Morphometric Analysis of the Middle Meningeal Artery Organization in Humans—Embryological Considerations

Tales Harthmann da Silva¹ Joel Henrique Ellwanger^{2,3} Helen Tais da Rosa Silva² Daniela Moraes¹
Anderson Cesar Dotto¹ Vinicius de Aguiar Viera¹ Deivis de Campos^{1,2,3,4}

¹Curso de Odontologia, Departamento de Enfermagem e Odontologia, Universidade de Santa Cruz do Sul, Santa Cruz do Sul, Brazil

²Curso de Ciências Biológicas, Departamento de Biologia e Farmácia, Universidade de Santa Cruz do Sul, Santa Cruz do Sul, Brazil

³Departamento de Biologia e Farmácia, Laboratório de Histologia e Patologia, Universidade de Santa Cruz do Sul, Santa Cruz do Sul, Brazil

⁴Programa de Pós-Graduação em Neurociências, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil

Address for correspondence Deivis de Campos, MD, Laboratório de Histologia e Patologia, Departamento de Biologia e Farmácia, Universidade de Santa Cruz do Sul, Av. Independência, 2293, Santa Cruz do Sul, RS, Brazil (e-mail: dcampos@unisc.br).

J Neurol Surg B 2013;74:108–112.

Abstract

The middle meningeal artery (MMA) is the largest branch of the internal maxillary artery supplying the meninges. The complex sequence of MMA development gives many opportunities for variant anatomy. Additionally, the variations in the origin of the MMA are of clinical importance when dealing with fractures of the base of the skull, epidural hematomas, and bypass procedures. Therefore, various anastomosis and aberrant origins of the MMA have been documented in literature. However, there are no reports about some morphometric aspects of this important arterial segment. Thus, in this study, we decided to investigate the anatomical organization of the MMA through the bony groove measurements from human skulls ($n = 50$ subjects). Six measurements were performed bilaterally: angle of the main trunk, length of the main trunk, angle between the frontal and parietal branches, length of the frontal branch, length of the parietal branch, and length of the bony tunnel formed by the frontal branch. We showed that the anatomical organization of the MMA is bilaterally similar, except for the length of the parietal branch ($p = 0.009$). Moreover, our results provide baseline normal values for future studies aimed at further elucidating the functional and morphological pattern of the MMA.

Keywords

- anatomy
- bony groove
- anatomical variation
- middle meningeal artery

Introduction

The Human Anatomy books for beginner students describe the structure of the body observed in most people. Students are frequently frustrated because the bodies they are examining or dissecting do not correspond to the one in the atlas or the text they are using. Therefore, anatomical variations when you dissect or inspect dissected specimens are expected.¹

Some authors² have commented that these variations have seldom been mentioned in books of anatomy and should be considered in the treatment and clinical diagnosis.¹ Among the numerous anatomical variations of clinical interest, some deserve particular attention.

Kresimir Lukic et al³ described that the knowledge of the anatomical organization of the middle meningeal artery

received
May 8, 2012
accepted after revision
November 3, 2012
published online
January 22, 2013

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Stuttgart · New York

DOI <http://dx.doi.org/10.1055/s-0033-1333615>.
ISSN 2193-6331.

Fig. 1 Internal view of the skull showing the six measurements performed bilaterally: (1) angle of the main trunk, (2) length of the main trunk, (3) angle between the frontal and parietal branches, (4) length of the frontal branches, (5) length of the parietal branches, and (6) length of the bony tunnel. (a) Main trunk, (b) frontal branches, (c) parietal branches of the middle meningeal artery, and (d) foramen ovale.

(MMA) is of great importance in surgery and radiology. This artery, or its branches, and other large intracranial extracerebral vessels have been implicated in the pathophysiology of migraine by theories suggesting neurogenic inflammation or cranial vasodilatation, or both, as explanations for the pain of migraine.⁴ Moreover, some studies^{5,6} have shown that detailed knowledge of the morphological organization of the MMA can assist in procedures like bypass.

Originating from the maxillary artery, the MMA is predominantly periosteal, irrigating the bone and dura mater.⁷ It enters the floor of the middle cranial fossa through the foramen spinosum, travels laterally through a middle fossa bony ridge, and curves anteriorly over the upper-greater wing of the sphenoid,¹ where it in a variable point is divided into frontal and parietal branches.⁸ The frontal branch can be located in a bony tunnel² and thus be particularly susceptible to tearing when the skull fractures. The resulting bleeding between the skull and dura mater (extradural hemorrhage) can produce severe neurological disorders.¹ Moreover, information about possible vascular asymmetries between the right and left sides in the organization of the MMA are still unknown and should be elucidated.⁹ Thus, we decided to investigate the anatomical organization of the MMA through the bony groove measurements from human skulls.

Materials and Methods

This study analyzed 50 adult skulls from the Laboratory of Human Anatomy at the Santa Cruz do Sul University, RS, Brazil. The analysis was performed by two experts in head and neck anatomy. Only skulls that had a bony tunnel and the

groove formed from the MMA evident on both sides (right and left) were used. Pearson's correlation coefficients were calculated to determine the relationship between the results obtained by the two blinded researchers.

Measuring the Angle of the Main Trunk

With the aid of an orthodontic wire and a goniometer, the angle of the main trunk of the MMA was measured (adapted to form impressions) from the foramen ovale (►Fig. 1).

Measuring the Length of the Main Trunk

Using a digital caliper (DIGIMESS, Brazil), it was possible to measure the length (mm) of the main trunk of the MMA. This measure extended from the foramen spinosum to the division of the frontal and parietal branches (►Fig. 1).

Measuring the Angle between the Frontal and Parietal Branches

The angle formed between the frontal and parietal branches was measured with the aid of an orthodontic wire adapted to form impressions of—and make a mold of—the frontal and parietal branches of the skull. After the mold was placed on a flat and smooth surface, the angle between the branches was measured using a goniometer (►Fig. 1).

Measuring the Length of the Frontal and Parietal Branches

A digital caliper was used to measure the length (mm) of the frontal and parietal branches of the MMA. This measure was extended to the beginning of the division of the frontal and parietal branches to the first division of both (►Fig. 1).

Measuring the Length of the Bony Tunnel

For the measurement of length (mm) of the bony tunnel formed on the inner surface of the skull, a wire was introduced across the whole channel and excess portions of the wire (outside the channel) were cut. Once removed from the channel, the wire was stretched and its length was measured with the aid of a digital caliper (►Fig. 1).

Statistical Analysis

The statistical analyses were performed using the GraphPad Prism 4.0 (GraphPad Software Inc., La Jolla, California, USA), and G*Power 3 Software (Institut Für Experimentelle Psychologie, Heinrich-Heine-Universität, Düsseldorf, Germany) was used to perform the statistical power analysis.¹⁰ The comparison between the morphometric organization of the right and left MMA from each skull were performed using a paired *t* test. A *p* value of 0.05 or less was considered significant in all statistical tests performed.

Results

In our study, there was no significant difference found between the morphometric measurements of the left and right side of the MMA, except for the length of the parietal branch (►Table 1). The values obtained by Pearson's correlation coefficients for the angle of the main trunk, length of the main trunk, angle between the frontal and parietal branches, length of the frontal branch, length of the parietal branch, and length of the bony tunnel for the right side were 0.9975, 0.6561, 0.9010, 0.8841, 0.8945, and 0.9988, respectively.

Over the left side, the values found were 0.9994 for the angle of the main trunk, 0.6227 for the length of the main trunk, 0.9545 for the angle between the frontal and parietal branches, 0.9229 for the length of the frontal branch, 0.9442 for the length of the branch parietal, and 0.9820 for the length of the bony tunnel. These values demonstrate the high level of reliability of the observations made by the blinded researchers.

Discussion

In this study, we demonstrate important morphometric parameters about the anatomical organization of the MMA and also provide data on the power of analysis of these

parameters. The statistical power test is a useful tool to calculate the minimum number of subjects that are necessary to obtain reliable results. This parameter can be estimated from the mean and standard deviation obtained in preliminary studies with few subjects, mainly in animal research. However, when working with a limited number of human subjects, this statistical test can be used to evaluate the real significance of the results found and also as a pilot test to indicate the variability between the groups, tendencies, and the necessary number of subjects for this kind of research.¹¹

Thus, more than a simple morphometric description of the MMA, our study provides essential information for the detailed knowledge of the anatomical organization of this important arterial segment and also provides data on the statistical power analysis for all morphometric variables not normally included in studies involving the branches of the MMA. Furthermore, we believe that this information is of great importance. Using this mathematical tool (statistical power analysis) ensures a more reliable vision of the results, especially when studying a limited number of human subjects.

Although some anatomic variations of the MMA regarding the origin, position, and intracranial branches were previously documented by Lasjaunias et al,¹² Krmpotić-Nemanić et al,¹³ Klisović et al¹⁴ and Shimizu et al,² we did not find much information in the medical literature on the morphometrical variables assessed in our study. According to our knowledge, no study described the relationship between variations of the length of the branches and their angles, or the differences between the right and left sides of the skull regarding to MMA.

The main result found in our study was the observed significant difference in length between the right side and left side of the parietal branch. Although we have not found differences between the anatomical organization of the right and left MMA for other morphometric parameters, we believe the knowledge about the morphometry of the MMA and its bilateral organization can be important for clinicians, surgeons, and academicians who handle this particular anatomical site.

Additionally, several anomalies of MMA have been reported,^{15–18} as well as embryological studies to improve the knowledge of possible anatomic variations.¹⁹ Thus, the complex embryology underlying the development of the

Table 1 Comparison of the Morphometric Parameters of Right and Left Side of the Middle Meningeal Artery (MMA)

	Right MMA	Left MMA		
MORPHOMETRIC PARAMETERS	Mean ± SD	Mean ± SD	<i>p</i>	SP
Angle of the main trunk (°)	89.1 ± 29.4	89.0 ± 26.4	0.995	5%
Length of the main trunk (mm)	24.8 ± 13.5	25.7 ± 13.6	0.987	7%
Angle between the frontal and parietal branches (°)	67.0 ± 17.1	68.2 ± 15.4	0.828	99%
Length of the frontal branch (mm)	65.6 ± 15.6	59.6 ± 13.4	0.077	58%
Length of the parietal branch (mm)	50.2 ± 17.4	60.9 ± 15.5	0.009	88%
Length of the bony tunnel (mm)	13.6 ± 7.8	14.9 ± 7.3	0.487	22%

Abbreviations: *P*, level of significance; SD, standard deviation; SP, statistical power analysis.

MMA may give rise to several anomalous origins, courses, and anastomoses involving this vessel. Reported variations include origin of the MMA from the ophthalmic or internal carotid artery, ophthalmic artery originating from the MMA, and meningolacrimal anastomosis, all of which have important clinical implications for endovascular therapy of skull base lesions.²⁰

At the fourth to fifth week of gestation, the MMA begins as a dorsal branch of the stapedia artery, which arises from the hyoid artery derived from the second branchial arch. After passing through the ring of the stapes, it divides into two main branches: the maxillofacial, which leaves the cranial cavity through the foramen spinosum, and the supraorbital branch, which supplies the orbit and the intracranial segment of the MMA anteriorly.^{16,21} At the seventh to eighth week of gestation, the stapedia artery involutes and the remnants become the tympanic branches of the MMA, which retains communication with the supraorbital and maxillofacial divisions. Thus, the distal portion of the internal maxillary artery forms, and communication with the intracranial components of the stapedia system is established.^{18,21} The branches of the normal adult MMA include a supraorbital branch to the orbit, as well as smaller branches to the trigeminal ganglion, the petrosal branch, and the superior tympanic artery.²¹

Rarely, the MMA may arise as a branch of the persistent stapedia artery. The persistent stapedia artery, usually a branch of the petrous portion of the internal carotid artery, enters the tympanic cavity through its floor and traverses the obturator foramen of the stapes. It is enclosed in a bony canal for a short distance and passes through the facial canal to emerge into the middle cranial fossa under the dura to give off the MMA.^{18,22}

Most attention has been directed to the anastomosis with the ophthalmic artery through the superior orbital fissure. This anastomosis can be so large that the lacrimal artery or the ophthalmic artery actually gives origin to the MMA. Thus, manipulations of the maxillary artery (e.g., in surgery of the nerve of the pterygoid canal or pterygopalatine ganglion) can cause dangerous irreparable complications including blindness if the ophthalmic artery originates from the MMA. In injuries of the MMA, one must be aware of the variations of its branches as well as of its anastomoses. This is very important for the fact that the ligation or clipping of the MMA for bleeding after injury will be totally or partially insufficient in many of the described cases of the mentioned variations. If the origin of the MMA is from the ophthalmic artery, the MMA will not be found in its normal place in the foramen spinosum.¹⁴

Finally, more than a simple morphometric description of the MMA, our study provides essential information for the detailed knowledge of the anatomical variations of this important arterial segment. These variations are of clinical significance in fractures of the squamous and petrous parts of the temporal bones and in surgical interventions involving the nerve of the pterygoid canal and maxillary artery. Moreover, we emphasize that though our morphological investigation provides innovative and reliable results about the morphometric organization of the right and left MMA, it

represents the bilateral analysis of only fifty subjects. Thus, we suggest that future studies with larger numbers of subjects will be needed to definitively confirm our findings, principally for the morphometric variables in which the statistical analysis power was less than 80%. Furthermore, the proposals in this paper should be considered a point of departure for future studies that may advance the understanding of development and the contributions of the branches variations of the normal adult MMA.

Conclusion

Our study provides not only innovator results but also reveals important insights about some aspects of the anatomical organization of the MMA bilaterally. Thus, our results undoubtedly will be useful to increase the detailed knowledge about this important arterial segment of the skull that has considerable clinical interest. Moreover, this study is unique in the literature as it fully describes the morphometric measurements of the MMA bilaterally using mathematical tools to provide a more reliable vision of the results. In addition, it provides baseline normal values for future studies aimed at further elucidating in knowledge the functional and morphological pattern of the MMA.

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