcuate eminence and foramen spinosum are the important landmarks in the MCF surgery.^{4,22}

Then the GSPN is dissected anteroposteriorly from the GSPN-V3 confluence, mentally drawing the geometrical middle fossa constructs: the Glasscock triangle and the MCF rhomboid. Jittapiromsak et al,²⁴

discussed the potential benefits of front to back dissection of the GSPN in their article which includes easy identification of V3 exiting the foramen ovale where a cleavage plane between the dural layers is identified, and elimination of traction on the proximal portion of the GSPN.

After this checklist, the classical drilling technique described,^{4,11–13} starts over the Glasscock's triangle which is then angulated toward the medial aspect of the rhomboid to expose the medial wall of carotid. The advantage of going "lateral" to "medial" is appreciated when quick access to proximal portion of petrous ICA is desired. Another technical strategy pertaining to the exposure of the petrous ICA, is the medial-to-lateral drilling of the MCF base. This is inspired from how the GSPN is oriented to the horizontal petrous segment.^{1,25} In substantial proportion of cases, the GSPN tends to overly the lateral portion of the arterial segment, therefore, it is reasonable to state that the "medial" to "lateral" approach would lead to a relatively early exposure of the carotid in majority of the patients. Driven by our own experience and review of literature,^{5,14,16} we hypothesized that if the MCF drilling proceeded from the rhomboid fossa toward the Glasscock's triangle, a better estimate of the point of exposure of lateral wall of carotid and consequently the eustachian tube could be obtained. We believe that this approach defines a zone of MCF base overlying the eustachian tube which need not be subjected to drilling in the 270 degree exposure of the horizontal segment of the petrous carotid; thus preventing inadvertent damage to the eustachian tube and

subsequent morbidity. Although the injured eustachian tube can be plugged off to prevent the paradoxical CSF rhinorrhea, several other side effects in relation to the acoustic conductance and middle-ear mucus retention have been reported, reflecting the physiological compromise of this conduit.^{26,27} In addition, there remains a cohort of cases in which the surgical endeavors such as packing the eustachian tube, fail to prevent the CSF rhinorrhea.²⁷ The present microanatomical study was thus guided by the philosophy of preserving the physiological integrity of anatomical structures as much as possible. The mean distance from the medial carotid wall midpoint to the medial-most point on the eustachian tube, in our study was 6.35 ± 0.58 mm (range, 5.4 to 7.1 mm) (Table 1). As the mean diameter of the horizontal portion of the petrous ICA is 4.7 ± 0.9 mm (range, 3.8 to 5.6 mm, data from our cadaveric study), it gives the operating surgeon a small zone of 0.2 to 1.9 mm lateral to the lateral wall of the ICA. This small safety zone for eustachian tube, transgressed the Glasscock's triangle which need not be subjected to drilling for exposing the horizontal segment of petrous ICA, thereby minimizing eustachian tube injury.

Limitations

Limited number of cadaver heads used in the analysis and paucity of in vivo experience are the major drawbacks. Nevertheless, the results of our study provide a practical, consistent, and safe method of maximizing horizontal petrous carotid artery exposure while minimizing the eustachian tube injury.

CONCLUSION

The results of our study provide a practical, consistent, and safe method of maximizing horizontal petrous carotid artery exposure while minimizing the eustachian tube injury. Initiation of drilling in middle fossa rhomboid and subsequently proceeding toward the Glasscock's triangle can potentially minimize inadvertent eustachian tube injury.

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