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A Novel Classification of the Internal Morphology of Mastoid Emissary Canals and st's Importance for Surgical Practice: an in Silico Anatomical Study

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ABSTRACT
Introduction: The aim of the present study was to determine the internal morphology of mastoid emissary canals and to classify them according to the number of external openings and the complexity of its morphology. In addition, we discussed the importance of the findings for surgical procedures performed in the retroauricular region.
Materials and Methods: An in silico anatomical study was performed using ninety-six dry human skulls, which were processed by computed tomography (CT) and underwent a segmentation process and construction of three-dimensional surfaces. The criteria used for classification of mastoid emissary canals was based on its morphological complexity and on the number of external openings.
Results: Canals were identified and initially classified into 4 groups. Groups were named after the number of external openings using numbers 1, 2, 3, and 4, which refer, respectively, to 1, 2, 3, or 4 foramens. Then, groups were divided into subgroups using up to the first three letters of the alphabet (a, b, and c) according to the morphological complexity of mastoid emissary canals. Finally, 10 types of mastoid emissary canals were established, as follows: 1a, 1b; 2a, 2b, 2c; 3a, 3b, 3c; 4a, 4b. We proposed a decreasing order of canals with potential to cause intracranial intercurrences and a decreasing order of canals with potential to cause moderate to severe hemorrhage.
Conclusion: A novel classification regarding the morphology of mastoid emissary canals was presented. In addition to the contributions in anatomical literature, it mainly represents new data to aid surgeons of various areas in the proper knowledge of important anatomical structures and planning of surgical procedures to reduce the occurrence of accidents and complications.
Keywords: Mastoid emissary canal; Mastoid emissary foramen; Segmentation; Classification; Computed tomography.

Introduction

The mastoid emissary foramen is a well addressed anatomical structure and it regards an opening located at the vicinities of the occipitomastoid suture. The mastoid emissary canal connects the mastoid emissary foramen to its internal opening, and through which passes the mastoid emissary vein, an important blood vessel that communicates the transverse or sigmoid sinus to the occipital or posterior auricular veins [1-8].

The mastoid emissary vein stablishes a communication that acts as an accessory drainage pathway to the internal jugular vein. Nevertheless, despite of what is classically known, authors had proven that the vertebral venous plexus (into which the mastoid emissary vein drains, indirectly) is the main pathway of cerebral venous drainage when one assumes an erect posture[9-12]. In addition, authors stated that this venous plexus enables a cooling mechanism for venous blood circulating through cephalic structures and prevents acute thermal damage[13,14].

Literature also cites that the knowledge regarding the anatomy of the mastoid emissary foramen and its canal is of utmost importance to perform surgical procedures in the mastoid region. Important surgical accidents and complications may occur due to injury to the mastoid emissary vein, such as hemorrhage, sigmoid sinus thrombosis, cerebellar ischemia and even death[13,22].

Studies were performed to study the mastoid emissary canal. However, authors had been studying it with no technological resources that could enable a proper and precise anatomical description. Hence, its necessary to perform a new study with the proper tools to do so.

Thus, the aim of the present study was to determine the internal morphology of mastoid emissary canals and to classify them according to the number of external openings and the complexity of its morphology. In addition, we discussed the importance of the findings for surgical procedures in the retroauricular region.

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Materials and Methods

Ethical approval

The research project was developed *a priori*, which was assessed and approved by the institutional ethics committee (ID number: 13197519.8.0000.5418).

Study design and sample

An *in silico* anatomical study was performed at the institutional Morphology and Social Dentistry Departments (Piracicaba Dental School, University of Campinas, Brazil). Ninety-six dry human skulls were included for the research. Sample size calculation was performed after Keskil *et al.* 2003, which established the occurrence of the mastoid emissary foramen in 88,5% of dry human skulls[5].

The present study included adult dry human skulls for analysis, with no distinction of sex or ancestralism. The following exclusion criteria were established: dry human skulls from non-adult individuals; skulls from a different species than *Homo sapiens*; skulls with any injury to the anatomical structures of interest; and hemi-skulls.

Methods of morphological assessment

The 96 adult dry human skulls were processed by computed tomography (CT) Aisteion Multislice 4 CT System (Toshiba Medical Systems Corporation - Japan), with 100 mA, 120 kV and 1mm voxel configuration. The CT images were imported to Materialise Mimics Research v.18 Software (Materialise, Belgium). In this software, a segmentation process of the mastoid emissary canal was performed, which consists in the identification, voxel demarcation, and isolation of this anatomical structure. For demarcation of the mastoid emissary canal, the voxels of bony structures were automatically selected by the grayscale threshold adjustment. Then, a manual demarcation of the mastoid emissary canal, including its external and internal openings, was performed using editing tools.

After segmentation, the three-dimensional surfaces were constructed, which comprises the segmentation of anatomical structures (already performed), and, the union and triangulation of voxels (Figure 1).

Classification of mastoid emissary canals

Using the three-dimensional reconstructions of mastoid emissary canals, we determined and characterized the different types mastoid emissary canals. Determination and characterization of canals were performed using visual inspection by two examiners (J.H., and O.B. de O.N.) with four years of experience in anatomical studies, each. These examiners scheduled weekly meetings to debate the anatomical findings to a third and more experienced examiner (A.R.F), with ten years of experience in anatomical and radiologic studies. The criteria used for classification of mastoid emissary canals was based on its morphological complexity and on the number of external openings (i.e. the number of mastoid emissary foramens).

Results

Mastoid emissary canals (MECs) were identified and initially classified into 4 groups. Groups were named after the number of external openings (i.e. the number of foramens) using numbers 1, 2, 3, and 4, which refer, respectively, to 1, 2, 3, or 4 foramens. Then, groups were divided into subgroups using up to the first three letters of the alphabet (a, b, and c) according to the morphological complexity of mastoid emissary canals, where "a" would be the simplest and "c" would be the most complex. Finally, 10 types of mastoid emissary canals were established, as follows: 1a, 1b; 2a, 2b, 2c; 3a, 3b, 3c; 4a, 4b.

Types 1a and 1b regard, respectively, one C-shaped canal that arouses from one foramen and ends into one

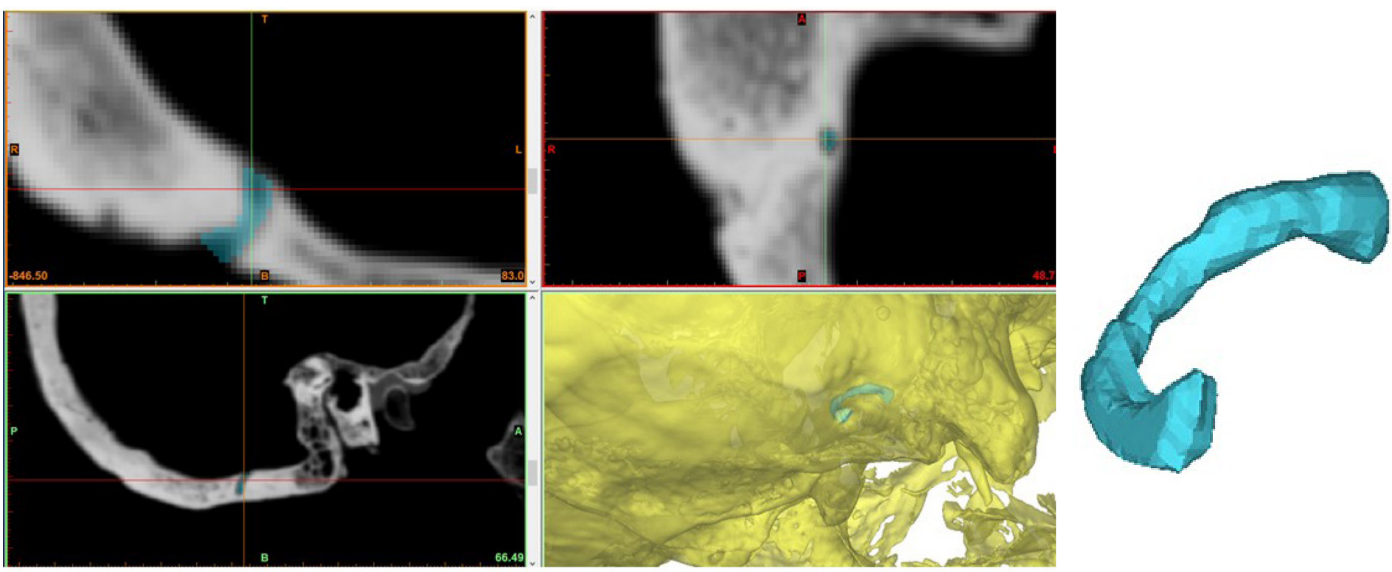

Figure 1. Steps performed to isolate the morphology of mastoid emissary canals. Segmentation (identification, voxel demarcation, and isolation) was performed prior to construction of three-dimensional surfaces.

internal opening, and one S-shaped canal that arouses from one foramen and ends into one internal opening.

Type 2a is a bridge-like canal that only communicates the two mastoid emissary foramens and has no internal openings; type 2b regards two independent canals arousing from individual foramens that converge into one another to form a single canal that ends in one internal opening; and type 2c was described as two individual canals arousing from individual foramens and that remain independent to end in two individual internal openings.

Regarding type 3 canals, type 3a was described as a combination of one canal that only communicates the two mastoid emissary foramens (a bridge-like canal, similar to type 2a) and has no internal openings associated to one canal that arouses from one foramen and ends into one internal opening (similar to type 1a); type 3b comprised three independent canals that arouse from three individual foramens and converge into one another to form a single canal that ends into one internal opening; and type 3c was a combination of two independent canals arousing from individual foramens and converge into one another to form a single canal that ends in one internal opening associated to one canal that arouses from one foramen and ends into one internal opening.

The presence of four mastoid emissary foramens regarded the type 4 canals. Type 4a was described as four foramens with independent canals that converge into one another to form a single canal that ends into one internal opening; and type 4b, the most complex of all, regarded two independent canals arousing from individual foramens that converge into one another to form a single canal that communicates transversally with one canal formed by the conversion of two independent canals that arouse from two individual foramens and converge into one another. The result of this union is one canal that ends into one internal opening.

Figures 2 and 3 show the types of canals from groups 1 and 2. Figures 4 and 5 show the types of canals from groups 3 and 4. Table 1 presents the detailed parameters of classification and the morphological description of mastoid emissary canals found in the present study.

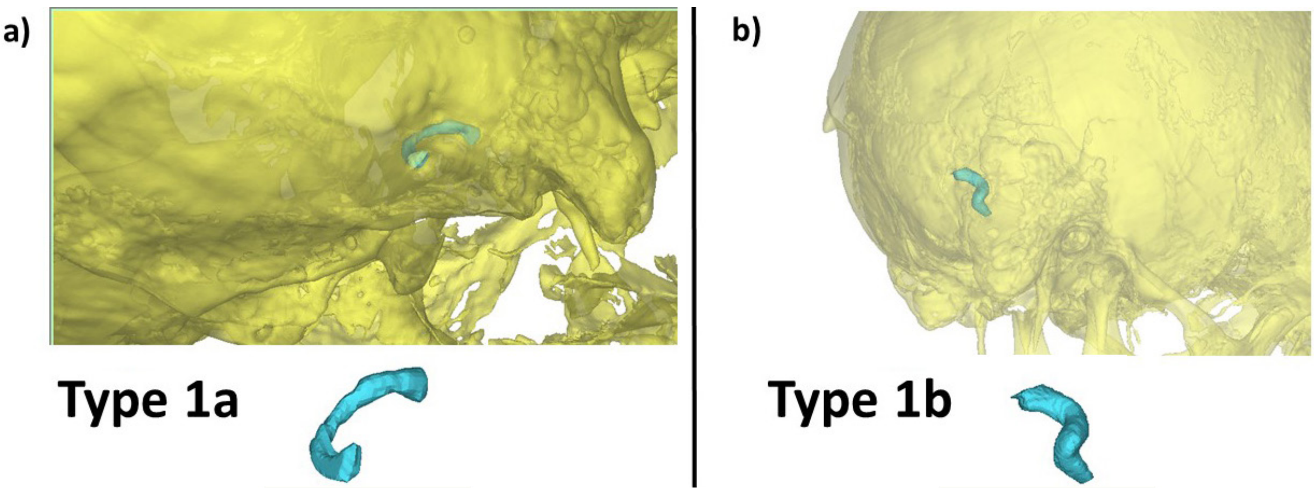

Figure 2. Mastoid emissary canals types 1a (a) and 1b (b).

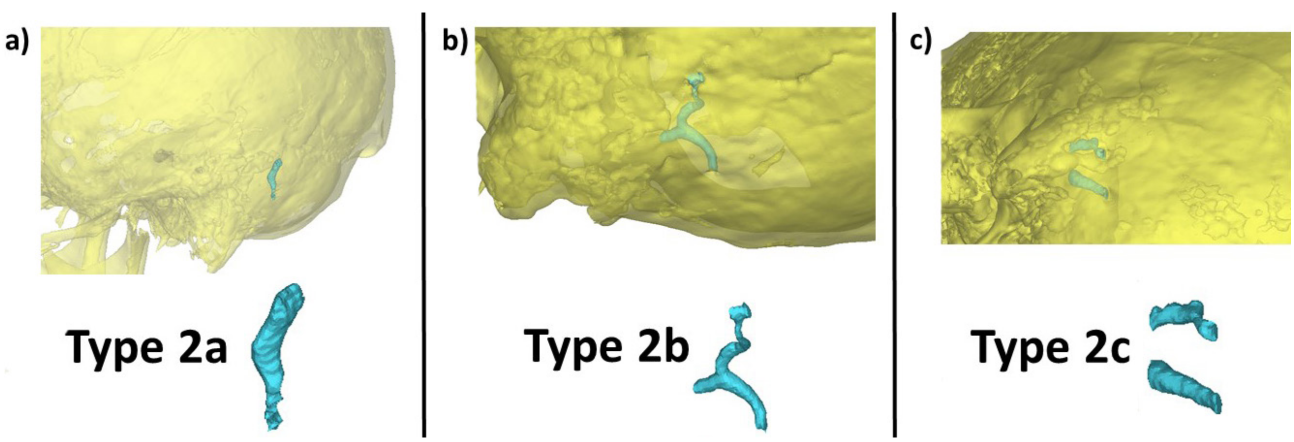

Figure 3. Mastoid emissary canals types 2a (a), 2b (b), and 2c (c).

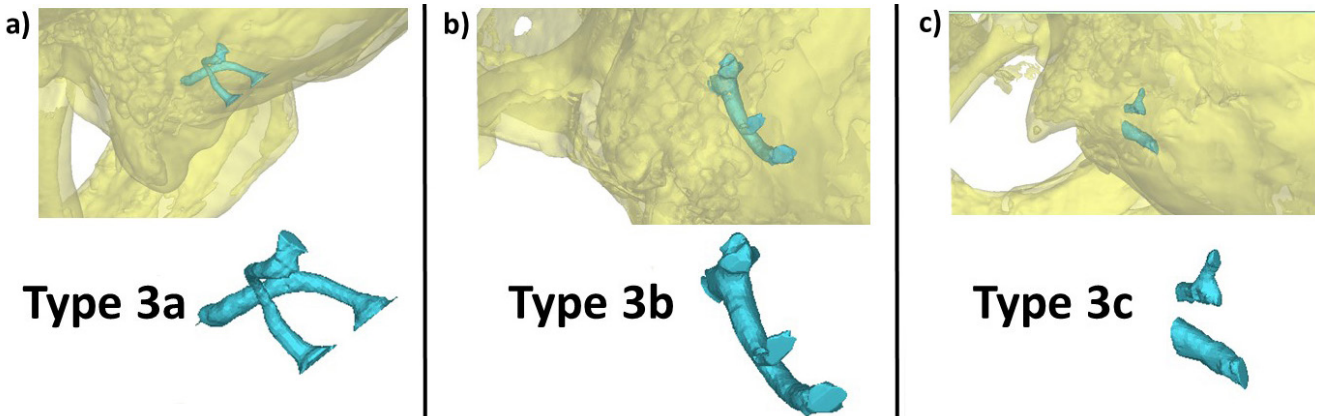

Figure 4. Mastoid emissary canals types 3a (a), 3b (b), and 3c (c).

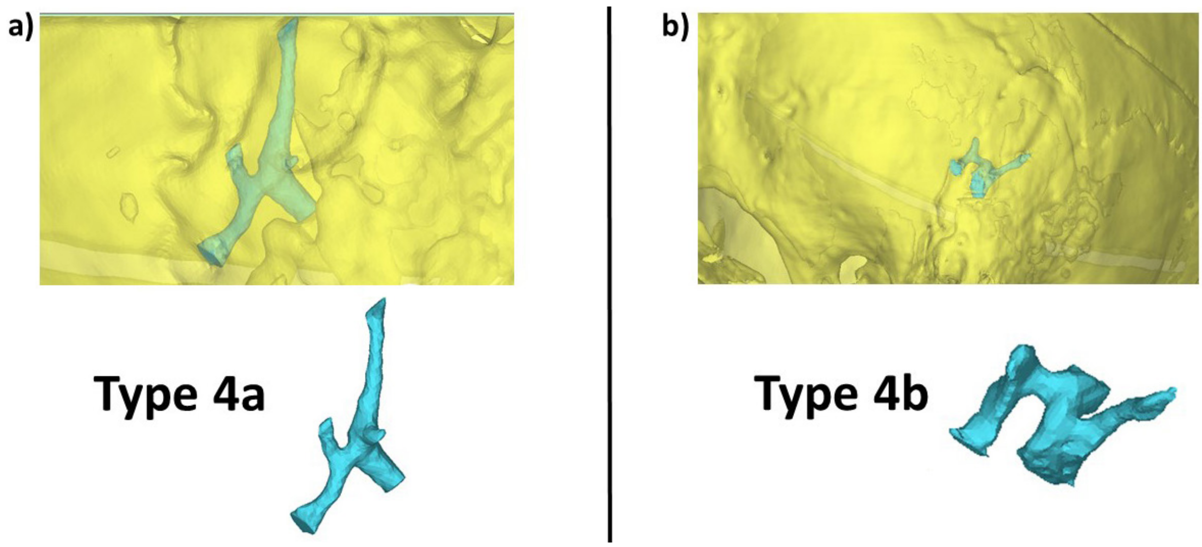

Figure 5. Mastoid emissary canals types 4a (a) and 4b (b).

Table 1. Parameters used for classification of mastoid emissary canals regarding type, number of external openings (foramens), number of internal openings, and anatomical description.

Type	Number of mastoid emissary foramens	Number of internal openings	Description of the canal
1a	1	1	One C-shaped canal that arouses from one foramen and ends into one internal opening
1b	1	1	One S-shaped canal that arouses from one foramen and ends into one internal opening
2a	2	0	One bridge-like canal that only communicates the two mastoid emissary foramens and has no internal openings
2b	2	1	Two independent canals arousing from individual foramens that converge into one another to form a single canal that ends in one internal opening
2c	2	2	Two individual canals arousing from individual foramens and that remain independent to end in two individual internal openings
3a	3	1	One canal that only communicates the two mastoid emissary foramens and has no internal openings + One canal that arouses from one foramen and ends into one internal opening
3b	3	2	Three independent canals that arouse from three individual foramens and converge into one another to form a single canal that ends into one internal opening
3c	3	2	Two independent canals arousing from individual foramens and converge into one another to form a single canal that ends in one internal opening + One canal that arouses from one foramen and ends into one internal opening
4a	4	1	Four foramens with independent canals that converge into one another to form a single canal that ends into one internal opening
4b	4	1	Two independent canals arousing from individual foramens that converge into one another to form a single canal that communicates transversally with one canal formed by the conversion of two independent canals that arouse from two individual foramens and converge into one another. The result of this union is one canal that ends into one internal opening

Discussion

The present study performed an *in silico* assessment of 96 adult dry human skulls using computational tools to determine the internal morphology of mastoid emissary canals and to classify them according to the number of external openings and the complexity of its morphology.

The types of mastoid emissary canals can be used for surgical planning to avoid accidents and complications in neurosurgery, otolaryngology surgery, and plastic and reconstructive surgery on the nuchal and posterior region of the scalp. Thus, the studied anatomical structure does not only present a descriptive anatomical importance, but also adds to clinical literature to aid healthcare professionals in the understanding and handling of adverse situations during surgeries, as well as to avoid them.

One must highlight that a wider perspective should be given to the mastoid emissary veins on surgical practice. Many surgeons state that, if injured, the mastoid emissary vein is not going to pose major problems because, if a moderate or a severe hemorrhage occur, the hemostasis of this vein is often easy to obtain, which is corroborated by us. However, professionals frequently forget or ignore that the problem often rests not in the mastoid emissary vein itself, but in the intracranial vein or veins that it communicates to, since the mastoid emissary vein is a potential pathway for thrombosis, thromboembolisms, and infections[13-22]. In this sense, noble intracranial structures, such as the cerebellum, the meninges, the brain stem, and the brain may be eventually put at jeopardy due to this communication, which corroborates and explains severe intercurrences regarding the injury of mastoid emissary veins during surgery, such as sigmoid sinus thrombosis, cerebellar ischemia, and even death[23-26].

From a surgical perspective, despite one may think at a first glance, the simpler the mastoid emissary canal morphology is the higher is the chance of facing the aforementioned accidents and complications. Taking into considerations the concepts of collateral circulation[30,31], if a higher number of vessels are serving or draining a given anatomical structure, the lesser is the chance of this structure loses its blood supply if one or more vessels are injured or obstructed. Thus, a higher attention should be given if one is facing MECs of types 1a or 1b, because there is probably only one blood vessel that, in the retroauricular region, will communicate the exocranial and intracranial circulations. Moreover, we propose the following decreasing order of canals that will potentially create intracranial intercurrences for surgeons: 1a>1b>2c>3c>2b>3a>3b>4a>4b>2a. Type 2a appears last because is a bridge-like canal with no internal openings. If the concern is the potential for moderate to severe hemorrhage in the surgical site, then the focus will be the number of (external) foramens, thus, we suggest the following decreasing order of canals with potential to cause this specific intercurrence: 4b>4a>3c>3b>3a>2c>2b>2a>1b>1a.

To be best of our knowledge, the present study features a novel classification of mastoid emissary canals that has no previous papers to compare with. Thus, famous and well addressed classifications of anatomical structures other than the mastoid emissary canals were used to inspire authors regarding the names and numbers that would refer to the types of canals[27-29].One must highlight that efforts were made to keep the classification as simple as possible in order to facilitate mnemonics, intraclass didactics, and communication between students, professors, researchers, and healthcare professionals.

The main strength of our study was to provide a novelty regarding the classification of an anatomical structure that can now be seen under a new morphological and functional perspective. Roser *et al.* 2016 and Demirpolat *et al.* 2016 studied mastoid emissary canals using routine CT images and multidetector computed tomography, respectively[17-19]. Although they considered biometrical parameters and performed statistical analysis, a 3D reconstruction of the canals was not performed and an attempt to classify the canals was not made. Several authors tried to study the mastoid canals using a metal wire[1,3,4]. However, this method is inadequate, and it does not provide the proper information to describe the morphology of mastoid canals.

The following difficulties occurred during the study and can be considered as limitations: 1) the overall quality of computed tomography impaired us from performing the segmentation of mastoid emissary canals in several antimeres; 2) for the same reason, a formal statistical analysis or even a simple descriptive statistics could not be performed because the number of viable canals was impaired for comparison.

In view of these difficulties, future researches should consider acquiring computed tomography of better quality (e.g. cone beam computed tomography), which would facilitate segmentation. Consequently, the use of computed tomography of better quality would also enable to perform a descriptive statistical synthesis or even a formal statistical analysis.

In conclusion, a novel classification regarding the morphology of mastoid emissary canals was presented. In addition to the contributions in anatomical literature, it mainly represents new data to aid surgeons of various areas in the proper knowledge of important anatomical structures and planning of surgical procedures to reduce the occurrence of accidents and complications.

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Mini Curriculum and Author's Contribution

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