Quantitative Anatomical Study of Tailored Far-Lateral Approach for the VA-PICA Regions

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Abstract

Objective The extent of the far-lateral approach (FLA) has not yet been quantified for the region of the vertebral and posterior inferior cerebellar arteries (VA-PICA). We quantitatively analyzed six main sequential steps of the FLA.

Methods A modified small FLA (msFLA) and a classic large FLA (clFLA) were performed sequentially on both sides of five cadaveric heads. A frameless navigational system was used to quantify the angle of attack for the origin (T1) and lateral medullary segment (T2) of the PICA and the surgical area of exposure above and below the vagus nerve (cranial nerve [CN] X).

Results The total area of exposure above CN X increased significantly ($p < 0.05$) from the msFLA to the clFLA. However, the surgical exposure area below CN X did not change ($p > 0.05$). C1 hemilaminectomy increased ($p < 0.05$) the vertical angle of attack, and drilling the posteromedial third of the occipital condyle increased ($p < 0.05$) the horizontal angle of attack to the origin of the PICA.

Conclusions For the VA-PICA region, the msFLA offered a similar practical surgical working area and similar angles of attack when compared with the clFLA. The FLA should be tailored based on the location, size, and pathology of lesions and on the exposure required for effective surgical treatment.

Keywords

- far-lateral approach
- quantitative anatomical study
- practical surgical working area

Introduction

The region of the vertebral and posterior inferior cerebellar arteries (VA-PICA) involves the anterior foramen magnum, lower clivus, and anterior aspect of the upper cervical vertebra. The site can involve various intra- and extradural tumors as well as complex vertebrobasilar aneurysms.^{1,2} The VA-PICA region has always been a challenging area for surgeons to operate on because it houses many vital neurovascular structures and is difficult to access.

Despite the welter of terminology used to describe the far-lateral approach (FLA),³ the standard approach and its many variations provide excellent surgical access to the VA-PICA

region. The FLA has been tailored to specific lesions to maximize surgical exposure while minimizing surgical morbidities and also to facilitate surgical planning.^{3,4} Consensus holds that the choice of the approach depends on the location, size, and type of lesion as well as on the degree of exposure required for effective surgical treatment.

Salas et al⁴ and Spektor et al³ systematically divided the FLA into six variants or steps according to the extent of bone removal. However, they did not consider the size or location of the craniotomy, which are important factors in determining the trajectory of approach. The FLA should be tailored to the specific anatomical location to avoid unnecessary

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exposure and risk of injury to neurovascular structures and the time required to enlarge the craniotomy. Krayenbuhl et al described three variations of the FLA craniotomy based on the different segments of the VA.⁵ However, they did not quantify the craniotomy based on the exposure or angle of attack. We quantified and compared the surgical exposure, practical working area, and angle of attack for the VA-PICA region provided by the small and large far-lateral craniotomies to help simplify the selection of the optimal approach for the surgical treatment of lesions in the VA-PICA region.

Material and Methods

Anatomical measurements were performed on five cadaveric heads (10 sides), with no known brain pathology. The arterial and venous systems of the cadaver specimens were injected with colored silicon. The FLA (►Figs. 1 and 2; ►Table 1) was performed in six sequential steps and was classified as either a modified small FLA (msFLA) or a classic large FLA (clFLA) group based on its size. The msFLA group involved a 2.5×2.5 cm craniotomy (step 1; ►Fig. 2A) and its variations (steps 2 and 3; ►Fig. 2B, C). The clFLA involved a 2.5×5 cm craniotomy (step 4; ►Fig. 2D) and its variations (steps 5 and 6; ►Fig. 2E, F). The variations included the removal of the C1 arch (steps 2 and 5) and the removal of the posterior third of the occipital condyle (steps 3 and 6). For the convenience of converting the smaller craniotomy (msFLA) to the larger one (clFLA), each step was performed in the following sequence: step 1, step 4, step 2, step 5, step 3, and step 6. After each approach, the area of surgical exposure and the horizontal and vertical angles of attack were measured. The steps and measurements were performed on all 10 sides.

Surgical Dissection

The cadaver heads were placed in a modified park-bench position to simulate the standard surgical position and were

Fig. 1 Illustration showing the modified small far-lateral approach (step 1, green), the classic large far-lateral approach (step 2, blue), and the extent of a C1 hemilaminectomy (steps 2 and 5) and posterior condyle drilling (steps 3 and 6, red). (Used with permission from Barrow Neurological Institute.)

held in place with a Mayfield head holder. The dissection was performed with standard microsurgical instruments, power drills, and a surgical microscope (Carl Zeiss AG, Oberkochen, Germany).

A paramedian incision and muscle-splitting procedure⁶ was performed in a straight line, 2 cm medial to the mastoid, from the level of the transverse–sigmoid sinus junction to the level of the C4 vertebra. The incision was made lateral enough to allow exposure of the mastoid and medial enough to provide midline exposure. The soft tissue was dissected carefully to maintain the correct orientation. The mastoid tip and the lateral arch of C1 were constantly palpated manually to avoid inadvertent injury to the VA. Subperiosteal dissection exposed the posterior fossa, down to the level of the foramen magnum and the laminae of C1 and C2. The extradural VA was identified within its surrounding venous plexus and then dissected to the point where it penetrated the atlanto-occipital membrane and dura. The posterior condylar emissary vein was carefully dissected away from the foramen magnum and cut, exposing the condylar fossa.

The msFLA, which involved removal of the condylar fossa area but not the lateral portion of the jugular tubercle,^{4,7,8} was performed as the first step. The first burr hole was placed on the occipital bone 2.5 cm superior to the margin of the foramen magnum and 2.5 cm lateral to midline. The second burr hole was placed 2.0 cm lateral to the first burr hole at the level of the inferior nuchal line. The craniotomy was initiated at the foramen magnum, 1 cm lateral to the midline, preceded to the first burr hole and continued to the second burr hole. The craniotomy terminated at the foramen magnum adjacent to the occipital condyle. Toward the lateral margin of the craniotomy, the vertical bone edge made it almost impossible to insert the footplate of a fine Kerrison rongeur. Therefore, further lateral exposure was obtained by drilling away the lateral aspect of the foramen magnum to the sigmoid sinus and to the superior most point along the posterior edge of the occipital condyle. The dura was then opened at midline from the entrance of the VA inferiorly to the lateral margin of sigmoid sinus superiorly. Next, the cerebellum was retracted 1.2 cm from the edge of the bone, and the surgical exposure and angle of attack were measured as later described.

After step 1, a burr hole was placed 1 cm anterior to the asterion, just inferior to the parietomastoid suture. Another burr hole was placed 2.5 cm behind the first burr hole at the level of the inion-asterion line. This bone flap was reserved for a future reconstruction. The craniotomy followed, and the approach was converted from an msFLA (step 1) to a clFLA (step 4). After step 4 was completed, the bony pieces were reattached rigidly using miniplates and screws (Codman; Johnson & Johnson, Raynham, Massachusetts, United States) to reconstruct step 1. Affixing the bone flaps easily allowed conversion between the small and large approaches while maintaining consistent brain retraction.

The extradural VA was carefully protected with a small dissector while a hemilaminectomy of C1 was performed from midline to just lateral to the sulcus arteriosus. The approach was converted from step 1 to step 2. The dura was then opened inferiorly toward the C2 lamina.

Fig. 2 Cadaveric dissections of the vertebral and posterior inferior cerebellar arteries region demonstrating the six sequential steps of approach. (A) Step 1: modified small far-lateral approach (msFLA) with C1 arch and occipital condyle intact. (B) Step 2: msFLA with C1 laminectomy. (C) Step 3: msFLA with C1 laminectomy and removal of posterior third of occipital condyle. (D) Step 4: classic large far-lateral approach (clFLA) with C1 arch and occipital condyle intact. (E) Step 5: clFLA with C1 laminectomy. (F) clFLA with C1 laminectomy and posterior third of occipital condyle removal. AOJ, atlanto-occipital joint; HC, hypoglossal canal; JT, jugular tubercle; OC, occipital condyle; PCEV, posterior condylar emissary vein; PICA, posterior inferior cerebellar artery; PSA, posterior spinal artery; SS, sigmoid sinus; VA, vertebral artery; VII and VIII, seventh and eighth cranial nerve complex; IX and X, glossopharyngeal and vagal nerves; XI, spinal accessory nerve; XII, hypoglossal nerve. (Used with permission from Barrow Neurological Institute.)

Again, the bone flap of the superior part of the retrosigmoid area was removed by unscrewing the miniplates, and the craniotomy was extended from step 2 to step 5.

After step 5, the bony pieces were reattached. Step 3 involved removing the lateral part of the jugular tubercle and the posteromedial third of the occipital condyle to the

Table 1 Corresponding level of dissection at the various steps

Steps of approach to VA-PICA region	Level of anatomical dissection	Figure
	msFLA	
1	msFLA (2.5 × 2.5 cm craniotomy)	2A
2	msFLA and C1 hemilaminectomy	2B
3	msFLA, C1 hemilaminectomy, and removal of posteromedial third of occipital condyle	2C
	clFLA	
4	clFLA (2.5 × 5 cm craniotomy)	2D
5	clFLA and C1 hemilaminectomy	2E
6	clFLA, C1 hemilaminectomy, and removal of posteromedial third of occipital condyle	2F

Abbreviations: clFLA, classic large far-lateral approach; msFLA, modified small far-lateral approach; VA-PICA, vertebral and posterior inferior cerebellar arteries.

edge of the hypoglossal canal. Finally, the bone flap was removed and step 6 was reached. The surgical exposure area and the angle of attack were measured for each step.

Measurements

Surgical Area

After each approach, the exposure area of the region above and below the vagus nerve (CN X) was measured (►Fig. 3) with a frameless navigational system (StealthStation Treon Plus; Medtronic Surgical Navigation Technologies, Louisville, Colorado, United States). For the region below CN X, the area of exposure was limited by three fixed reference points and two variable points. The fixed points were (1) the point where CN X exited the brainstem, (2) the point where the VA penetrates the dura, and (3) the jugular foramen. The two variable points were (4) the lowest visible point of the fascicle of CN X where it exited the brainstem and (5) the most lateral point at the level of the tip of the condyle (►Fig. 3A). For the

region above CN X, the area of exposure was limited by four fixed reference points: (6) the point where CN X exited the brainstem, (7) the point where the vestibular nerve (CN VII) exited the brainstem, (8) the internal auditory meatus, and (9) the jugular foramen. The two variable points were (10) the uppermost point visible in the direction of cerebellum and (11) the uppermost point visible in the direction of the petroclival area (►Fig. 3B).

The x, y, and z coordinates of each point were obtained with the probe of the frameless stereotactic navigational system. The reference arc of the frameless navigational system was attached near the cadaveric head and remained fixed during the measurements for both sides. Brain retractors remained rigidly fixed and permanently secured, whereas the points of interest were relocated for each exposure to prevent errors in measurement while the points were located spatially. Distances and angles between each point were calculated with Spherical Area software (Bitwise Ideas Inc., Ottawa, Ontario, Canada). The area of exposure was measured and calculated by summing the areas formed by unit triangles. Triangular areas were calculated with the Eq. $1/2ab(\sin\theta)$, where ab was the magnitude of the vector cross product of the vectors forming the two sides of a triangle and θ was the angle where the vectors crossed.

Angle of Attack

The maximum allowable angles of approach in the vertical and horizontal axes were used to evaluate the angular exposure. The horizontal axis was defined as an axis parallel to the cranial base; the vertical axis was the main axis of the approach in a plane perpendicular to the cranial base (►Fig. 4). The origin of the PICA was selected as target point 1 (TP1), and the end point of lateral medullary segment of

Fig. 3 Reference points used to measure areas of exposure. (A) Region below cranial nerve (CN) X. The area of exposure was limited by three fixed reference points: (1)* the exit point of CN IX from brainstem, (2)* the point where the VA penetrates the dura and (3)* the jugular foramen, and by two variable points, (4) the lowest visible point of the fascicle of CN XI on the brainstem and (5) the most lateral point at the level of the tip of the condyle. (B) Region above CN X. The area of exposure was limited by four fixed reference points, (6)* exit point of CN X from brainstem, (7)* exit point of CN VII from brainstem, (8)* internal auditory meatus, and (9)* the jugular foramen, and two variable points, (10) the uppermost point visible in the direction of cerebellum and (11) the uppermost point visible in the direction of petroclival area. The lines connecting the points in (A) and (B) lie in the same planes. (Used with permission from Barrow Neurological Institute.)

Fig. 4 Angles of attack for target point 1 (T1), posterior inferior cerebellar artery origin on right-sided specimen. The horizontal angle of attack (solid black line) was parallel to the cranial base, whereas the vertical angle (dashed white line) was on a plane perpendicular to the cranial base. The medial and lateral points limited the horizontal angle; the caudal and cranial points limited the vertical angle. For the horizontal angle, there was no significant difference ($p < 0.05$) between steps 1 and 2 and 4 and 5; however, there was a significant increase ($p < 0.001$) between steps 2 and 3 and 5 and 6. The vertical angle increased between steps 1 and 2 ($p = 0.010$) and between groups ($p < 0.05$), but there was no significant difference ($p > 0.05$) noted between steps 2 and 3, 4 and 5, or 5 and 6. (Used with permission from Barrow Neurological Institute.)

PICA was selected as TP2. These two points represented the deep and superficial structures in the VA-PICA region, respectively. The angles in the vertical and horizontal axes were evaluated for both points. The mean distance from TP1 to TP2 and from the point where the VA penetrated the dura to TP1 was measured. The medial and lateral limits of the exposure constituted the points that limited the horizontal angle, whereas the caudal and cranial limits of the exposure represented the points that defined the vertical axis (►Fig. 4).

Statistical Analysis

The surgical exposure areas, below and above CN X, for each type of craniotomy (msFLA and clFLA) were compared using a paired *t* test. A single-factor analysis of variance was used to compare the differences in areas between the stepwise variations within each type of craniotomy. A paired *t* test was used to compare angles of attack between the types of craniotomies and their variations. In all cases, values of $p < 0.05$ were considered significant.

Results

Area of Surgical Exposure

The total surgical area and the surgical area above and below CN X are shown in ►Fig. 5. The total surgical area increased significantly from steps 1 to 3 ($p = 0.011$) and from Steps 4 to 6 ($p = 0.011$). There was also a significant increase in area between the msFLA and clFLA as indicated by the difference between steps 1 and 4 ($p = 0.001$), steps 2 and 5 ($p = 0.003$), and steps 3 and 6 ($p = 0.001$). The surgical area below CN X increased from steps 1 to 3 ($p = 0.003$) and from steps 4 to 6 ($p = 0.002$). However, no significant increase in this area was observed between the msFLA and clFLA as shown by the comparison between steps 1 and 4 ($p = 0.665$), steps 2 and 5 ($p = 0.371$), and steps 3 and 6 ($p = 0.200$). There was no

statistical significance in the surgical area above CN X between steps 1 and 3 and between steps 4 and 6 ($p > 0.05$). However, there was a significant increase in the area between steps 1 and 4, steps 2 and 5, and steps 3 and 6 (msFLA to clFLA) ($p \leq 0.001$).

Angles of Approach

The various angular components for each target point are shown in ►Fig. 6. There was no significant difference ($p > 0.05$) in the horizontal angle of attack at the origin of PICA (TP1) between steps 1 and 2 and steps 4 and 5; however, there was a significant increase ($p < 0.001$) between steps 2 and 3 and steps 5 and 6. There was no significant increase in the horizontal angle at TP1 between msFLA and clFLA ($p > 0.05$). The vertical angle at TP1 increased between steps 1 and 2 ($p = 0.010$) and between the msFLA and clFLA (steps 1–4, steps 2–5, and steps 3–6) ($p < 0.05$). However, there was no significant difference ($p > 0.05$) between steps 2 and 3, steps 4 and 5, or steps 5 and 6.

There was no difference in the horizontal angle at TP2 between any of the various steps ($p > 0.05$) or in the vertical angle of TP2 between steps 1 and 2, steps 2 and 3, steps 4 and 5, and steps 5 and 6 ($p > 0.05$). Although the vertical angle at TP2 between the msFLA and clFLA increased significantly between steps 1 and 4 ($p = 0.028$) and steps 2 and 5 ($p = 0.010$), there was no statistical difference between steps 3 and 6 ($p = 0.142$). The mean distances from TP1 to TP2 and from the point where the VA penetrates the dura to TP1 were 8.6 ± 3.9 mm and 18.3 ± 4.7 mm, respectively.

Discussion

The common indications of the FLA for the VA-PICA region are aneurysms involving PICA and the confluence of the VA, cavernous vascular malformations of the brainstem, meningiomas of the anterior foramen magnum, and schwannomas of the lower cranial nerves.^{1,2,9–11} The VA-PICA region is surgically challenging because of the proximity of the lower cranial nerves and other critical vascular structures including the anterior spinal artery, posterior spinal artery, and the small medullary branches originating from either the VA or PICA.

In the first report of the FLA by Heros,² the surgical indications for its use involved lesions of VA, the vertebrobasilar junction, and the proximal basilar trunk. The extent of bone removal was obscure in the areas of the foramen magnum, condylar fossa, jugular tubercle, and occipital condyle. The craniectomy extended from the junction of the transverse and sigmoid sinuses superolaterally to just beyond the midline through the foramen magnum inferiorly in a teardrop fashion with the wider opening superolaterally, resulting in a large craniotomy. Since then, several modifications of the FLA have been developed and described extensively in terms of a more lateral approach to provide access to the ventral brainstem.^{1,12}

The clFLA craniotomy described by Heros^{2,13,14} is still used to manage lesions in the VA-PICA region, although a few investigations^{1,4,9,15} have used an msFLA. Some authors

Fig. 5 Bar graph of the surgical exposure areas: above and below cranial nerve X and total area. Total area increased ($p < 0.05$) between steps 1 and 3 and 4 and 6 and also between the modified small far-lateral approach (msFLA) (steps 1–3) and classic large far-lateral approach (clFLA) (steps 4–6) groups ($p < 0.05$). Area below CN X increased ($p < 0.05$) between steps 1 and 3, and 4 and 5, but no increase ($p > 0.05$) was observed between msFLA and clFLA. Area above CN X did not increase ($p > 0.05$) between steps 1 and 3 and 4 and 6, but a significant increase was noted from the msFLA to clFLA. (Used with permission from Barrow Neurological Institute.)

Fig. 6 Bar graphs demonstrating angles of attack in horizontal and vertical planes for target point 1, origin of posterior inferior cerebellar artery (PICA), and for target point 2 (T2), lateral medullary segment of PICA. (A) Horizontal angle of attack at T1 increased ($p \leq 0.001$)* between steps 1 and 3, 2 and 3, 4 and 6, and 5 and 6, but there was no significant difference ($p > 0.05$) between the modified small far-lateral approach (msFLA) (steps 1 to 3) and classic large far-lateral approach (clFLA) (steps 4 to 6) groups. (B) Vertical angle of attack at T1 significantly increased ($p < 0.05$)* from steps 1 and 2 and from msFLA to clFLA. (C) Horizontal angle of attack at T2 did not differ significantly between any of the steps ($p > 0.05$). (D) Vertical angle of attack at T2 did not differ significantly ($p > 0.05$) between the steps within the msFLA and clFLA groups. There were significant changes ($p < 0.05$)* between steps 1 and 4 and 2 and 5, but no significant increase ($p = 0.142$) between steps 3 and 6. (Used with permission from Barrow Neurological Institute.)

select and tailor the FLA for each specific lesion.^{3,4} Their main concern has been to obtain a lateral extension of the FLA. The extent of craniocaudal exposure should be tailored to the type of pathology and to its location and longitudinal extent. Unnecessary cranial exposure increases surgical time and leaves a large surgical dead space, whereas an insufficient exposure provides inadequate intradural visualization of important neurovascular structures.

The msFLA craniotomy (step 1) is the least aggressive form of the FLA. It is similar to the retrocondylar approach of Salas et al.⁴ in terms of the extent of bone removed from the condylar fossa and jugular tubercle. It is also similar to the size of the craniotomy that Bertalanffy and Seeger¹ performed. Salas et al.⁴ described six variations of the extreme-lateral craniocervical approach depending on the extent of bone removal. Of these, the retrocondylar approach was used to treat intradural lesions located predominantly lateral or anterolateral to the spinomedullary area, and removal of the lateral portion of the jugular tubercle was excluded. Salas et al.⁴ made a small craniotomy ~3 cm posterior to the sigmoid sinus, but the exact size of the craniotomy was not mentioned. Bertalanffy and Seeger¹ used a small craniotomy by enlarging the foramen magnum 2 to 3 cm dorsolaterally; however, they removed the same amount of bone from the area of the condyle and jugular tubercle regardless of the underlying pathology.

Surgical Area and Angle of Attack

The total surgical area increased as expected between the msFLA and clFLA, reflecting the increase in the size of the craniotomy. This increase in area mainly involved the increase in the area above CN X; the area below CN X remained the same in both craniotomies. As D'Ambrosio et al noted, surgeons should approach the VA-PICA region via a caudorostral trajectory, beneath the lower cranial nerves rather than through these fragile structures, to minimize the incidence of lower cranial nerve dysfunction.¹³ Therefore, the preferred trajectory of approach for the VA-PICA region is caudorostrally, and the preferred working space is beneath CN X to avoid lower cranial nerve injury.

Because the preferred working space for the treatment of the VA-PICA lesions^{2,13} is below CN X, the clFLA offers no advantage over the msFLA in terms of practical working space. The horizontal angle of attack for TP1 and TP2 did not change significantly between the msFLA and clFLA groups. There was a significant increase in the vertical angle of attack for TP1 and TP2 in the clFLA compared with the msFLA; this increase was attributed to the cranial extension of the craniotomy. After the craniotomy was extended, the increased portion of the vertical angle of attack for TP1 was mostly in the craniocaudal direction.

After an FLA craniotomy is performed (steps 1 and 4), the surgical field for the VA-PICA region is still limited by the cranial nerves, occipital condyle, jugular tubercle, and C1 lamina. Bone removal is critical because it improves the vertical and horizontal surgical angles of attack while necessitating minimal or no brainstem retraction at the level of the foramen magnum. Of the many types of additional bone work

involving the FLA, extensions are often made by removing the C1 lamina and drilling away the occipital condyle and the jugular tubercle, which is the essential part of the transcondylar approach.

The area below CN X increased in a stepwise manner within the different variations of bone work. Performing a C1 laminectomy (steps 2 and 5) and drilling away the posterior third of the occipital condyle and the jugular tubercle (steps 3 and 6) increased the areas below CN X in the inferior and lateral directions, respectively. This increase is important because the area below CN X, as opposed to the area above CN X, is fundamentally involved in accessing the VA-PICA region.

When each type of craniotomy was compared, additional horizontal angle of attack for T1 was obtained by removal of part of the jugular tubercle and condyle (between steps 2 and 3 and steps 5 and 6). The vertical component of TP1 increased after the C1 hemilaminectomy in the msFLA (between steps 1 and 2) but was not associated with the clFLA (between steps 4 and 5) probably due to the extended size of the craniotomy, superiorly, on the same plane, which may have been confounding. There was no change in the horizontal angle of attack for TP2 across the variations because the superficial location of TP2 minimized the effect on the horizontal component. The vertical component of TP2 only increased between msFLA and clFLA where the craniotomy and C1 laminectomy were concerned (between steps 1 and 4 and steps 2 and 5).

Selection of Type of Far-Lateral Approach

The following sections illustrate the advantages of the use of the msFLA and the clFLA for various types of pathology to illustrate the practical application of these data. Although these pathologies are typical of the indications for an FLA, subtleties may influence the choice of the surgical approach.

Aneurysms

Proximal PICA aneurysms are perhaps the best example of an aneurysm for which microsurgery continues to play a primary role in treatment.¹⁶ The msFLA opens a direct caudal-rostral trajectory to the lower neurovascular structures through a low suboccipital craniotomy. The preferred direction of approach to VA-PICA aneurysms is parallel to the long axis of the VA.^{2,13} The msFLA offers a similar practical surgical working area as well as similar angles of approach because the horizontal angle of attack is not affected by the type of craniotomy. Furthermore, the cranially increased vertical trajectory associated with the clFLA may be not helpful for clipping aneurysms of the VA-PICA regions. An unobstructed view to the origin of the PICA, VA, and neural structures can be obtained without needing a large suboccipital craniotomy as proposed by others.^{2,17} Finally, there is no need to traverse septic spaces because the extent of the craniotomy is limited.

Even if most parts of the VA-PICA region can be exposed sufficiently through the msFLA alone (step 1), the surgeon should work in a narrow space between rootlets of CN X and CN XI. Postoperative lower cranial nerve palsies have been

attributed to surgical manipulation of these nerves during aneurysm dissection and clipping.^{13,18–20} Therefore, a lateral extension may improve outcomes and lower the postoperative rate of morbidity. Drilling the jugular tubercle and occipital condyle (step 3) is a critical step to assure maximal lateral exposure with the FLA craniotomy. The surgeon should approach proximal PICA aneurysms via a caudal-rostral trajectory beneath the lower cranial nerves to avoid their injury. If an aneurysm is located above the hypoglossal canal, only the lateral part of the jugular tubercle can be drilled away extradurally without injuring the atlanto-occipital joint, instead of drilling both jugular tubercle and occipital condyle.^{7,8,21}

The site of the origin of the PICA from the VA varies from below the foramen magnum to the vertebrobasilar junction.²² The course of PICA itself is highly variable. In this study, the PICA exited from the VA intradurally in all 10 dissections, and PICA originated below CN X and above the foramen magnum. The distance between the aneurysm base and foramen magnum is important in planning the optimum craniotomy. If a PICA aneurysm is located high above the foramen magnum, there is no need to resect the C1 lamina. If the aneurysm is located near or at the foramen magnum, the C1 lamina should be resected (step 2). Extension of the craniotomy should be considered when optimal brain relaxation is not expected after a subarachnoid hemorrhage (SAH), or in cases of recent SAH with significant amount of cisternal blood. When an aneurysm is located above the vertebrobasilar junction, mobilizing the VA and complete removal of the jugular tubercle may also be indicated.^{3,4,9,12}

Tumors

The size of a tumor, combined with the direction and extent of its expansion, is important for deciding whether an msFLA or a clFLA is needed. The resectability of a tumor is influenced by its nature, location, and extension rather than by the extent of bone removal.^{23–26} It is not always necessary to use an extensive cranial base approach when a simpler approach may be sufficient. Displacement of the brainstem by a tumor mass may open a corridor that facilitates resection and significantly increases the working space and angle of attack, allowing the use of a more conventional retrosigmoid approach. Therefore, the msFLA alone (step 1) may be optimal for accessing small intradural tumors located anteriorly or anterolaterally to the spinomedullary area. Condylar resection may not be needed to expand the operative field.^{4,24,27}

The clFLA group is indicated for large or giant meningiomas of the posterior fossa when a small craniotomy would restrict the angle of view, provide inadequate brain relaxation, and risk herniation as a result of the combination of mass effect and lack of cerebrospinal fluid egress.^{10,28} Compared with the msFLA, the cranially increased vertical trajectory of the clFLA improves the rostral-caudal angle of view and provides a more superior direction between CN VII–VIII and CN IX–X.^{2,10,28} The clFLA provides a larger field of view, improving the line of site. It allows the surgeon to view the regional anatomicopathologic features from both sides, below and above, and with a more direct and less

tangential view, especially when large tumors extend from the cerebellopontine angle to the lower clivus.

Microvascular Decompression for Glossopharyngeal Neuralgia

Matsushima et al reported that the transcondylar fossa approach seems best suited for microvascular decompression for the treatment of glossopharyngeal neuralgia.²⁹ We selected TP2 (the usual target point for a microvascular decompression) as an end point of the lateral medullary segment of PICA, which terminates at the level of the origin of the glossopharyngeal, vagus, and accessory nerve rootlets.²² Unlike TP1, the angle of attack for TP2 was affected little by the additional steps. Therefore, during microvascular decompression in glossopharyngeal neuralgia, the msFLA alone (step 1) provides enough of an angle of attack to explore the exit zones of the glossopharyngeal and vagus nerves roots while still maintaining a caudorostral trajectory.

Cavernous Malformations

Cavernous malformations located within lateral or antero-lateral aspects of the medulla can usually be treated via an FLA.^{30,31} The most critical factor is to choose a surgical pathway that avoids incising essential neural tissue. We use the two-point method to select the optimal surgical approach.³² On appropriate diagnostic images the center of the lesion is marked, as is the point at which the lesion abuts or comes closest to a pial or ependymal surface or overlying tissue. A line drawn from the center point through the superficial point shows the optimal approach for resection of the lesion. The approach for a cavernous malformation in the VA-PICA region should be parallel to this line. It also should provide a small cortical opening through which the lesion can be removed piecemeal with minimal stretching of the brainstem fibers. The craniotomy does not have to be big. When the two-point method is used, the msFLA provides sufficient working area and angle of attack. As our surgical treatment of brainstem cavernous malformations has evolved, we have largely abandoned more extensive approaches including anterior petrosectomy, transcochlear, and full orbitozygomatic craniotomy in favor of approaches such as the retrosigmoid, suboccipital with or without telovelar approach, and lateral supracerebellar infratentorial.³⁰ We have also largely abandoned the cFLA in favor of the msFLA for the surgical removal of brainstem cavernous malformations.

In this cadaveric study, we used the same paramedian linear skin incision for quantification. In real surgery, we prefer the paramedian linear skin incision for the msFLA and the hockey-stick incision for the cFLA. Some advantages and disadvantages are associated with the different skin incisions.^{15,33} When surgical reconstruction of the distal VA with an occipital artery-to-VA bypass is planned, the hockey-stick incision should be considered for localization of the occipital artery. When the paramedian incision is used to expose the VA, the risk of inadvertently encountering the VA cannot be overemphasized. Therefore, vigilance is critical to avoid this complication.

Preoperative imaging studies are crucial for selecting the appropriate type of FLA. The location of neurovascular structures in the VA-PICA region can vary significantly.^{5,34,35} Awareness of the presence of anatomical variations is important for performing these procedures safely. Care should be taken to identify important vital structures including the anterior and posterior spinal artery and the perforating arteries to the brainstem.

It is difficult to simulate real surgery in living patients in a cadaveric study. However, the quantitative data presented from our study may be helpful in planning the degree of bone work required to optimize exposure and to minimize the risks of morbidity when an FLA is indicated for pathologic entities located in the VA-PICA region. A comprehensive understanding of the regional anatomy and knowledge of the pathologic process are required when approaching such cases. A single stereotypical strategy for the FLA may not be applicable in all patients.^{3,4} The value of tailoring the approaches based on a given disease process must be appreciated, and judgment must be balanced against the extent of surgery, risk of additional bone work, and most of all the familiarity of the surgeon with the approach. Therefore, certain young and unexperienced neurosurgeons may benefit by using the cFLA because it affords a larger total surgical area.

Conclusion

The practical surgical working space (area below CN X) and the angles of approach to the VA-PICA region were not affected by the size of craniotomy. In the msFLA, the removal of the lateral portion of the jugular tubercle with the occipital condyle and the C1 hemilaminectomy increased the horizontal and vertical angles of attack, respectively. According to the location, extent, and pathology of lesions in the VA-PICA region, the type of the FLA, including the craniotomy and lateral and inferior extensions, should be individually tailored to obtain the exposure needed without unnecessary surgical steps.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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