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Original Article

A standalone minimally invasive presigmoid retrolabyrinthine suprameatal approach: A cadaveric morphometric study

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ABSTRACT

Background: Presigmoid approaches provide access to several structures anterior to the sigmoid sinus (SS) and may be intended for the treatment of lesions located in the middle and posterior fossa. We conducted a morphometric cadaveric study investigating the infratentorial presigmoid retrolabyrinthine suprameatal approach (PRSA) as a unique operative corridor. The typical anatomic-radiological characteristics and variations were evaluated and analyzed to predict surgical accessibility.

Methods: A total of 10 surgical dissections were performed on both sides of five adults, injected, and cadaveric heads. Fifteen morphometric parameters were measured, analyzed, and categorized into pre-procedural, intra-procedural, and additional parameters.

Results: Preoperative anatomic-radiological parameters provide valuable information to select patients with favorable anatomy that may offer appropriate surgical accessibility to the medial part of cerebellopontine angle cistern, lateral pons, and prepontine cistern through a PRSA corridor. An obtuse petroclival angle of ≥144° with a more horizontally oriented petrous bone, a posterior SS position, and a large mastoid cavity provided the greatest surgical accessibility through the PRSA corridor. The superior petrosal sinus drainage and the degree of petrous apex pneumatization were important factors affecting surgical fluency and speed. However, they were not determinant factors for selecting the most appropriate patients eligible for the PRSA.

Conclusion: The PRSA represents a minimally invasive modification of the trans-labyrinthine approach that may be offered in patients with lesions medial to the internal auditory canal or anterior/lateral to the brainstem, with the goal of preserving vestibulocochlear functions. Preoperative anatomic-radiological parameters are mandatory for a patient-tailored selection of the most effective surgical approach.

Keywords: Cerebrovascular, Lateral skull base, Neuro-oncology, Presigmoid, Retrolabyrinthine, Sigmoid sinus, Vestibular schwannoma.

INTRODUCTION

Presigmoid approaches provide access to critical structures located anteriorly to the sigmoid sinus (SS) and may be used for the treatment of complex middle and posterior fossa lesions. Presigmoid corridors often involve a posterior petrosectomy with different volumes of petrous bone removal, ranging from a simple mastoidectomy to substantial skeletonization and resection of the semicircular canals.[14] As frequently reported in the literature, some surgical variants include transotic, translabyrinthine, partial translabyrinthine, retrolabyrinthine, and combined supra-infratentorial approaches.[2,3,10,15] More extended bone removal allows better visualization of lesions sited anteromedially to the brainstem but also increases the risks of injuring cranial nerves (CNs) VII/VIII, vascular structures, and the auditory apparatus.[8]

In this anatomical morphometric study, we investigate the infratentorial presigmoid retrolabyrinthine suprameatal approach (PRSA) as a unique operative corridor. The typical anatomic-radiological characteristics and variations were evaluated, and the related anatomical and radiological parameters were analyzed to predict surgical accessibility.

MATERIALS AND METHODS

Five formalin-fixed, triple-injected[24] adult cadaveric heads were used in adherence to our institution's ethical standards and regulations. No IRB approval was required for this cadaveric study. Pre-procedural thin-cut head computed tomography (CT) scans (1.0 mm per slice) were obtained. Dissections were performed on both sides, for a total of ten sides operated under ×3 to ×40 magnifications using an operative microscope (Haag-Streit®, Germany). Rigid Storz (El Segundo, CA) 0° and 30° endoscopes (4 mm diameter, 18 cm length) were also utilized for appraising the endoscopic anatomy. Post-procedural thin-cut head CT scans were obtained, and OsiriX (open-source software; www.osirixviewer.com) was used for all the radiographic analyses.

Surgical technique

The head was placed in a lateral position. A straight or slightly anteriorly curved incision was made behind the ear, from 3 cm above the pinna to 3 cm inferior to it, passing over the retro-auricular sulcus and along the anterior edge of the mastoid process. The pericranium and the sternomastoid muscle were reflected inferiorly by a self-retaining retractor to expose the posterior margin external auditory canal (EAC), MacEwen's triangle, and the upper part of the mastoid process. The superficial landmarks were used to identify the anterior (posterior margin of EAC) and superior limit of the mastoid drilling (also called MacEwen's triangle). The landmarks to identify the transverse-sigmoid junction and the mastoid tip exposure were not required because the SS, which represents the posterior limit, was immediately identifiable at a later stage through the inside-out drilling technique. This allowed the straight linear incision and avoided extensive exposure of the superficial bony landmarks.

A mastoidectomy limited to the suprameatal crest and parallel to the posterior wall of the EAC was performed using a 4 mm diamond burr (Medtronic drill, Dublin, Ireland). The bone drilling was continued toward the middle fossa dura, defining the upper limit of the proposed surgical cavity, and then widened posteriorly toward the sino-dural angle. Partial or total exposure to the SS was not required. A pre-designed surgical corridor on the 3D reconstructed head CT scan was used as part of the preoperative planning.

Drilling of the retrolabyrinthine area was extended anteriorly and medially into the sino-dural angle to expose the lateral part of the superior petrosal sinus (SPS). The SPS was used as a landmark to remove the inferior and anterior bony strips and preserve the posterior semicircular canal (PSC). The petrous ridge was drilled to enlarge the surgical corridor in the anterosuperior direction. An inside-out approach was then performed to widen the operative corridor. A cone-shaped cavity was created by unroofing the presigmoid bone posteriorly and by thinning the posterior wall of EAC, using the SPS as the apex, SS as the posterior margin, and EAC as the base. This provided adequate angular visualization of the deeper structures and improved the maneuverability before further drilling into the petrous bone.

After obtaining sufficient exposure to the surgical cavity, the suprameatal extension of the approach was performed. This step required changing the angle of the operative microscope to be parallel and tangential to the SS, offering more anterosuperior-medial projection. The course of the SPS was followed medially by thinning the suprameatal part of the petrous apex while avoiding the internal auditory canal (IAC) inferiorly and the labyrinth posteriorly. Lateral drilling was performed with caution to avoid inadvertent injury to the IAC. Thinning of the posterior plate of the petrous apex was required for safe and sufficient exposure. Before further drilling, the SPS was elevated off the petrous ridge to avoid injury. The dissection was performed along with the SPS on the petrous ridge to minimize the risk of injury to the petrous internal carotid artery and the cochlea.

The dura over the upper part of the Trautman's triangle (TT) (bounded superiorly by the SPS, posteriorly by the SS, and anteriorly by the bony labyrinth) and the suprameatal area (i.e., the area below the SPS from the SS to the petrous apex) was opened and reflected. Care was taken to avoid injury to the superior petrosal vein, which drains into the SPS. Dural leaflets were retracted with stay sutures. Once the posterior petrous apicectomy was achieved, the operative corridor was used with an hourglass configuration. A multiangled exposure was contemplated with effective micro-surgical maneuverability, exposing (1) CN-V in its root-entry zone; (2) CN-VII and CN-VIII at the IAC; (3) CN-V in its root-entry zone; and (4) CN-VI, anterior inferior cerebellar artery (AICA) and basilar artery (BA) in the anterior and anterolateral peri-brainstem area.

Pertinent terminology

In our approach, four anatomy-based operative stages were encountered: (1) presigmoid, also called posterior trans-petrosal or trans-mastoid; (2) retro-labyrinthine, also called trans-TT or supra-bulbar; (3) petrous ridge, namely, extension by partial drilling of the superior petrosal ridge underneath the SPS; and (4) suprameatal, also called posterior petrous apicectomy. Several different synonyms can be devised based on the distinct anatomy stages. We opted for the presigmoid retro-labyrinthine suprameatal approach (PRSA) for simplicity and self-explanatory purposes. Exposure of all the neurovascular structures in the surgical field was identified and analyzed.

Morphometric measurements

A total of 15 morphometric parameters were measured, analyzed, and categorized into pre-procedural, intra-procedural, and additional parameters.

The following pre-procedural parameters were analyzed on pre-procedural head CT scans and used for preoperative planning: (I) SS position:[22] grade-1 (favorable), if the SS does not conceal the view of the presigmoid bony plate nor of the PSC, with a wide TT; grade-2 (intermediate), if the SS sits anteriorly and covers the view of the presigmoid bony plate but not of the PSC, with a narrower TT; grade-3 (unfavorable), if the SS sits anteriorly and conceals the visualization of the presigmoid bony plate and of the PSC, with a severely narrow TT; II) SS dominance: left-sided, right-sided, or co-dominant; III) petroclival angle: [4] measured from the petrous bone to the clivus, just below the inferior border of the IAC; (IV) sinu-clival angle: measured from the SPS, at the level of the petrosal groove on the upper border of the petrous bone, to the clivus; (V) BA position within clival zone II,[4] which extends from the IAC to the jugular tubercle into: grade-0, midline; grade-1, right paramedian; grade-2; left paramedian; grade-3, right petroclival junction, and grade-4, left petroclival junction [Figures 1a and b]; and (VI) petrous apex pneumatization (PAP),[26] based on the amount of pneumatization medial to the labyrinth: grade-1, no air cells present in the vicinity of the petrous apex; grade-2, less than half of the petrous apex pneumatized; grade-3, more than half of the petrous apex pneumatized; grade-4, completely pneumatized petrous apex.

The intra-procedural parameters were assessed within the surgical field during the dissection: (I) depth of the approach: measured from the mastoid bone surface at the level of sinu-dural angle to the medial end of the operative bony cavity; (II) BA depth: measured from the mastoid bone surface at the level of sinu-dural angle to the BA at a depth of operative field (if the BA was not exposed, this distance was measured using the midline as a reference); (III) outer mastoid opening size: measuring the area delimited by the length and width of the outer bony opening; (IV) CN exposure: identifying the exposed CN-V, CN-VI, CN-VII, and CN-VIII and their segments; (V) arterial exposure: identifying the exposed AICA and BA with their segments in the depth of the operative field; and (VI) surgical maneuverability score modified from Bernardo *et al*.,[5] based on the exposure of the main target structures at the depth of the PRSA corridor (i.e., CN-V, CN-VI, and proximal AICA), coupled with the feasibility to access microsurgical instruments.

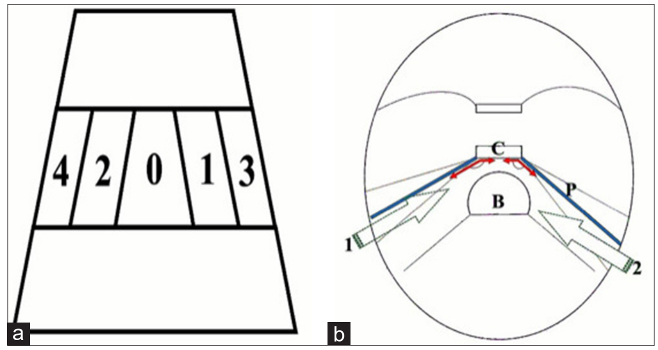

Figure 1: (a) Depiction of the clival zone II with longitudinal classification of the basilar artery position in relation to the midline: grade-0, midline; grade-1, right paramedian; grade-2; left paramedian; grade-3, right petroclival junction, and grade-4, left petroclival junction. (b) Depiction of cranial base anatomy and the orientation of the petrous bone related to the Presigmoid retrolabyrinthine suprameatal approach (PRSA) and accessibility of the retro-clival area: (1) On the left side, the petroclival angle is obtuse, the petrous bone is more horizontally oriented, and the PRSA corridor can access more anteromedial structures; (2) On the right side, a more acute angle and more vertically oriented petrous can be considered unfavorable anatomy for the PRSA. B: Brainstem, C: Clivus, P: Petrous bone (upper border).

The additional parameters included parameters not directly related to the procedure: (I) operative need for PSC drilling, (II) type of SPS venous drainage [1], and (III) presence of a high jugular bulb. Separately, the implementation of navigation-assisted and endoscopic-assisted procedures was also assessed.

RESULTS

Pre-procedural measurements

The SS position was favorable (grade-1) in seven specimens and equally dominant on both sides (four sides left-dominant, four sides right-dominant, and two sides co-dominant). The petroclival angle varied from 129° to 150° with a mean (±SD) of 141.5° (±6.3°). The sinu-clival angle varied from 123° to 136° with a mean (±SD) of 130.4° (±3.6°). In clival zone II, the BA position was midline (grade-0) in two specimens and the right paramedian (grade-1) in four specimens. The petrous apex was not pneumatized (grade-1) in 50% of the specimens and completely pneumatized (grade-4) in 20% of the specimens [Table 1].

Intra-procedural measurements

The mean (±SD) depth of approach to the dural opening was 5.47 cm (±0.43), and the mean (±SD) BA depth was 7.15 cm (±0.45) [Table 1]. The mean (±SD) area of mastoid opening size was 6.15 cm^2 (±1.84) [Figure 2]. The AICA was exposed on all ten sides, and the BA was exposed on eight sides. The CN-V root entry zone and CN-VII/CN-VIII complex were exposed in all specimens, and the CN-VI was exposed on nine sides [Figure 3]. The surgical maneuverability score was grade-4 (i.e., multiangle exposure with facilitated surgical maneuverability) in all specimens [Figure 4].

Additional measurements

On post-procedure CT scans, an absent SPS was noted on two sides and a high jugular bulb on the other two sides of

Table 1: Measurements of morphometric parameters for the standalone presigmoid retrolabyrinthine suprameatal approach.

Specimen ID	Side of approach	SS position	SS dominance	Petroclival angle (degrees)	Sinu-Clival Angle (degrees)	Clival zone II BA position (degrees)	Petrous Apex Pneumatization	Depth of approach (cm)	BA depth (cm)	Outer mastoid opening size (cm^2)
1	R	2	Co	135	132	0	2	5.45	7.09	7.20
1	L	2	Co	129	136	0	2	5.2	6.75	3.82
2	R	2	R	136	128	4	1	4.68	6.69	3.74
2	L	1	R	139	130	4	1	5.28	7.3	3.91
3	R	1	L	149	130	2	1	5.42	6.68	8.50
3	L	1	L	150	134	2	1	5.39	6.98	7.59
4	R	1	R	144	132	1	1	6.09	7.88	6.61
4	L	1	R	142	131	1	2	6.17	7.95	8.40
5	R	1	L	145	123	1	4	5.6	6.97	5.71
5	L	1	L	146	128	1	4	5.4	7.21	6.01

Specimen ID	Exposure CN-V REZ	Exposure CN VI	Exposure CN-VII, CN-VIII	Exposure AICA	Exposure BA	Surgical maneuverability score	Required PSC drilling	SPS drainage	High jugular bulb
1	+	-	+	+	-	4*	+	2	-
1	+	-	+	+	-	4*	+	3	+
2	+	-	+	+	-	4*	+	2	-
2	+	-	+	+	+	4*	+	3	-
3	+	+	+	+	+	4	-	1	-
3	+	+	+	+	+	4	-	3	-
4	+	+	+	+	+	4	-	3	-
4	+	-	+	+	-	4*	+	2	-
5	+	+	+	+	+	4	-	1	-
5	+	+	+	+	+	4	-	4	+

AICA: Anterior inferior cerebellar artery, BA: Basilar artery, CN: Cranial nerve, Co: Codominance, L: Left, PSC: Posterior semicircular canal, R: Right, REZ: Root entry zone, SPS: Superior petrosal sinus, SS: Sigmoid sinus. Grading of the SS position: Grade 1 (favorable): The SS does not obstruct the view of the presigmoid bony plate nor of the PSC, with a wide Trautmann triangle. Grade 2 (intermediate): Anterior placement of the SS, obscuring the view of the presigmoid bony plate but not of the PSC, with a narrowed Trautmann triangle compared to grade 1. Grade 3 (unfavorable): The SS sites far anteriorly obstructing the visualization of the presigmoid bony plate and the PSC, with a Trautmann triangle severely narrowed. Clival zone II BA position: 0: Midline; 1: right paramedian; 2: left paramedian; 3: touching the right petroclival junction; 4: touching the left petroclival junction. Degree of Petrous Apex Pneumatization (calculated using the labyrinth as the reference structure): 1: no air cells present in the vicinity of the petrous apex medial to the labyrinth; 2: less than half of the petrous apex medial to the labyrinth pneumatized; 3: more than half of the petrous apex medial to the labyrinth pneumatized; 4: most of the petrous apex area medial to the labyrinth pneumatized. Surgical maneuverability score: 4*: grade 4 reached only after PSC drilling. SPS drainage type: 1: Medial; 2: Lateral; 3: Complete; 4: Absent

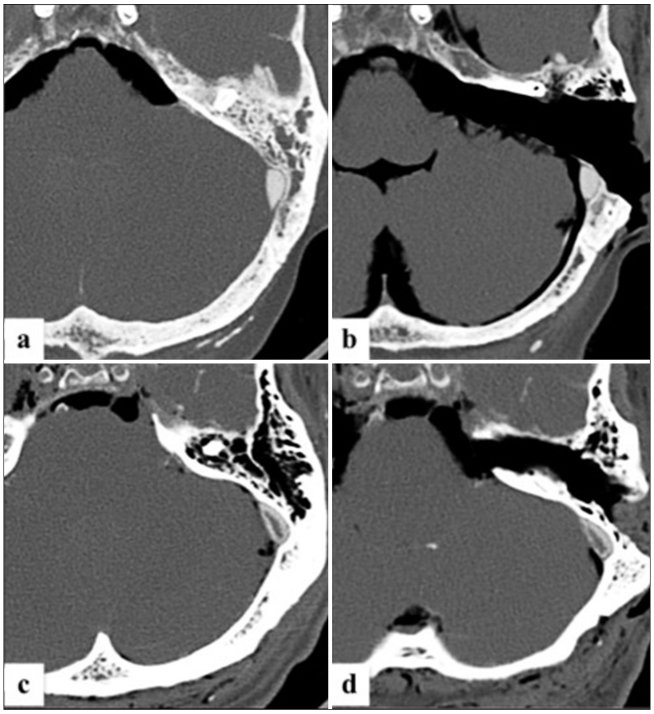

Figure 2: Pre- and post-procedural cranial computed tomography scans showing the variation of the presigmoid retrolabyrinthine suprameatal approach (PRSA) corridor and the exposure of prepontine territory based on petrous bone orientation, petroclival angulation, and the type of sigmoid sinus location: (a and b) pre- and post-procedure examples of obtuse petrous angulation with a straight operative trajectory to the central prepontine area; (c and d) pre- and post-procedure examples of acute angulation with a relatively limited surgical corridor. The sigmoid sinus was not exposed in any case.

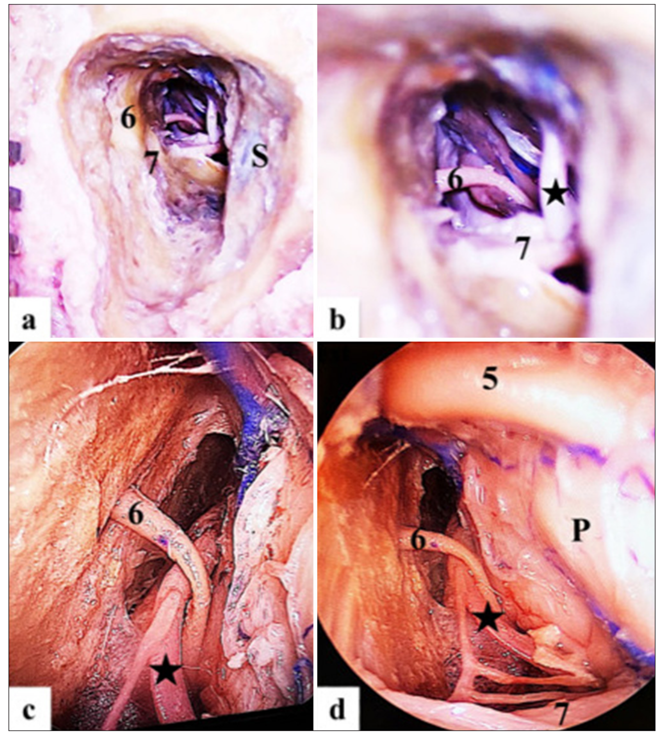

Figure 3: Operative steps on injected cadaver head showing the extent of the minimally invasive bone cavity of left side Presigmoid retrolabyrinthine suprameatal approach: (a and b) microscopic views (zoom out) exposing the trigeminal, abducent, and vestibulocochlear nerves, along with the anterior inferior cerebellar artery (AICA), and basilar artery (BA) in the anterior, and anterolateral, peri-brainstem area; (c and d) endoscopic views of the operative field for the same cadaver, using 0° and 30° scopes showing the relation of the AICA to the surrounding structures, including the BA, trigeminal, and abducent cranial nerves. 5: Trigeminal nerve; 6: Abducent nerve; 7: Facial nerve; P: Pons; S: Sigmoid sinus; Star*: AICA.

the same specimens [Table 1]. The navigation was used as a confirmatory tool to localize the critical neurovascular structures within the petrous temporal (i.e., SS, carotid artery, and the labyrinth). The endoscope was utilized to confirm the course of the exposed neurovascular structures of interest [Figures 3c and d]. In three cadavers, drilling of the PSC was mandatory to attain full exposure and maneuverability (grade-4).

DISCUSSION

The presigmoid approach per se has been extensively analyzed and recently classified in the literature.[3,10-13] The presigmoid corridor comprises several variants, ranging from the relatively invasive transotic approach to the minimally invasive retrolabyrinthine approach.[10] In addition, the presigmoid approach is usually included in different combined approaches, such as the anterior petrosal approach. More extended bone removal allows better visualization of lesions sited anteromedially to the brainstem but also increases the risks of injuring the CN-VII/CN-VIII complex, vascular structures, and the auditory apparatus.[8]

Surgical accessibility of the PRSA corridor

Several preoperative anatomic-radiological factors should be considered and studied to select patients who may benefit from a PRSA technique with appropriate surgical accessibility. We defined the operative accessibility for PRSA as the sufficient exposure of the medial part of the cerebellopontine angle up to the ipsilateral prepontine cistern. Based on our study, the PRSA selection and planning as a unique corridor should be mainly considered based on the following three significant parameters: (1) the petroclival angle, (2) the SS position and the volume of the mastoid cavity, and (3) the BA position at the level of the clival zone II.

From our cadaveric analysis, we found that the petroclival angle is the most consistent factor for determining the accessibility of operative trajectory to the zone medial to the IAC (i.e., premeatal AICA). A petroclival angle of ≥144° appears to offer the best anatomy for selecting the PRSA

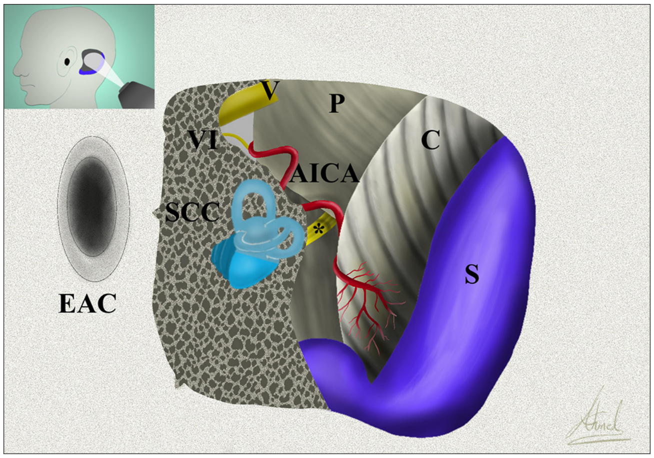

Figure 4: Artistic depiction of the Presigmoid retrolabyrinthine suprameatal approach with related operative anatomy. AICA: Anterior inferior cerebellar artery; C: Cerebellum; EAC: External auditory canal; P: Pons; S: Sigmoid sinus; SSC: Semicircular canals; V: Trigeminal nerve; VI: Abducent nerve; Asterix*: Facial nerve complex. Illustration prepared by Ahmed Muthana and courtesy of Samer Hoz.

corridor. More obtuse angles (>144°) are correlated to more horizontally oriented petrous bones and may result in the superior ability of the unique PRSA trajectory to access the retroclival area [Figure 1b]. Among our specimens, 5 sides (50%) showed a ≥144° angle, achieving an optimal operative trajectory that exposed the full course of the pre-meatal AICA. It should be noted that, due to the anatomical conformation of the petrous ridge, the measurements of the petroclival angle vary depending on where they are taken in relation to the IAC.[16,22] Due to this variability, we decided to take all measurements at the level of the inferior border of the IAC to lessen the effect of the resultant angle by the peri-canalicular focal bony irregularities.

We also found that a more favorable SS position was associated with a larger mastoid cavity. Grade-1 (favorable) and grade-2 (intermediate) SS positions accounted for 70% of the sinus anatomy in our specimens, which offer a large exposure to the PRSA corridor. These grades can be evaluated on preoperative CT scans, demonstrating a lack of concealment of the presigmoid area by the SS and an acceptable operative corridor using the PRSA.

The BA position from the midline determines the accessibility of the origin of AICA from the BA through a PRSA corridor, and it should be measured at the level of any surgical approach due to the common variations and tortuosity of the BA course. For this reason, we analyzed the BA position at the middle clival area (also called clival zone II[4]), which extends between the level of IAC and the jugular tubercle. In addition, we proposed a longitudinal classification to describe the BA position in relation to the midline within the clival zone II [Figure 1a]. In our cohort, 8 sides (80%) had midline or paramedian BA, and the BA could be exposed in all five sides with typical anatomy for PRSA, namely, having an obtuse petroclival angle and favorable SS location. Among our specimens, one side had a BA located more laterally within the clival zone II, positioned on the left of the midline and touching the left petroclival junction. In this specimen, a left PRSA approach resulted in feasible exposure of the BA despite the atypical anatomy. We found that the SPS drainage and the degree of PAP were mostly related to the feasibility of performing the PRSA technique but were not determinant factors for evaluating surgical accessibility.

The advantages of PRSA

Based on our study, we found that the PRSA characterizes a minimally invasive and feasible approach for exposing the CN-V, CN-VI, and proximal AICA, with several intrinsic advantages. The relatively small bone window avoids extensive brain exposure, with minimal brain retraction following the release of cerebrospinal fluid at the level of the cerebellopontine angle cistern. In addition, PRSA allows hearing preservation while exposing the surgical area of interest along with the preservation of the SPS with its drainage, compared to other presigmoid approaches.[10] The drilling may be guided by the preoperative planning based on the relations with the EAC and SPS, using an inside-out technique that shortens the procedure time without exposing the four critical neurovascular structures (i.e., SS, IAC, labyrinth, and the cerebellar surface), thus decreasing risks of surgical complications. Endoscopic-assisted microsurgery may further improve the surgical exposure and maneuverability. Other benefits include avoidance of supratentorial craniotomy, tentorial resection, and dissection of temporalis or suboccipital muscles.

The removal of the PSC provides the avenue for the suprameatal part of the procedure. However, we found that the PSC can be preserved, achieving the same exposure of the suprameatal part by changing the angulation of the operating microscope into a more anteromedial-superior trajectory tangential to the anterior edge of the SS. This angulation will create an hourglass shape operative cavity centered on the retrolabyrinthine space, connecting the superficial (lateral) mastoidectomy with the deep (medial) suprameatal cone. Based on our anatomic study, we found that the full course of premeatal AICA can be exposed with the PRSA [Figure 3a]. The exposed area comprises a trapezoid that connects the IAC, the CN-VI, the CN-V, and the BA groove. The implementation of endoscopic-assisted surgery can mitigate the deep and stretched surgical corridor achieved with the PRSA. Variable angled optics and adapted endoscopic instruments may allow optimal visualization of previous inaccessible corners in the retroclival area, offering feasible operative corridors [Figure 3b].

There are numerous advantages of the PRSA over the classic transcochlear, presigmoid supra-infra-tentorial, and combined transpetrosal, trans-sigmoid, and endoscopic trans-clival approaches.[3,10] The most important comprises the limited mastoid drilling, the avoidance of exposure and traction of the SS, and the preservation of the SPS, labyrinthine, cochlea, and CN-VII functions. In addition, the avoidance of the retraction of the temporal lobe and cerebellum, coupled with the preservation of the vein of Labbe, characterizes critical differences in the PRSA as compared to other lateral and posterolateral approaches targeting the area of the petroclival region between the IAC and the upper border of the jugular tubercle (clival zone II).[4,6,7,9,16-21,23,25,27,28]

Limitations

The PRSA is a useful and minimally invasive method to expose CN V, VI, and proximal AICA. However, its usage is limited to the petroclival and adjacent retro-clival areas in patients with favorable anatomy. Detailed knowledge of the anatomy of this area, including cadaver dissections, is needed before doing this procedure in the clinical setting. As this study was performed on cadaveric specimens, surgical complications, such as a cerebrospinal fluid leak, CN deficits, vascular injuries, hearing loss, or other CN injures, could not be evaluated.

CONCLUSION

The PRSA represents a minimally invasive modification of the trans-labyrinthine approach. It may be offered in patients with lesions medial to the IAC or anterior/lateral to the brainstem, with preservation of both vestibular and cochlear functions. This study highlights the importance of preoperative anatomic-radiological parameters for selecting the most effective surgical approach on a patient-specific basis. The most favorable presigmoid anatomy for obtaining optimal PRSA corridors with large and safe anatomical exposure includes a more horizontally oriented petrous bone with an obtuse petroclival angle and a more posterior position of the ipsilateral SS.

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Declaration of patient consent: Patient's consent was not required as there are no patients in this study.

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