Direct Comparison Between the Kawase Approach and Retrosigmoid Intradural Suprameatal Corridor to Access the Petroclival Region Using Computed Tomography Quantitative Volumetric Analysis: A Cadaveric Study

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■ OBJECTIVE: **The anterior petrosectomy, also known as the Kawase approach, and the retrosigmoid intradural suprameatal approach (RISA) have both been used to reduce the petrous apex and access the petroclival region. Our goal was to compare the volumes and 3-dimensional shapes of bony resection obtained through each approach while trying to resemble realistic surgical settings.**

■ METHODS: **Five cadaveric specimens totaling 10 sides were dissected and analyzed. In every specimen, 1 side was used for the Kawase approach while the opposite side was used for the RISA. Petrosectomy volumes were assessed by comparing preoperative and postoperative thin-sliced computed tomography scans.**

■ RESULTS: **Petrosectomy volumes were significantly larger through the Kawase approach than through the RISA (0.82 ± 0.11 vs. 0.49 ± 0.07 cm^3, $P < 0.001$). In addition, surgical maneuverability and freedom were greater in the Kawase operative variant. Lastly, the morphology of the bony window achieved through each approach was clearly different: trapezoid for the anterior petrosectomy versus elongated ellipsoid for the RISA.**

■ CONCLUSIONS: **The Kawase approach invariably results in larger volumes of bony removal than the RISA operative variant, and the volume of petrosectomy that is spatially congruent is only partially identical. The Kawase corridor is best suited for middle fossa lesions that extend into the posterior fossa, while the RISA is suitable for pathologies mainly residing in the posterior fossa and extending into the Meckel cave.**

INTRODUCTION

The petrous apex is a complex anatomic and tight surgical region. The most frequent regional tumors encountered in routine skull base practice are meningiomas and trigeminal schwannomas. However, the differential diagnosis includes a variety of rare neoplastic, developmental, and inflammatory lesions (i.e., epidermoid cyst, chordoma, chondrosarcoma, cholesterol granuloma, inflammatory pseudotumor, etc.).[1] Pathologies originating from or extending to the petrous apex pose a discrete surgical challenge as they often expand significantly into both the middle and posterior cranial fossae on time of initial diagnosis, through the natural route of the trigeminal porus and Meckel cave.

Various operative trajectories have been proposed to access the petroclival region, and although tumor resectability and patient outcome have improved, surgical maneuverability remains

Key words
- Anterior petrosectomy
- Middle fossa
- RISA
- Skull base
- Trigeminal nerve

Abbreviations and Acronyms
CT: Computed tomography
GSPN: Greater superficial petrosal nerve
IAC: Internal auditory canal
RISA: Retrosigmoid intradural suprameatal approach

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arduous and formidable.[2] To this end, both the anterior petrosectomy, also known as the Kawase corridor, and the retrosigmoid intradural suprameatal approach (RISA) are effective operative variants used to reduce the bone of the petrous apex, mobilize the trigeminal nerve, and allow access to Meckel cave. The Kawase approach is a middle fossa approach first described in 1985 that involves drilling of the petrous apex through the rhomboid surface, bounded by the trigeminal nerve anteriorly, the petrous part of the internal carotid artery anterolaterally, the greater superficial petrosal nerve (GSPN) and cochlea laterally, the arcuate eminence posteriorly, and the superior petrosal sinus medially.[3] RISA, conversely, is an extension of the standard retrosigmoid avenue, during which the suprameatal tubercle is removed. Bone drilling is limited by the tentorium and trigeminal nerve superiorly and the contents of the internal auditory canal (IAC) posteroinferiorly.[4]

Although it has been suggested that the osseous window to the petrous apex and Meckel cave is similar in RISA and Kawase corridors, only a few quantitative comparisons of the bony resection achieved in each case are available.[5] To better understand and estimate the extensions and limitations associated with these 2 basic skull base techniques, we performed a cadaveric study and opted to compare the volumes and 3-dimensional shapes of bone resection offered by each approach. The 2 approaches were performed in a tandem manner in all specimens using a meticulous microneurosurgical technique and with emphasis on resembling the surgical maneuverability and dexterity achieved in real operative scenarios. Our overarching

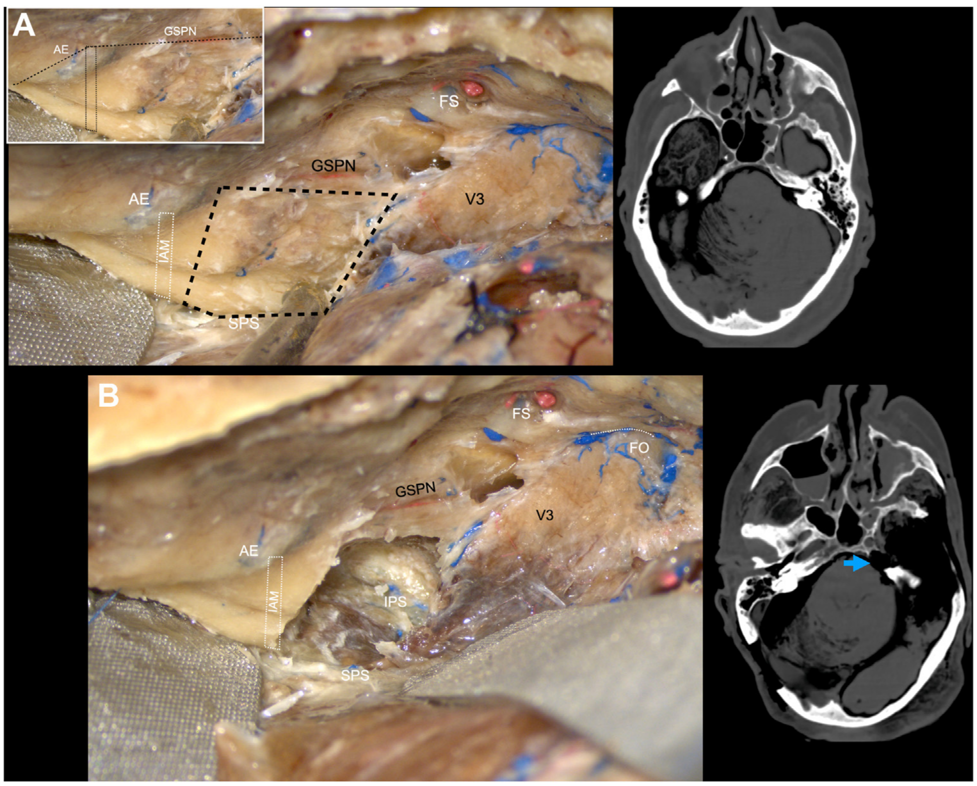

Figure 1. Left-sided Kawase approach. (**A**) To elevate completely the middle fossa dura, the middle meningeal artery has been incised and the foramen spinosum is recognized in the upper right corner of the image. A fixed retractor blade is used against the petrous ridge, offering optimal microsurgical maneuverability. The rhomboid fossa landmarks, namely the V3 branch of the trigeminal nerve anteriorly, greater superficial petrosal nerve laterally, arcuate eminence posteriorly, and petrous ridge medially, are recognized and illustrated with a *black dashed line*. The foramen ovale is noted with a *white dashed line*. The approximate position of the internal acoustic meatus is represented with a *white dotted line* at the posterior limit of the rhomboid fossa, based on the surgeon's assessment and on imaging verification. A computed tomography scan of the intact petrous bone of the specimen, before dissection, is included in the inlet. (**B**) The rhomboid fossa has been completely drilled away, and the posterior fossa dura, between the superior and inferior petrosal sinuses, has been exposed. Note the extent of the dura exposed and the available space within the fossa, for surgical maneuvers. On the right, a computed tomography scan of the specimen after the dissection. The *blue arrow* shows the bone defect. AE, arcuate eminence; FO, foramen ovale; FS, foramen spinosum; IAM, internal auditory meatus; IPS, inferior petrosal sinus; GSPN, greater superficial petrosal nerve; SPS, superior petrosal sinus; V3, third division of the trigeminal nerve.

goal was to conduct a "realistic" skull base cadaveric study without pushing the limits of the dissection out of the boundaries normally dictated by surgical wisdom and realism.

MATERIALS AND METHODS

Five formalin-fixed and silicone-injected cadaveric heads (10 sides) without known brain pathology were used to perform 10 approaches (5 Kawase and 5 RISA). In every specimen, 1 side was used for the Kawase approach while the opposite side for the RISA approach (3 right-sided and 2 left-sided RISAs) aiming to limit bias with respect to the efficiency of optimally performing each approach. All dissections were conducted in cooperation by the 2 most experienced skull base surgeons (C.K. and P.S., both right handed), under microscope and by implementing a meticulous microsurgical technique, thus avoiding preference bias or discrepancy of skill. At the end, the limit of bone drilling was confirmed by intraoperative navigation. During the study many photos were obtained to document and illustrate the regional anatomy of interest.

Surgical Procedures

For the Kawase approach (Figure 1), the specimen was fixed in a Mayfield clamp and rotated 90° to the contralateral side. The Kawase rectangle was drilled until the dura of the posterior fossa up to the level of the inferior petrosal sinus was exposed.

For the RISA (Figures 2 and 3), the head was secured in a typical way for a retrosigmoid craniotomy. A standard craniotomy was turned, and the cerebellopontine angle (CPA) was dissected. The suprameatal tubercle was identified and drilled off, providing access to the Meckel cave and allowing mobilization of the trigeminal nerve.

Both procedures were performed in a realistic fashion, avoiding aggressive, excessive drilling, and unnecessary risks so as to mimic real operative settings. At the end of each dissection, the limits of bone removal were confirmed using intraoperative navigation (Medtronic Fusion Compact ENT Navigation System, Minneapolis, Minnesota, USA).

Volumetric Analysis

We used computer-assisted volumetric analysis to measure the volume of bone removed in all approaches: All specimens underwent a thin-sliced (1-mm) computed tomography before and after completing the dissections. The images were fused and for each axial computed tomography slice, the resected bone in both sides was traced using the iPlan software (Brainlab AG, München, Germany) (Figure 4). Volumes were calculated as the product of the area traced and the corresponding slice thickness. The sum of each slice volume gave the total volume of the resected bone in cubic millimeters. All measurements were performed independently by 2 experienced skull base neurosurgeons (P.S. and C.K.), and the volumes were expressed as the mean of the 2 measurements.

Statistical Analysis

The Student's t-test was used to compare the mean of the volumes of bone resection between the 2 approaches. A P value < 0.05 was considered significant. Statistical analysis was performed using SPSS v.23 (IBM Inc., Chicago, Illinois, USA).

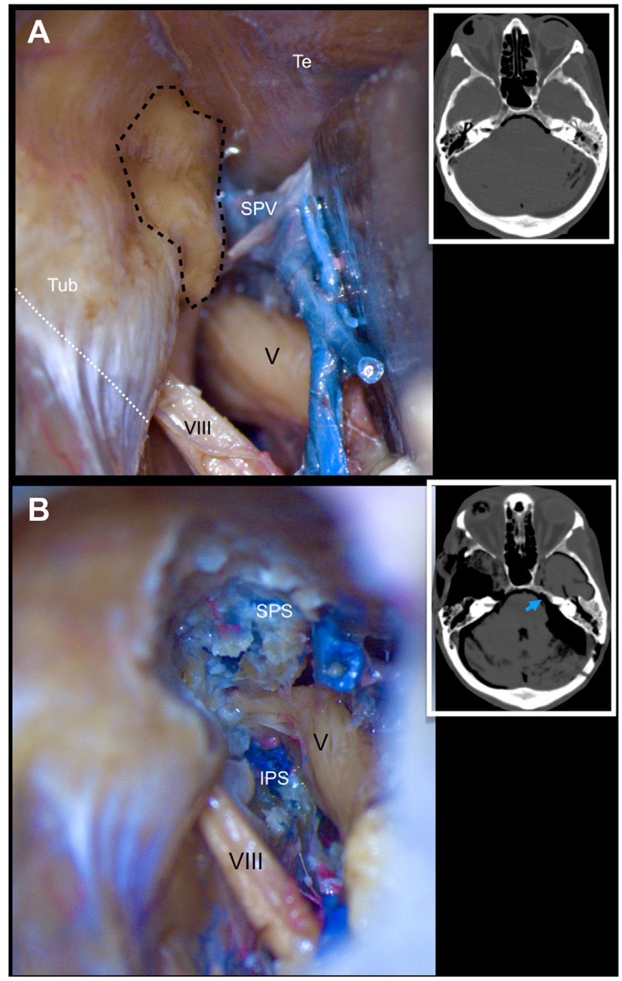

Figure 2. Left-sided retrosigmoid intradural suprameatal approach (RISA). (**A**) A standard retrosigmoid craniotomy has been performed, and the neurovascular structures of the cerebellopontine angle have been exposed. The Tubingen line, the imaginary line connecting the dural folds between the jugular foramen and the medial part of the sigmoid sinus, is illustrated with a *white dotted line*, indicating the inferior limit of the internal auditory canal. The dura over the suprameatal tubercle has been peeled off, and the limits of the drilling are demarcated with a *black dashed line*. The trigeminal nerve is observed anteroinferiorly to the suprameatal tubercle, whereas the VII-VIII complex runs posteroinferior. The superior petrosal veins are seen to join the superior petrosal sinus at the lateral edge of the tentorium. The inlet shows a corresponding computed tomography scan of the specimen before dissection. (**B**) Drilling of the suprameatal tubercle reveals the distal part of the trigeminal nerve. The RISA allows for mobilization of the trigeminal nerve and grants access into the Meckel cave. The *blue arrow* shows the bony defect. IPS, inferior petrosal sinus; SPS, superior petrosal sinus; SPV, superior petrosal veins; Te, tentorium; Tu, Tubingen line; V, trigeminal nerve; VIII, vestibulocochlear nerve.

RESULTS

Both approaches provided access to the trigeminal porus and allowed for mobilization of the trigeminal nerve inside the Meckel cave. The mean volumes of resected bone offered through the

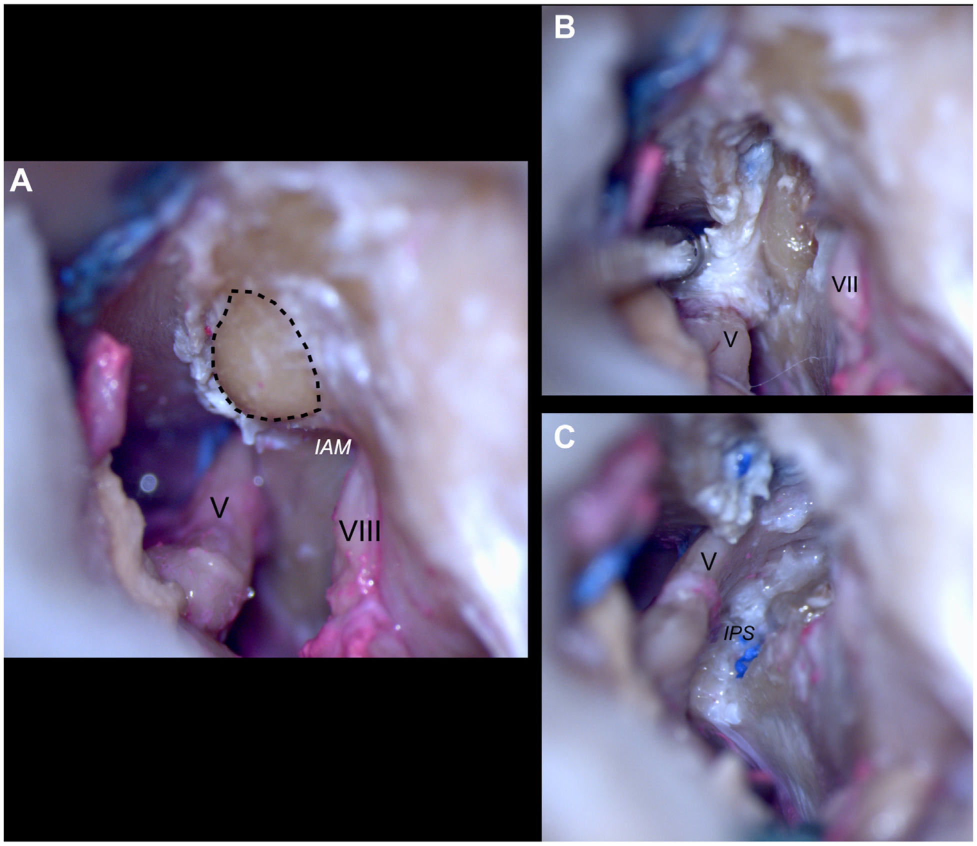

Figure 3. Right-sided retrosigmoid intradural suprameatal approach (RISA). (**A**) A standard retrosigmoid craniotomy has been performed, and the neurovascular structures of the cerebellopontine angle have been exposed. The dura over the suprameatal tubercle has been elevated, and the tubercular bone is delineated with a *black dashed line*. The trigeminal nerve runs anteroinferiorly, while the VII-VIII complex is seen posteroinferiorly entering the internal auditory meatus. (**B**) Drilling of the suprameatal tubercle. The dural fold overlying the tubercle is incised in a semilunar fashion and reflected medially to protect the trigeminal nerve from injury during the drilling process. (**C**) Exposure of the distal trigeminal nerve after completion of bone drilling. IAM, internal auditory meatus; IPS, inferior petrosal sinus; V, trigeminal nerve; VIII, vestibulocochlear nerve.

Kawase approach and the RISA were 0.82 ± 0.11 cm^3 and 0.49 ± 0.07 cm^3, respectively. This difference was highly significant ($P < 0.001$) (**Table 1**). There was no difference in resected bone volume between sides (**Figure 5**).

The extradural part of the Kawase approach allowed for exposure of the trigeminal ganglion and postganglionic part of the trigeminal nerve for a mean length of 2 cm (±0.2 cm), while removing the suprameatal tubercle provided access to the preganglionic part of the trigeminal nerve for an average length of 0.9 cm (±0.2 cm).

The degree of surgical freedom and maneuverability, defined as an objective estimate of the surgeons' ability to move the instruments unhindered in all directions, was felt to be greater with the Kawase approach; however, objective measurements were not taken. We consistently noticed that with the middle fossa approach the surgeon could freely move the drill and instruments over and along the entire surface of the rhomboid area, whereas with the RISA approach the drilling action was much confined to a mediolateral trajectory. Angling the drill was fairly unobstructed during the middle fossa petrosectomy, aided by the fact that the brain could be effectively elevated by a retractor blade resting safely behind the petrous ridge, whereas with the RISA this maneuver was hindered by the cerebellum and posterior semicircular canal in the horizontal plane and the tentorium and neural contents of the IAC in the vertical plane.

Illustrative Case 1

A 30-year-old female patient presented with a short history of left-sided abducens palsy and facial numbness. Magnetic resonance imaging revealed a dumbbell-shaped lesion of the left cavernous sinus extending into the posterior fossa (**Figure 6A**). An extradural middle fossa approach with an additional anterior petrosectomy

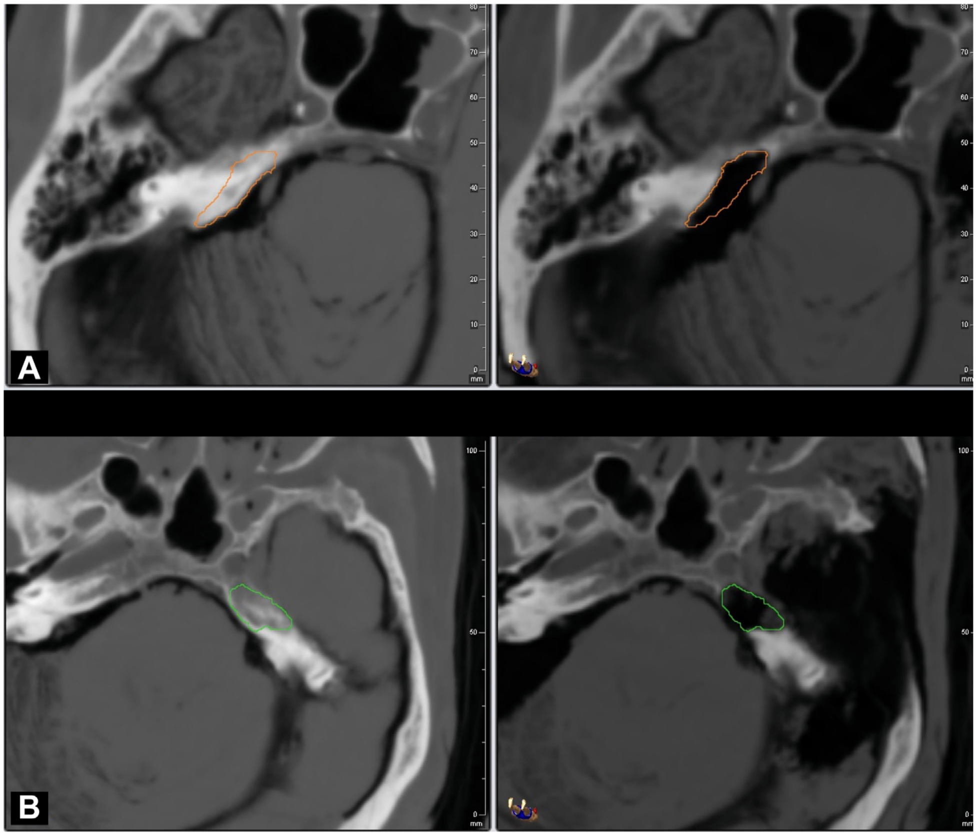

Figure 4. Computed tomography scans of the cadaveric specimens before and after dissection. Fusion of the predissection and postdissection images allows for exact identification of the petrous bone resected. (**A**) Delineation of the bony defect resulting from drilling of the suprameatal tubercle (retrosigmoid intradural suprameatal approach). An ellipsoid bony defect is produced, extending to the base of the middle fossa. (**B**) Delineation of the bony defect, resulting from drilling of the rhomboid fossa during the Kawase approach. A trapezoid bone defect is produced.

(Kawase corridor) was performed. The tumor was completely removed (Figure 6B). Histology revealed a trigeminal schwannoma.

Illustrative Case 2

A 59-year-old male presented with a history of headaches accompanied by long-standing right-sided facial numbness. MRI revealed a lesion of the right CPA with significant extension into the Meckel cave. There was a notable preservation of the arachnoid plane inside the Meckel cave (Figure 7A). Gross total tumor resection was achieved via a retrosigmoid approach with an additional removal of the suprameatal tubercle (RISA) (Figure 7B). Histology revealed a grade I meningioma.

DISCUSSION

The petrous apex along with the petroclival region is a tight, compartmentalized skull base zone that contains important neurovascular structures. Surgery around this area has always been considered a challenging task, carrying the risk of considerable morbidity.[6] In the quest for a safe and effective corridor to the petrous apex, a handful of skull base approaches have been devised. Charles Drake proposed the subtemporal transtentorial approach for aneurysms of the basilar artery.[7] Bochenek and Kukwa[8] in turn were the first to describe an extended middle fossa approach to the CPA and IAC for large vestibular schwannomas. In 1985 and 1991 Kawase reported on the treatment of lower basilar aneurysms and petroclival tumors, respectively, by similarly using a middle fossa approach and extensive drilling of the anterior pyramidal bone.[3,9] Finally, in 2004 Goel and Muzumdar were the first to describe the lateral supracerebellar approach through a standard retrosigmoid approach, without further petrous bone drilling, for petrous apex lesions.[10]

With the Kawase technique, the rhomboid bony area defined by the mandibular division of the trigeminal nerve, the GSPN, the petrous ridge, and the line that dichotomizes the GSPN and arcuate eminence is drilled, exposing the dura of the posterior

Table 1. Volume and Difference of the Petrous Apex Bone Removed Between the Kawase and Retrosigmoid Intradural Suprameatal Approach (RISA) Technique

	Approach	
	Kawase	RISA
Cadaver	Volume (cm^3)	Volume (cm^3)
1	0.91	0.52
2	0.75	0.36
3	0.65	0.53
4	0.87	0.48
5	0.90	0.55
Mean	0.82	0.49
SD	0.1	0.7

The volumes for each specimen are expressed as the mean of the 2 measurements of the independent observers.

SD, standard deviation.

fossa.[11] This allows access to the Meckel cave, the ventral brainstem above the level of the IAC, and the petroclival junction after the trigeminal nerve has been mobilized. The Kawase approach offers the advantages of an extradural procedure, minimizing the ill effects of brain retraction and injury to the vein of Labbe, and it can act as a "modular" technique implemented in a standalone fashion (e.g., for pons cavernomas) and as a component of more extended skull base corridors such as the transtentorial middle fossa or the presigmoid posterior-middle fossa combined approaches.[12]

The RISA, in turn, is a modification of the well-known retrosigmoid approach. Cheung proposed in 1995 the retrosigmoid route with additional petrosectomy for tumors with a large posterior fossa component and small middle fossa extension, although Samii et al[5,13] reported 5 years later that they have been using the same approach since 1983. The RISA is essentially an "add-on" to the retrosigmoid craniotomy and involves drilling of the suprameatal tubercle (i.e., the bony prominence of the petrous part of the temporal bone located between the IAC and trigeminal porus).[4] In this manner it allows for early identification of the neurovascular structures in the CPA and uses the surgical corridor created by the lesion itself.[5]

In the relevant literature, these 2 techniques have been regarded as fairly similar with respect to the surgical goal of reducing the bone of the petrous apex. It has been further suggested that 1 approach is the counterpart of the other because both can "target the same area," just from a different route, with the RISA being an inverted Kawase" when it comes to the petrous apex and Meckel cave.[14-16] We opted to challenge this view by performing both approaches on the same specimen and by implementing meticulous microsurgical techniques and computed tomography (CT) volumetric analysis to accurately calculate the amount of bone removed and superimpose both volumes 3-dimensionally.

We found that the volume of maximal bone resection of the petrous apex was significantly larger through the Kawase approach, with an average of almost 40% greater bone removal achieved when compared with the RISA variant. Furthermore, the shape of the osseous window created differed considerably at the end of each approach; the Kawase corridor resulted in a trapezoid

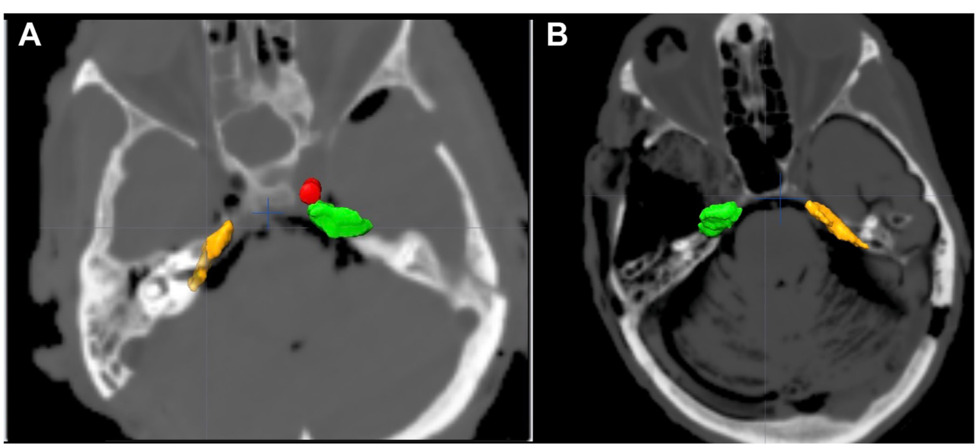

Figure 5. Computer-assisted volumetric analysis of the 2 approaches in 2 separate specimens. The different bone volumes are represented in 3-dimensional renderings and projected on the specimens' scans. (**A**) Right-sided retrosigmoid intradural suprameatal approach (RISA) and left-sided Kawase. The bony window created through the Kawase approach is represented in green and the bony defect from the RISA in orange. The internal carotid artery is marked in red, showing the close relationship to the rhomboid area of interest. (**B**) Right-sided Kawase and left-sided RISA. Color coding has been retained.

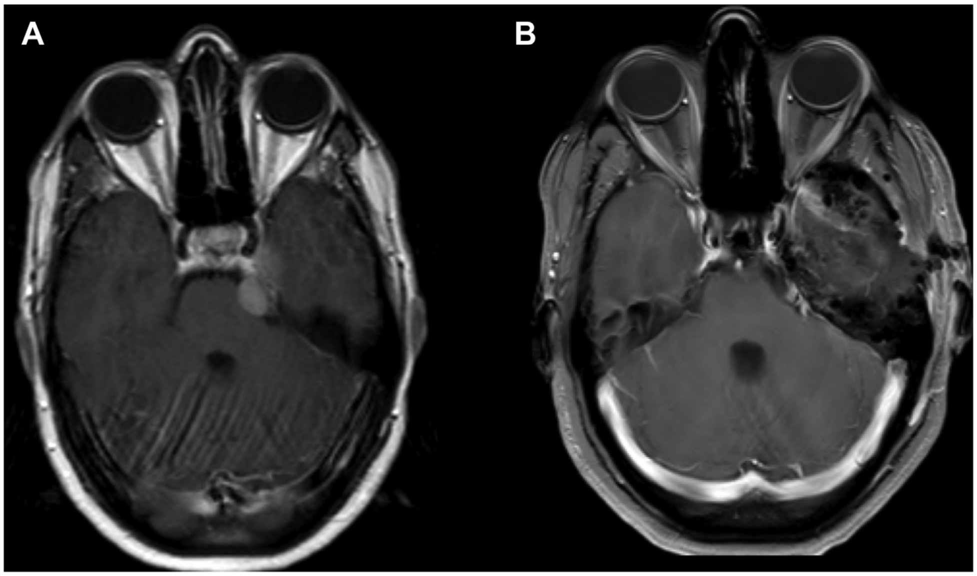

Figure 6. Magnetic resonance imaging of patient with a left-sided, dumbbell-shaped trigeminal schwannoma of the cavernous sinus extending into the posterior fossa. (**A**) Preoperative scan. (**B**) Postoperative scan showing complete resection of the tumor through an extradural middle fossa Kawase approach.

bone defect while RISA produced an elongated ellipsoid osseous deficit (**Figure 4**). This reflects the surgical freedom provided during these 2 skull base corridors; coming from the middle fossa in the Kawase, the surgeon can drill the rhomboid bone more freely and therefore more aggressively in all directions, while with the RISA the width of the resected volume is dictated by the distance between the vestibulocochlear nerve bundle and trigeminal nerve. On the sagittal plane, this distance measures up to a few millimeters, thus confining the drilling trajectory to an axis parallel to the petrous ridge.[17] Furthermore, the

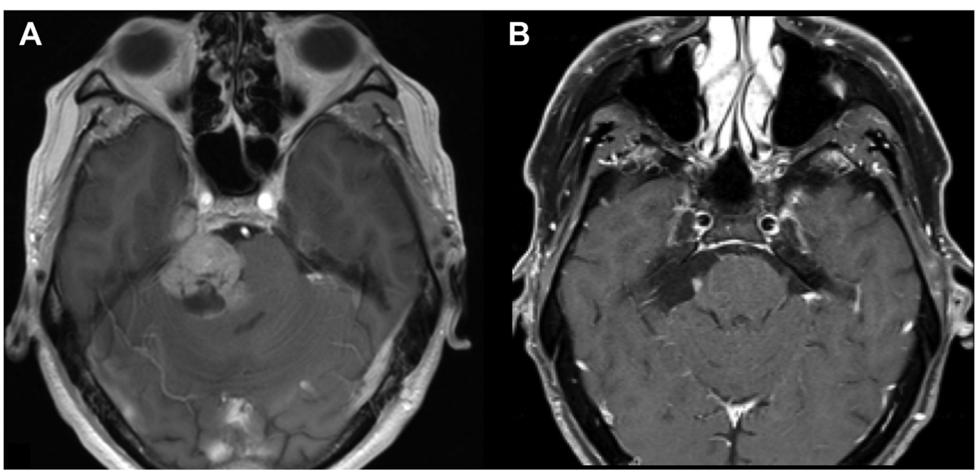

Figure 7. Magnetic resonance imaging of a patient harboring a right-sided cerebellopontine angle meningioma with extension into Meckel cave. (**A**) Preoperative image. Note the retained arachnoidal plane inside the Meckel cave. (**B**) Postoperative scan showing complete removal of the tumor via a retrosigmoid approach with an additional removal of the suprameatal tubercle (retrosigmoid intradural suprameatal approach).

overlapping volume (i.e., the volume of the bony area that is spatially congruent) can be viewed as comparable but is not identical, meaning that the RISA addresses not only a different amount of bony volume but also a relatively different skull base area.[16,18,19]

It was also evident during our study that the volumes of bony removal were variable across specimens. This is in agreement with recent studies and reflects the variations in bony anatomy and also the fact that by using precise computerized quantitative techniques in a limited space, even small differences in the 2-dimensional plane translate in significant differences in the size of removable bone.[20,21]

Interestingly, our CT quantitative analysis yielded lower volumes of bone removal when compared with other studies. In a paper by Hasanbelliu et al,[22] the mean bone removal in the anterior petrosectomy through the middle fossa approach was 1.20 ± 0.12 cm^3. In the same vein Maina et al[23] found that the maximal area of bone that can be removed while preserving anatomic structures was 1.06 ± 0.19 cm^3, but they calculated all volumes using less precise linear measurements. Perez et al[20] measured the volume of the anterior portion of the petrous apex corresponding to the Kawase rhomboid space to be 1.89 ± 0.52 cm^3 but did so only by analyzing computer tomographic images. We believe that the reason for this discrepancy lies on the following factors: First, in our study 3 of the 5 specimens were of female gender. It has been shown that females have smaller surgical corridors, particularly in the anterior area of the petrous bone.[20,23] Second, we intentionally used a more "conservative" drilling strategy aiming to mimic and resemble real operative settings rather than maximizing the cadaveric anatomic exposure of the adjacent structures. In this regard, when performing the middle fossa approach, we kept a safe distance from the IAC, cochlea, and internal carotid artery and similarly, when coming from the retrosigmoid route, we did not risk injury to the posterior semicircular canal nor did we retract the cerebellum excessively.

Our study has certain limitations. Although we tried to simulate a realistic operative scenario, cadaveric specimens cannot fully replicate the surgical setting since relevant clinical factors such as vascularization, bleeding, brain pulsations, cranial nerve function, etc. cannot be replicated. Further, anatomic distortions resulting from tumor mass effect cannot be accounted for. Surgical freedom and maneuverability were only assessed in a subjective manner. Nevertheless, the utilization of computer-assisted quantitative assessment of the studied volumes and cross-validation of our measurements by 2 experienced skull base surgeons (P.S. and C.K.) support our conclusions.

We believe that both approaches should be viewed as add-ons and not as stand-alone techniques. In the era of modern neurosurgery where preserving patients' functional status is our top priority, it is hard to imagine performing these techniques for the original indication for which they were conceived (i.e., an anterior petrosectomy for a basilar artery aneurysm or a RISA for a small adherent remnant of a petroclival meningioma). This is more so, when there are other treatment options with considerably less morbidity such as stereotactic radiosurgery. In this context, the Kawase approach is best suited for lesions of the middle fossa that have a limited extension to the posterior fossa while the RISA is primarily indicated for patients harboring posterior fossa tumors with a minor extension into the middle fossa. Ideally, in both cases the tumor should extend into but not infiltrate the Meckel cave and the cavernous sinus and maintain an intact arachnoid plane at the level of the trigeminal porus.

CONCLUSIONS

In our anatomic study it was documented through a robust CT quantitative volumetric analysis that the Kawase approach results in greater volumes of bone removal at the level of the petrous apex compared with the RISA operative variant. In addition, it was shown that the 2 techniques address relatively different skull base areas and consequently different brainstem zones, although there was significant overlapping at the level of the trigeminal porus. In both cases the trigeminal nerve could be safely and effectively mobilized, allowing access to the Meckel cave.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Pantelis Stavrinou: Conceptualization, Methodology, Funding acquisition, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Evangelos Drosos:** Funding acquisition, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Spyridon Komaitis:** Formal analysis, Investigation, Writing – review & editing. **Georgios P. Skandalakis:** Writing – review & editing. **Nektarios K. Mazarakis:** Formal analysis, Investigation, Writing – review & editing. **Aristotelis V. Kalyvas:** Formal analysis, Investigation, Writing – review & editing. **Troupis Theodore:** Writing – review & editing. **Roland Goldbrunner:** Writing – review & editing. **George Stranjalis:** Writing – review & editing, Project administration, Formal analysis, Software. **Christos Koutsarnakis:** Conceptualization, Methodology, Funding acquisition, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Supervision, Approved the final version of the manuscript on behalf of all authors.

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