Volumetry and Analysis of Anatomical Variants of the Anterior Portion of the Petrous Apex Outlined by the Kawase Triangle Using Computed Tomography

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Abstract

Background Anterior petrosectomy has become an increasingly used approach for petroclival lesions. This study measures the volume and the anatomical variants of the anterior portion of the petrous apex outlined by the Kawase triangle using computed tomography (CT).

Methods This was a transversal retrospective study. We assessed the anterior petrous apex portion outlined by the Kawase triangle in consecutive patients > 18 years of age from CT scans of temporal bone stored in an archive system. The volumetry was performed on a workstation.

Results A total of 154 petrosal apex were analyzed in 77 patients (36 men). The average volume of the region outlined by the Kawase triangle was 1.89 ± 0.52 cm^3. The volume average in men was 2.01 ± 0.58 cm^3, and the average in women was 1.79 ± 0.41 cm^3. Intra- and interobserver agreement were both excellent, and there was little variance. Nineteen petrous apex demonstrated anatomical variations. In 18 cases it was pneumatized, and in one case a vascular or nerve-like structure was identified, a report we did not find in the literature.

Conclusion The volumetry of the petrous apex anterior portion outlined by the Kawase triangle can be made by CT with excellent intra- and interobserver agreement and reproducibility. There are anatomical variants in this region that are relevant to surgery.

Keywords

- petrous apex
- volumetry
- Kawase triangle
- surgical approach

Introduction

Most skull base tumors are associated with considerable rates of morbidity and mortality.[1,2] Surgery is often required for treatment, but it is a challenge due to the complex anatomy of the region,[1–7] making imaging evaluation before surgery mandatory.[6,8,9] Over the past 30 years, advances in the approaches to the skull base mainly through the middle fossa, such as anterior petrosectomy, have helped reduce the morbidity and mortality associated with these tumors.[10,11]

Anterior petrosectomy creates an extra dural corridor with access to the superior half of the clivus, superior and middle petroclival areas, pontocerebellar cistern, and prepontine cistern.[2,7,12–15] During the procedure the anterior portion of the petrous apex outlined by the Kawase space is resected (►**Fig. 1**). Upon review, we found that studies addressing the area of the Kawase triangle are scarce,[5,14,16,17] and although computed tomography (CT) is performed preoperatively in most patients, only one study used it to help assess the Kawase triangle.[16] However, the evaluation of a triangle by

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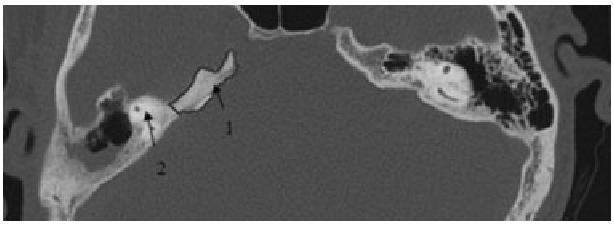

Fig. 1 Cadaver specimen. Posterosuperior view. 1, Internal auditory canal; 2, cochlea and semicircular canals.

CT is complicated because it is a flat structure, two-dimensional, has no volume-only area, and its demonstration by imaging requires complex and laborious reconstructions. But the volume of bone structure outlined by the triangle may more closely match the reality faced by the surgeon. The larger the volume of the bone area to be resected, the greater the surgical field tends to be. This increases the possibility of tipping movements because small changes in distance between certain structures in the skull base can lead to significant limitations of movement, brain retraction, and even preclude complete resection.[1,16,18] The volumetric evaluation also facilitates the assessment of anatomical variations, which is very valuable information before surgery.

The objectives of the present study were to measure the volume of the portion of the petrous apex outlined by the Kawase space using temporal bone CT and to assess the frequency of anatomical variants.

Patients and Methods

A retrospective cross-sectional study conducted in the Radiology Department of a tertiary care institution (Hospital de Clinicas de Porto Alegre, Porto Alegre, Brazil) was performed. The temporal bone CT scans of all consecutive adult patients (≥18 years of age) performed from March 2009 to July 2010 and stored in the picture and archiving communications system of our institution were reviewed.

This study was approved by the institutional ethics review board, and the data use commitment term was applied. Individual patient consent was not required.

Image Acquisition and Analysis

All temporal bone CT scans were performed using a 16-multidetector CT scanner (Brilliance 16 Power 2.3.0, Phillips, the Netherlands) with the following parameters: angled gantry parallel to orbitomeatal line, tube voltage 120 kV, tube current 330 mA, 750 msec gantry rotation time, 16 × 0.75 mm collimation, 1024 × 1024 imaging array, and 0.75-mm slice thickness with no interslice gap and with a convolution filter for edge enhancement and noise reduction. The images were postprocessed on a workstation using dedicated software (Voxar 3D Barco v.6.3, United Kingdom), in which a semiautomatic segmentation algorithm defines an HU threshold between adjacent structures selected by the user. This dynamic selection is performed in the acquisition plane and depends on the contour of the selected structure and its relationship with the surrounding anatomy. This tool replicates the selected contour pattern to remaining images where the structure was not contoured by the user, and it calculates the volume of the selected region.

The parameters of the measurements were selected by a neurosurgeon with expertise in skull base (GRI) and by a radiologist (JAP). The radiologist performed the volume measurements in all patients and assessed for anatomical variants. Both readers blinded to the previous measurements repeated 20 measurements that were selected at random.

The following locations were marked to guide the volume measurement: anterior wall of the internal auditory meatus, lower limit of the intrapetrous internal carotid artery, medial limit of the petrous apex (next to the petroccipital fissure), superior limit of the petrous apex, cochlea, and semicircular canals. Studies in which the anatomy required to perform the measurements were not adequately demonstrated were excluded.

Landmarks were chosen to standardize the volume measurement. The first measurement was performed at the level of the internal auditory meatus excluding the inner ear structures (►**Fig. 2**). Then the measurement was performed on the upper level of the petrous apex excluding the intracavernous portion of the internal carotid artery. The lateral limit of this measurement was the sphenopetrosal fissure (►**Fig. 3**). The third landmark was the horizontal segment of the intrapetrous portion (C2) of the internal carotid artery until its posterior limit (►**Fig. 4**). Finally, the measurement was performed at the level of the floor of the intrapetrous internal carotid artery next to the petroclival fissure (medial limit) (►**Fig. 5**). Later the whole bone structure was totally outlined and the volume was measured automatically (►**Fig. 6**).

We excluded all CTs with temporal bone disease.

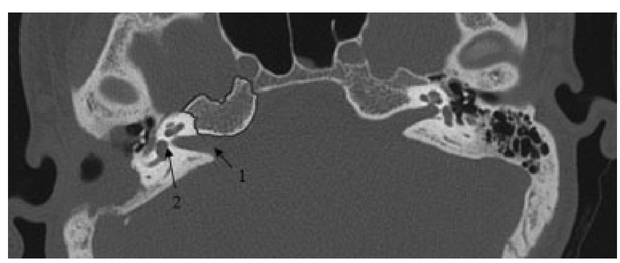

Fig. 2 1, Internal auditory canal. 2, Cochlea and semicircular canals.

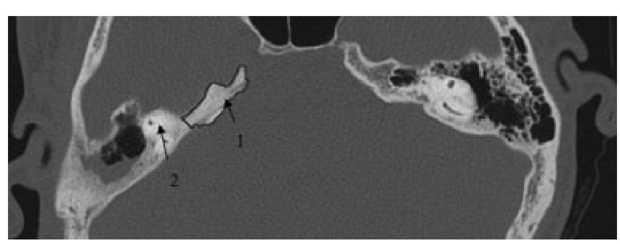

Fig. 3 1, Superior portion of the petrous apex. 2, Otic capsule.

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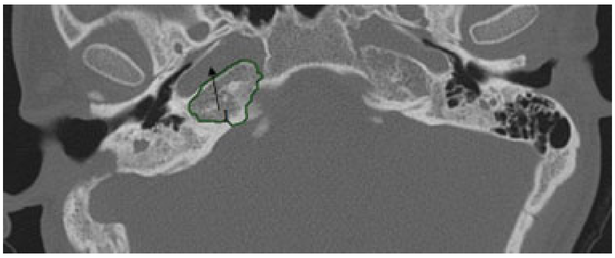

Fig. 4 1, Intrapetrous internal carotid artery.

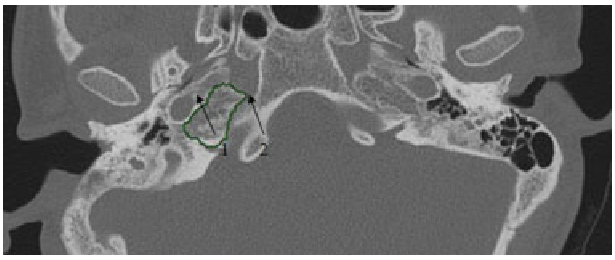

Fig. 5 1, Floor of the intrapetrous internal carotid artery. 2, Petroclival fissure.

Statistical Analysis

Key demographic and clinical variables were described by using the mean, standard deviation, and range (numeric variables) or frequency and percentage (categorical variables). The volume average in the population was measured. Male and female averages were compared, as well as differences in the average between those with and without anatomical variants using the *t* test for independent samples. The intraclass correlation coefficient (ICC) was calculated, and Bland and Altman plots were generated to assess intra- and interobserver agreement.

Results

The CT scans of 77 patients were reviewed including 36 men (46.7%) with a mean age of 46 years (range: 18–80 years). Preselected anatomical landmarks were well identified in all tests, and therefore none were excluded.

A mean volume of a total of 154 petrosal apices (2 per patient) was 1.89 ± 0.52 cm^3 (range: 0.93 cm^3–3.56 cm^3). Mean volume for men was 2.01 ± 0.58 cm^3 and for women was 1.79 ± 0.41 cm^3.

Anatomical variants were found in 19 petrous apices. Pneumatization was found in 18 petrous apices (11.6%) in 11 patients (14.2%). Seven patients (4.5%) had bilateral pneumatization, and 4 patients (2.5%) had unilateral, with a mean volume of 2.29 ± 0.52 cm^3 in pneumatized and 1.84 ± 0.50 cm^3 in nonpneumatized petrous apices. The largest volume among men and among women was observed in pneumatized petrous apices (3.56 cm^3 and 2.68 cm^3, respectively).

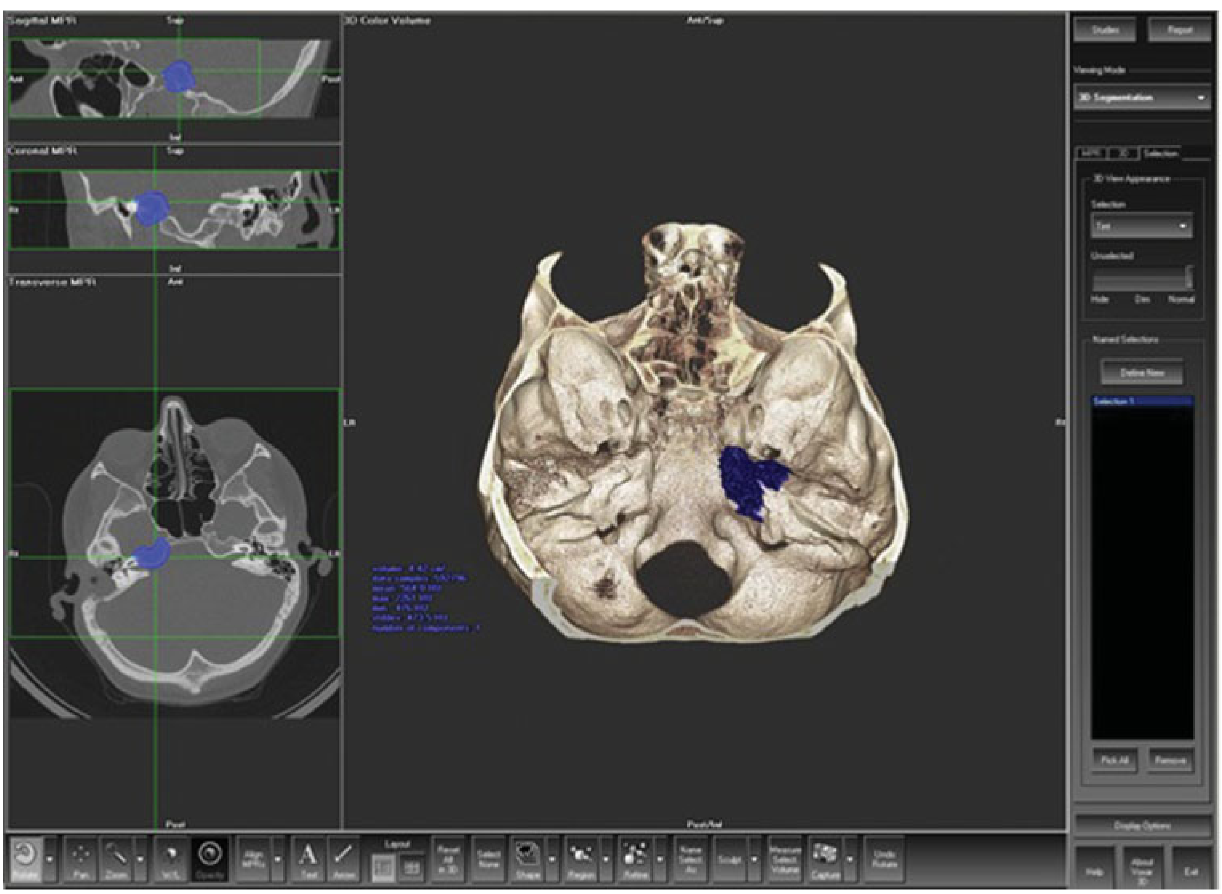

Fig. 6 Volumetry of the whole structure.

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In one case a linear and tortuous structure was identified that extended from the superior limit of the petrous apex to the petroclival fissure at the level of the intrapetrous internal carotid artery.

The ICC for both intra- and interobservers was 0.87 ($p < 0.001$). Mean intraobserver variation was 0.07 cm^3, and the 95% limits of agreement were – 0.29 to 0.48 cm^3. Mean interobserver variation was 0.08 cm^3, and the 95% limits of agreement were – 0.47 to 0.34 cm^3.

Discussion

The measurement of the Kawase space area is relevant in the study and development of anterior petrosectomy. However, the structure of the petrous bone resected is not really a triangle because it is not a two- but rather a three-dimensional geometric structure. This study offers a new vision of the anterior petrous apex. This space is in fact one of the sides of what could be classified as a polygon, a pyramid-like bone whose base lies within the limits of the internal auditory canal, cochlea, and semicircular canals and whose apex lies near the clivus, close to the intrapetrous portion of the internal carotid artery. Therefore, the measurement of the Kawase triangle area may be insufficient to fully characterize the region to be resected. The volumetry could be more useful to the neurosurgeon than just the measurement of the area of the triangle because it considers the three orthogonal planes and not just the two-dimensional shape of a triangle. This study was designed to measure the volume of the petrous apex portion outlined by the Kawase space using CT and to assess anatomical variants. A total of 154 petrous apices were measured, and the mean volume was 1.89 ± 0.52 cm^3; 19 showed anatomical variants.

To the best of our knowledge, this is the first study to measure anterior petrous apex volume. Previous studies have addressed the Kawase triangle area. Hsu et al described a mean area of 62 ± 43 mm^2 in 11 cadaveric specimens,[14] Maina et al reported a mean of 106.72 ± 19.44 mm^2 in 18 cadaveric specimens,[16] Watanabe et al reported a mean of 81.7 ± 23.3 mm^2 in 12 specimens,[17] and our group reported a mean of 97.69 ± 8.13 mm^2 in 22 cadaveric specimens.[5]

The difference in the mean volume of the petrous apex between men and women was statistically significant ($p = 0.007$) in agreement with the significant differences between men and women in the anterior apex petrous area described in the current literature.[5]

We found a wide variation in the volumetry of the anterior portion of the petrous apex outlined by the Kawase space (3.56–0.98 cm^3) in agreement with the descriptions of Villavicencio et al, who assessed petrous apex thickness by CT.[19] This finding is inconsistent with the descriptions by Watanabe et al that the Kawase triangle has a relatively constant area.[17] This discrepancy indicates the importance of volumetry and not only the two-dimensional measurement of the area because the amount of bone to be resected may show a wide variability among individuals even if the surface of the triangle that outlines this region is relatively constant.

The technique developed for volumetric assessment considered the boundaries of the resected bone during anterior petrosectomy. Because this technique has never been reported, we stipulated the parameters, taking into account the surgical limits. We also tested the intra- and interobserver reproducibility. Both were considered excellent (ICC: 0.87).[20] The Bland and Altman plots showed little intra- and interobserver variance, and the biggest differences were < 0.5 cm^3.

Petrous apex pneumatization (►**Fig. 7**) was found in 14.2% of patients, in agreement with the prevalence reported in the literature that ranges from 9 to 33%.[6,8,9,21–23] Unilateral pneumatization was found in 2.5% of patients. The prevalence reported in the literature ranges from 5% to 10%.[9,24] Knowledge of petrous apex pneumatization prior to the procedure is essential because it influences skull base reconstruction when it is necessary to be careful to avoid liquoric fistula.[25] The mean volume of pneumatized petrous apices was statistically higher than nonpneumatized, and the highest volumes among men and women were observed in the pneumatized petrous apex.

In one of the petrous apices, we found a vascular or nerve-like structure whose description we could not locate in the literature. This finding is inconsistent with the classic concept that the anterior portion of the petrous apex can be resected because it is devoid of nerve or vascular structures.[12] However, it is only on the CT finding. It may be the diploic vein, which is uncommonly observed at surgery. In a case of meningioma, the operator sometimes finds a feeding artery penetrating the petrous apex, and it can be coagulated.

Knowledge of the patient's anatomy and possible anatomical variants is essential for surgical planning. Therefore CT and magnetic resonance imaging are indicated prior to surgery. This study measured the volume of the bony portion delineated by the Kawase space by reviewing hospital records to assess this approach for routine examinations without the need for a specific protocol or additional exposure to ionizing radiation. Thus the systematic approach used in this study can be performed in any preoperative examination. CT was the selected imaging modality because it is widely used and has superior image resolution compared with MRI, which is a fundamental property for the assessment of the complex and

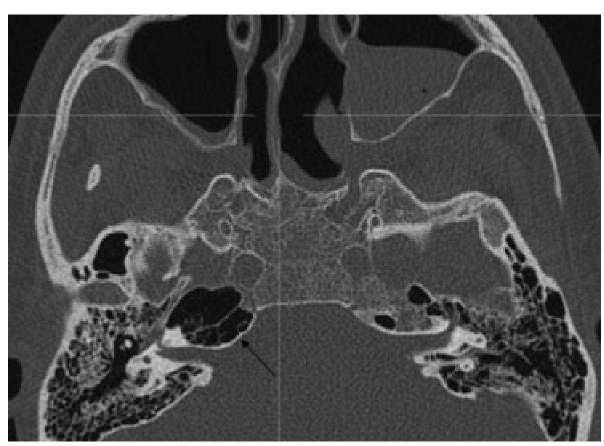

Fig. 7 Pneumatized petrous apex.

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delicate skull base osseous anatomy.[6,9,26] The literature reveals that the capacity of CT for the measurement of skull base structures has been previously tested with good results.[16]

Patients < 18 years of age were excluded because pathologies that affect this population and can be treated with anterior petrosectomy are uncommon.[27,28]

The trigeminal nerve is a superb landmark in middle fossa and petrous apex surgery. The trigeminal nerve after peeling the middle fossa can be displaced anteriorly, increasing the surgical corridor through the petrous apex. However, because CT measurements were used strictly for osseous structures, we did not consider the trigeminal nerve.

This study has some limitations. The measurement parameters may not reflect the real bone volume that will be resected during surgery because this technique requires detailed knowledge of fossa media microsurgical anatomy, microsurgical laboratory training, and surgeon experience, and these factors may determine different amounts of bone resection. Moreover, all volumetrics were performed on the same workstation, and its reproducibility in stations from other manufacturers has not been tested. Patients with skull base lesions were not evaluated. These lesions may distort the local anatomy and make the measurement difficult. There are parts of the so-called volume that are unlikely to be resected (i.e., that included posteroinferior to the horizontal petrous carotid canal) and are unlikely to contribute significantly to the surgical field; however, they would contribute greatly to the volume calculations.

Conclusion

The volumetry of the petrous apex anterior portion outlined by the Kawase triangle can be made by CT with excellent intra- and interobserver agreement and reproducibility. There are anatomical variants in this region that are relevant to surgery. Future studies are needed to correlate the resected volume with surgical outcomes.

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