The Middle Cranial Fossa: Morphometric Study and Surgical Considerations

Raffaella Maina, M.D.,^{1,2} Alessandro Ducati, M.D.,² and Giuseppe Lanzino, M.D.¹

ABSTRACT

The anatomical features of the temporal bone can vary significantly among different individuals. These variations affect the operative view in middle cranial fossa surgery. We performed 18 middle fossa approaches in 9 cadaveric heads, with detailed morphological analysis, to identify unfavorable situations and reliable systems to avoid complications during surgery. We recorded linear, angular measurements and calculated areas. We performed a computed tomography (CT) scan with analysis of the amount of bone to remove in two temporal bones. We found that the location of the internal auditory canal (IAC) is the keystone of bone removal. We also found accuracy in the system suggested by E. and J. L. Garcia-Ibanez for its identification and that there is a smaller surgical window in female patients (statistically significant) that can be predicted on preoperative imaging studies. Our study also confirms significant individual variability in the mutual relationships of different surgical landmarks. We concluded that surgery of the middle fossa requires detailed understanding of the complex temporal bone anatomy. The surgeon has to be aware of extreme variability of the more commonly used anatomical landmarks. The method to identify the position of the IAC described by E. and J. L. Garcia-Ibanez seems to be the simplest and most reliable. When the surgical strategy includes an anterior petrosectomy, interindividual variability can critically affect the working area, particularly in females. The working area can be estimated on preoperative CT scans through the petrous bone.

KEYWORDS: Middle fossa approach, temporal bone, landmarks, measurements, microsurgical anatomy, transpetrous approach

¹Department of Neurosurgery, Microneurosurgical Laboratory, Illinois Neurological Institute, University of Illinois College of Medicine at Peoria, Peoria, Illinois; ²Molinette Hospital, University of Torino, Italy.

Address for correspondence and reprint requests: Giuseppe Lanzino, M.D., Department of Neurosurgery, Illinois Neurological Institute, 530 NE Glen Oak Avenue, Peoria, IL 61637 (e-mail:

Lanzino@uic.edu).

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The middle cranial fossa approach was originally described by Parry in 1904.¹ In the 1960s, with the introduction of the operative microscope, this approach was popularized by House.² Since then, interest in this procedure has increased rapidly because it allows effective treatment of different pathological conditions in this region while minimizing trauma to the facial nerve and hearing functions. With further advances in skull base surgery, extension of the middle fossa approach has become the key to accessing regions notoriously challenging such as the cerebellopontine angle,^{3,4} the petroclival area,⁵⁻⁸ the upper basilar artery,⁹⁻¹¹ and the posterior cavernous sinus.¹²

Despite these advantages, the safe and effective performance of the middle fossa approach and its variations requires a detailed knowledge of the temporal bone anatomy, awareness of topographic variations, and a mandatory practice in cadaver laboratory. Therefore, this approach continues to be considered one of the most difficult surgical exercises in skull base surgery. The present study was undertaken with the goal of investigating the mutual relationships between anatomical landmarks and their variations.

MATERIALS AND METHODS

The middle fossa approach was performed with the aid of the surgical microscope (Leica Microsystems GmbH, Wetzlar, Germany) in nine (3 female, 6 male) (18 sides) injected cadaveric specimens. The distance between different structures of interest exposed during this approach was measured with an electronic digital caliper under microscope view. Areas were calculated applying Carnot's theorem for triangle's resolution ($a^2 = b^2 + c^2 - 2bc \cos \alpha$). Polygonal areas were divided into triangles and their areas were calculated with Carnot's theorem. Angle measurements were also recorded. Analysis of variance (ANOVA) was used to verify statistical significance.

High-resolution computed tomography (CT) scans (axial sections with thickness of 1 mm) of each head were obtained before dissection using a Siemens 4-slice CT scanner (Siemens, Pennsylvania). On the CT scan, the area of bone between the internal carotid artery (ICA), the third trigeminal branch (V3), the cochlea, and the internal auditory canal (IAC) (area which can be potentially removed through the middle fossa approach) was visualized. Linear measurements between these structures were taken on the CT. Using Carnot's theorem, the area of the fossa was calculated and later compared with the dissection of the same specimen to assess the predictive value of preoperative high-resolution CT scan (Fig. 1).

Middle Fossa Approach

In each specimen the same microneurosurgical approach was performed according to the following surgical steps:

1. The head was placed in a head holder and positioned at 90 degrees. A 4 × 4-cm craniotomy was performed after making a reverse question mark skin incision starting in front of the tragus. Additional drilling of the base was performed to obtain a flush exposure of the floor of the middle fossa. The dura mater was elevated from the middle fossa floor to identify the arcuate eminence (AE) and the middle meningeal artery at the foramen spinosum. After dividing the middle meningeal artery, dural elevation continued medially up to the superior petrosal sinus, exposing the following structures: V3 at the foramen ovale, the gasserian ganglion, the porus trigeminus, the greater superficial petrosal nerve (GSPN) from its junction with the trigeminal nerve (GSPN/V₃ junction) to the hiatus Fallopii, and the tegmen tympani.
2. After identifying the extradural anatomical structures, drilling started with unroofing of the IAC. Exposition of IAC dura started at its midpoint and then proceeded medially to reach the geniculate ganglion and laterally to reach the

Figure 1 Computed tomography (CT) of the right temporal bone: (A) Internal auditory canal (straight arrow), cochlea (double straight arrow), and internal carotid artery (curved arrow). (B) The area of bone anterior to the internal auditory canal (IAC), which can be removed through the extended middle fossa approach, is delimited. This area is schematically divided into triangles. Applying Carnot's theorem, the triangles' area can be calculated from linear measurements.

internal auditory meatus (IAM). The portion of the GSPN covered by bone was then exposed along with the geniculate ganglion and the petrous ICA. Bone removal was completed to reach the posterior fossa dura while sparing the cochlea. The superior semicircular canal was then exposed, and the bone between the IAC and superior semicircular canal was removed. Removal of the petrous apex was then performed under direct vision following mobilization of the gasserian ganglion from its adhesions with the ICA. To complete the dissection, the foramen rotundum and the foramen ovale were decompressed and V_3 was divided. After each of these maneuvers, the length of the exposed ICA was recorded.

RESULTS

While elevating the dura, exploration of the floor of the middle fossa detects relevant anatomical variations. In 3 of the 18 dissections (17%), there was no bony covering of the geniculate ganglion; in 7 temporal bone specimens, the roof of the carotid canal was incomplete, exposing the ICA. The length of bone covering the GSPN showed great variability (mean 3.84 mm; standard deviation [SD] 2.33; range 0–7.61 mm).

The next step in the middle fossa approach is the identification of anatomical landmarks that aid the surgeon's orientation and help identify portions

Figure 2 Surgical view (A) and line drawing (B) of the floor of left middle fossa after dural elevation. Significant landmarks are labeled: gspn, greater superficial petrosal nerve (lateral); V_3 , third branch of trigeminal nerve (anterior); Po, porus trigeminus (antero-medial); AE, arcuate eminence (posterior).

Table 1 Distance between Relevant Landmarks on the Middle Fossa Floor (mm)

	Mean	SD	Range
AE–porus trigeminus	21.68	3.22	15.77–27.10
Porus trigeminus–GSPN–V ₃ junc	12.45	1.57	9.76–15.32
GSPN/V ₃ junc–GG	15.23	2.23	11.11–18.92
GG–AE	11.34	2.05	7.61–15.45
GSPN/V ₃ junc–foramen spinosus	7.80	1.20	4.87–10.56
GSPN/V ₃ junc–foramen ovale	7.36	0.94	6.03–9.85
GSPN/V ₃ junc–foramen rotundum	19.58	1.91	16.48–25.17

SD, standard deviation; AE, arcuate eminence; GSPN, greater superficial petrosal nerve; GG, geniculate ganglion; V₃, third trigeminal branch; junc, junction.

of bone to be removed (Fig. 2). Table 1 summarizes the distances between different landmarks in the floor of the middle fossa measured before bone removal. For each measurement, there was a wide range with a high SD. This indicates that the anatomical conformation of the middle cranial fossa varies between subjects.

Localization of the IAC is the keystone to start bony drilling. Table 2 summarizes angular measurements useful to clarifying the position of the IAC in relation to other middle fossa landmarks. Although the range of single measurements is wide, the ratio between the GSPN–IAC angle and the GSPN–AE angle is quite constant (mean 0.42, SD 0.08).

Table 3 reports the distance between different structures of the middle fossa after drilling was completed. In five approaches (27.7%), there was no anatomical coincidence of the superior semicircular canal with the AE. Although the range of measurements between different structures varies by only a few millimeters, these small differences can result in significant differences in the size of removable bone in such a limited space.

Table 4 indicates the maximal areas of bone that can be removed while preserving anatomical

structures. The areas of bone analyzed were the anterior area, bounded by the gasserian ganglion, V₃, ICA, cochlea, and IAC (corresponding to the area described by Kawase¹⁰); and the posterior area, bounded by the geniculate ganglion, IAC, and

Table 3 Morphometric Data after Bone Drilling (mm)

	Mean	SD	Range
Cochlea–GG	3.06	0.92	1.60–4.97
Cochlea–ICA genu	3.57	0.79	2.23–4.58
GG–IAM	12.13	1.23	10.45–14.28
ICA genu–IAM	10.74	1.21	8.00–12.52
ICA genu–GG	6.73	1.34	3.27–8.80
GG–distal SSC	10.93	1.63	6.79–13.10
IAM–distal SSC	13.65	2.00	9.75–16.03
Cochlea–porus trigeminus	12.47	1.68	9.77–15.86
Porus trigeminus–IAM	8.65	1.55	6.70–11.66
Cochlea–IAM	9.87	1.37	8.06–13.31
Foramen spinosus–cochlea	13.10	1.21	11.34–16.08
Cochlea–GSPN/V ₃ junc	12.14	1.69	8.47–15.39

SD, standard deviation; GG, geniculate ganglion; ICA, internal carotid artery; IAM, internal auditory meatus; SSC, superior semicircular canal; GSPN, greater superficial petrosal nerve; V₃, third trigeminal branch; junc, junction.

Table 2 Angular Measurements (°)

Angle Measured	Mean	SD	Range
GSPN–AE	122.92	16.65	96.29–158.90
GSPN–IAC	51.45	8.93	33.42–68.01
SSC–IAC	77.68	13.30	54.96–102.97

SD, standard deviation; GSPN, greater superficial petrosal nerve; AE, arcuate eminence; IAC, internal auditory canal; SSC, superior semicircular canal.

Table 4 Surfaces of Removable Bone (mm²)

Area	Mean	SD	Range
Anterior area	106.72	19.44	73.33–144.36
Posterior area	59.52	10.65	40.62–73.40
Total bone removal	166.25	24.67	128.16–208.40

SD, standard deviation.

Figure 3 Surgical view (A) and line drawing (B) of the left middle fossa floor after complete bone removal. GG, geniculate ganglion; gspn, greater superficial petrosal nerve; ICA, internal carotid artery; V₃, third branch of trigeminal nerve; ssc, superior semicircular canal; Co, cochlea; IAC, internal auditory canal; ips, inferior petrosal sinus. (C,D) Areas of bone removal. A, anterior area; P, posterior area.

superior semicircular canal (corresponding to Fukushima's postmeatal triangle)¹² (Fig. 3). The measurements of these two areas were then added to obtain the total bone removal area. We found a wide variability in the size of the bone windows; some were so small as to limit the efficacy of this approach.

Table 5 compares the size of the bone windows in the middle fossa approach between males and females. We found significant differences in the anterior area ($\alpha = 0.025$) and the total area ($\alpha = 0.01$) despite the limited number of specimens (Fig. 4). A significant difference was not found for the posterior area.

In one specimen (bilateral temporal bones), the measurements of the anterior area on high-resolution CT scan were compared with the measurements taken in the same specimen through the surgical microscope. We found a very good correlation between the CT scan and the actual dissection (left side: CT = 109 mm², dissection = 107.18 mm²; right side: CT = 98 mm², dissection = 95.90 mm²).

Table 6 summarizes the measurements of the petrous ICA exposed after different stages of dissection. The maximal length from the genu to the gasserian ganglion varied from 6.54 mm to 11.50 mm. After dividing connective attachments

Table 5 Surfaces of Removable Bone: Comparison between Males and Females (mm²)

Area	Mean	Male SD	Range	Mean	Female SD	Range
Anterior area	115.20	18.15	79.59–144.63	91.19	9.69	73.33–105.13
Posterior area	62.44	9.18	41.76–73.40	54.19	11.08	40.62–69.99
Total bone removal	177.64	21.78	142.10–208.40	145.38	13.50	128.16–165.73

SD, standard deviation.

Figure 4 Graph showing extension of anterior bone removal area in male and female populations.

between the gasserian ganglion and the ICA, the ganglion could be mobilized to obtain further exposure of the artery (mean gain of 3.51 mm in ICA exposure). Decompressing the foramen ovale and rotundum and dividing V_3 further increased the artery's exposure (mean gain of 2.55 mm and 2.35 mm, respectively).

DISCUSSION

Anatomical Observations

The middle fossa approach and its variations offer a suitable surgical avenue to deal with a variety of pathological lesions located at the junction of the

middle and posterior cranial fossae. A clear understanding of the anatomical landmarks and their variations is critical to effectively manage these lesions while avoiding disabling complications. Numerous authors have described frequent variations in the middle fossa anatomy. Absence of bone over the geniculate ganglion resulting from a congenital defect in the development of the roof of the temporal bone can occur in 15% of cases.¹³ The length of the GSPN covered by bone varies considerably,^{14,15} from 0 to 7.61 mm in our dissections. In ~20% of cases, the petrous ICA is exposed along the carotid canal by the absence of bone in the roof of the canal.¹⁴ Likewise, the topographic relationship between the AE and the superior semicircular canal is not consistent,^{16,17} and we found this to be true in 27% of our dissections. Lack of bone covering these structures may increase the risk of injury while elevating the dura off the floor of the middle fossa. Surgeons have to be familiar with these differences to avoid such complications.

Identification of the Internal Auditory Canal

In the 1960s, when the middle fossa approach was popularized by House, the main indications were

Table 6 Length of Internal Carotid Artery Exposure (mm)

	Mean	SD	Range
ICA genu- V_3	8.90	1.51	6.54–11.50
After V_3 mobilization	12.41	1.24	11–14.43
After foramens' decompression	14.97	1.64	12.31–17.82
After V_3 cutting	17.32	2.01	13.74–21.81

SD, standard deviation; ICA, internal carotid artery; V_3 , third trigeminal branch.

small acoustic schwannomas confined to the IAC, Meniere's syndrome, and decompression of the acoustic and facial nerves.² Thus, the initial goal of this approach was to expose the entire length of the IAC while preserving the facial nerve and the inner ear structures. In the extended middle fossa approaches, identification of the IAC still remains a crucial step in identifying portions of bone to be removed.

Different authors have described various methods to identify the position of the IAC. House suggested following the GSPN to the facial nerve, reaching it directly²; however, this may jeopardize the facial nerve by direct injury. Fisch reported that the IAC can be identified by finding the superior semicircular canal and visualizing the IAC as lying at an angle 60 degrees anteriorly.¹⁸ Unfortunately, our angular measurement showed high variability in the angle he used (mean, 77.68 degrees; SD, 13.30; range, 54.96 degrees to 102.97 degrees). The method described by E. Garcia-Ibanez and J. L. Garcia-Ibanez allows reaching the IAC without drilling over the superior semicircular canal or the geniculate ganglion, minimizing the risk of injury. They drill over the bisection of the angle formed by the GSPN and the AE (the main axis of the IAC).¹⁹ We found the ratio between the GSPN-IAC angle and the GSPN-AE angle to be quite constant (SD = 0.08) and very close to 0.50 in all specimens. Thus, we found that the drilling zone indeed corresponds to the bisection of the GSPN-AE angle, making this the most reliable method in locating the IAC by anatomical landmarks. Additionally, risky maneuvers, such as drilling the superior semicircular canals and unroofing the geniculate ganglion, are avoided.

Morphometric Analysis

To facilitate surgical orientation, many authors have proposed subdivisions of the middle fossa in topographic areas. In 1969, Glasscock described the posterolateral triangle (bounded by the foramen spinosum, the cochlea, and the GSPN/V₃

junction), allowing exposure of the horizontal petrous ICA.²⁰ Kawase described removing a portion of petrous bone to gain access to the petroclival region and the basilar artery (bounded by the trigeminal ganglion, the IAC, the cochlea, the GSPN, and the petrous ICA).^{5,11} In 1994, Day et al approximated the floor of the middle fossa to a rhomboid complex of anatomical landmarks delimiting bone removal on the petrosal surface.²¹ These landmarks were the AE, the porus trigeminus, the GSPN/V₃ junction, and the junction of imaginary lines projecting through the GSPN and the AE. They also described the postmeatal triangle (bounded by the geniculate ganglion, the IAC, and the superior semicircular canal) as an additional volume of bone that can be removed. They identified the perimeatal triangle (bounded by the IAC, the carotid genu, and the geniculate ganglion) as useful for safely localizing the cochlea.²¹

Definition of these topographical areas relies on recognition of anatomical landmarks. Unfortunately, numerous anatomical studies have reported extreme individual variability in temporal bone anatomy.^{14,15,21-28} Our data confirm this variability. Even small differences in linear measurements result in a large variability of the width of the working area exposed after bone drilling. An interesting observation in our specimens was the significant differences between males and females, especially in the so-called "anterior area." Current high-resolution neuroimaging can help in assessing the width of the working area with good correlation between the area imaged and the actual dissection, as demonstrated by one of our specimens. Calculation of bone superficies on CT is an easy and fast procedure that can help the surgeon in preoperative planning. Additionally, more sophisticated three-dimensional images²⁹⁻³¹ and image-guided intraoperative navigation³²⁻³⁴ provide valuable technical adjuncts to provide more detailed information and intraoperative real-time feedback. These adjuncts might be particularly helpful in female patients because of the more limited surgical corridor through the temporal bone.

CONCLUSIONS

The middle fossa approach and its variations require a detailed understanding of the complex temporal bone anatomy. The surgeon has to be aware of the extreme variability of some of the more commonly used anatomical landmarks. The method described by E. and J. L. Garcia-Ibanez¹⁹ seems to be the simplest and most reliable method to identify the position of the IAC, a critical step in bone removal during these approaches. When the surgical strategy includes an anterior petrosectomy to reach deeper intracranial areas, interindividual variability can critically affect the working areas. This is particularly true in female patients because of the naturally smaller space anterior to the IAC. The working areas can be estimated on preoperative thin-cut CT scans through the petrous bone and the skull base.

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Commentary

This article nicely confirms the usefulness of the E. and J. L. Garcia-Ibanez approach to the internal auditory canal from the middle fossa. The authors also demonstrate again that the anatomy of the middle fossa is extremely challenging and variable. However, the middle fossa remains a true “utility approach,” allowing access to several vital structures without compromising normal function, and it is also associated with minimal morbidity. Unfortunately, with this approach, there is no shortcut to the extensive temporal bone work required to develop the detailed knowledge of this complex anatomy necessary to achieve successful outcomes.

Peter Weisskopf, M.D.¹

¹Barrow Neurological Institute, Phoenix, Arizona.
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