

ANGIOARCHITECTURE OF THE MIDDLE MENINGEAL ARTERY: AN INTEGRATIVE REVIEW

Angioarquitetura da artéria meníngea média: uma revisão integrativa da literatura

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ABSTRACT

Introduction: The middle meningeal artery is the most important artery of the dura mater and has a complex embryological origin, resulting in anatomical variations. Knowledge of its anatomy, morphometric aspects, and anatomical variations is important in surgeries and in understanding clinical conditions. **Objective:** To integratively review the angioarchitecture, organization, variations, and morphometric aspects of the middle meningeal artery. **Methods:** An integrative review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations. The search was conducted in PubMed, Virtual Health Library, and MEDLINE databases considering the following terms: middle meningeal artery, anatomical variations, and anatomy. This study considered articles published in English. **Results:** After duplicate removal, 89 studies were identified and 10 met the eligibility criteria and were included in the synthesis. **Conclusion:** A relationship was observed between the aspects of the middle meningeal artery and various clinical conditions, with anatomical variations being the conditions best documented in the literature. Furthermore, morphometric data on the middle meningeal artery is scarce, reiterating the importance of promoting studies to understand this vessel.

Keywords: Middle meningeal artery, anatomy, variations, morphometric aspects.

RESUMO

Introdução: A artéria meníngea média, uma das mais importantes artérias da dura mater, possui uma complexa origem embriológica. O conhecimento de sua anatomia, aspectos morfométricos e variações anatômicas são importantes em situações cirúrgicas e no entendimento de condições clínicas. O presente artigo buscou revisar de maneira integrativa a organização anatômica, as variações e os aspectos morfométricos da artéria meníngea média. **Objetivo:** Revisar, de maneira integrativa, a angioarquitetura da artéria meníngea média. **Métodos:** Tratou-se de uma revisão integrativa da literatura redigida conforme às recomendações do *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA), a qual analisou estudos publicados na língua inglesa tendo como referência as bases de dados PubMed (*Public Medline* ou *Publisher Medline*), Biblioteca Virtual em Saúde e MEDLINE empregando os seguintes descritores: *middle meningeal artery*, *anatomical variations* e *anatomy*. **Resultados:** Dos 89 estudos identificados após a remoção de duplicatas, dez atingiram os critérios de elegibilidade e foram incluídos na síntese. **Conclusões:** Observou-se uma grande relação entre os aspectos desse segmento arterial e uma variedade de condições clínicas, sendo as variações anatômicas as condições mais bem documentadas na literatura. Por outro lado, existe uma escassez de informações no que diz respeito às informações sobre dados morfométricos desse vaso sanguíneo, fato que reitera a importância da promoção de estudos direcionados ao entendimento desse vaso.

Palavras chaves: Artéria meníngea média, anatomia, variações, aspectos morfométricos.

INTRODUCTION

The middle meningeal artery (MMA) is one of the most important dural arteries, irrigating more than two-thirds of the dura mater. MMA originates from the internal maxillary artery, one of the largest branches of the external carotid artery, and is clinically and surgically relevant due to its intimate relationship with the cranium.^{1,2}

When entering the cranial fossa through the spinous foramen, the MMA laterally crosses the bone crest and curves above the upper wing of the sphenoid, bifurcating into anterior and posterior branches. MMA presents a complex embryological origin, which occurs through the stapedia artery early in embryological development. The complex nature of this process allows for the appearance of several anatomical variations and anastomoses.²

Morphological variations are of clinical importance, evident in cranium base fractures, epidural hematomas, and during endovascular and surgical interventions.³ Therefore, this study aimed to summarize the literature on the anatomical organization of the meningeal artery, its variations, and morphometric aspects due to the significant clinical and surgical importance

of this information.⁴

METHOD

This study is an integrative literature review considering studies with various methodologies investigating the anatomical and morphometric aspects and the prevalence of anatomical variations of MMA. The main objective of this review was to summarize the morphometric and anatomical aspects of the MMA and its relationship with clinical and surgical practice.

This review was conducted and reported according to the PRISMA recommendations.⁵ The search was conducted in November 2021 in the PubMed, Virtual Health Library, and MEDLINE databases. The following terms were used: “middle meningeal artery,” “anatomical variations,” and “anatomy”. The search was performed by combining the descriptors with the Boolean operator “AND.”

The inclusion criteria comprised i) articles; ii) with full text available for free; iii) addressing the specific theme of anatomical and morphometric aspects and variations of the MMA; and iv) written in English. Studies not addressing the guiding question and duplicates were excluded, according to Figure 1.

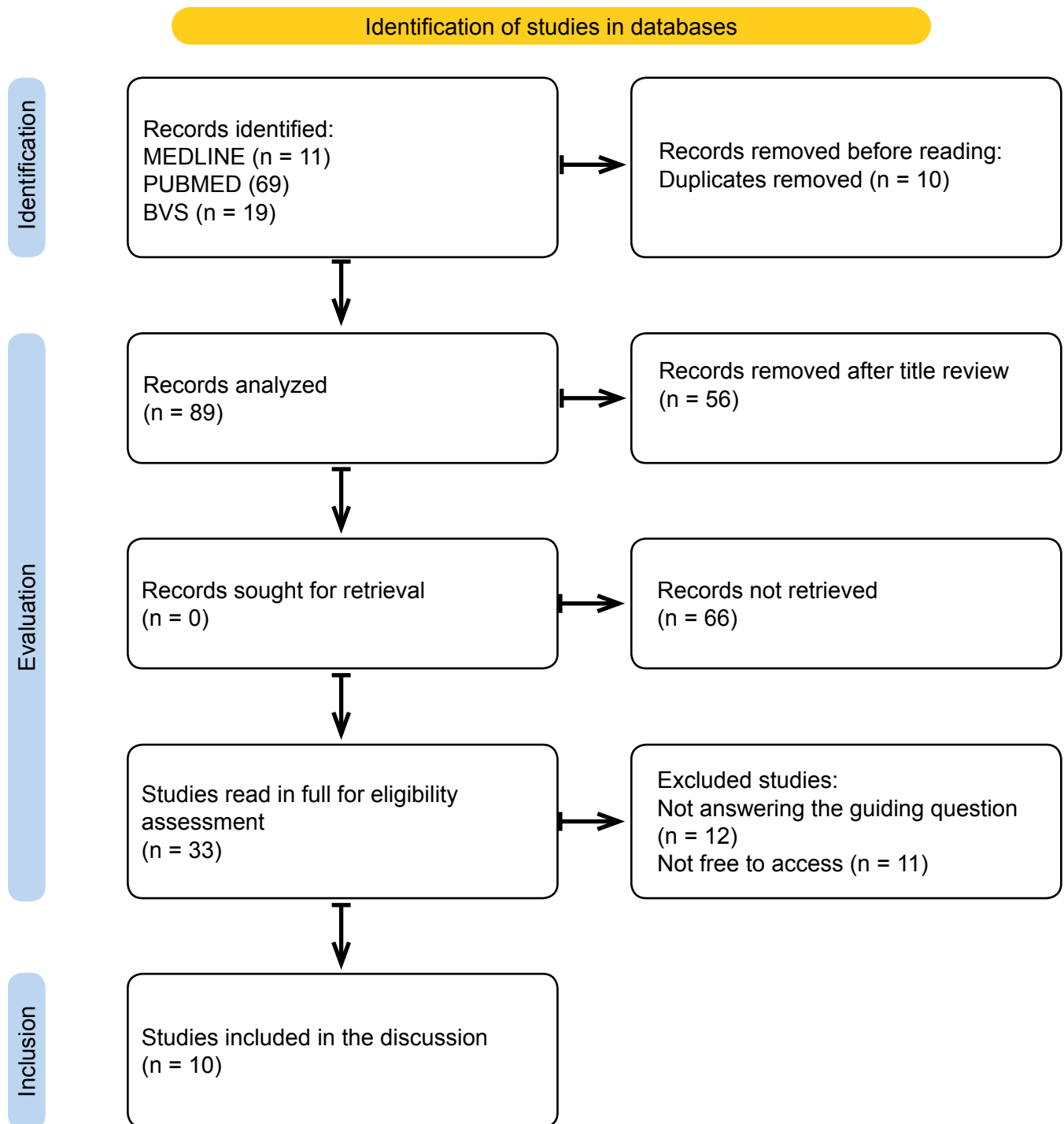


Figure 1. The selection of studies flowchart according to the PRISMA.

RESULTS

Table 1. Studies from search refinement.

| | Title | Author | Objectives | Conclusions |
|----|--|---------------------------------|--|---|
| 1º | Middle Meningeal Artery: Anatomy and Variations. | Bonasia <i>et al.</i> (2020) | To review and analyze the anatomical aspects and variation of the MMA. ¹ | The MMA has numerous anatomical variations due to its complex embryological origin. ¹ |
| 2º | Neuroanatomy, Middle Meningeal Arteries. | Natali <i>et al.</i> (2020) | To review the neuroanatomy of the MMA, citing clinical repercussions related to this arterial segment. ² | Understanding the vascular anatomy of MMA is important in clinical practice for neuroradiologists and neurosurgeons due to its relationship with pathologies (e.g., epidural and chronic hematomas, and meningiomas). ² |
| 3º | Abnormality of the Foramen Spinosum due to a Variation in the Trajectory of the Middle Meningeal Artery: A Case Report in Human. | Ellwanger <i>et al.</i> (2013) | To report the occurrence of an anatomical abnormality of the spinous foramen due to variations in the trajectory of the MMA, and review aspects of the MMA. ³ | Many anomalous origins of the MMA have been observed in the literature. In this study, the right foramen ovale was significantly larger than the left, except for an unusual form of the spinous foramen. This difference might be explained by the MMA widening the foramen ovale, on specific occasions. ³ |
| 4º | Morphometric analysis of the middle meningeal artery organization in humans-embryological considerations. | Harthmann <i>et al.</i> (2013) | To analyze the morphometric aspects and embryological considerations of the MMA. ⁴ | Important morphometric parameters of the MMA were demonstrated, including the difference between the right and left sides in the length of the parietal branch of the MMA. ⁴ |
| 5º | Morphometry of organization of middle meningeal artery through the analysis of bony canal in human's skull: A clinical-anatomical and embryological insight. | Honnegowda <i>et al.</i> (2019) | To identify the course of the bone canals of the MMA and their morphometric and structural aspects to allow safer explorations during surgeries. ⁶ | A significant difference was identified between the right (12.8 ± 4.5 mm) and left (13.7 ± 9.3 mm) length of the bone canal produced by the MMA. Furthermore, the bone canal was always located around the pterion, posterior to the coronal suture, and inferior to the temporal line. ⁶ |

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|-----|---|----------------------------------|---|---|
| 6° | Middle meningeal artery arising from the basilar artery: report of a case and its probable embryological mechanism. | Kumar S <i>et al</i> (2014) | To report and describe a case of anomalous origin of the MMA. ⁷ | Despite the rarity of the aberrant origin of the MMA from the basilar artery, these variations demonstrate the importance of planning any neurovascular procedure to reduce the risk of complications. ⁷ |
| 7° | Bony Tunnel Formation Associated with the Distal Segment of the Frontal Branch of the Middle Meningeal Artery. | de Campos D <i>et al</i> (2019) | To investigate the incidence of a bone tunnel originating from the distal segment of the frontal branch of the MMA in the adult cranium. ⁸ | A higher prevalence of the bone tunnel formed by the distal segment of the MMA on the left side of the cranium (about 5.88%) was identified compared with the right side (about 1.18%). ⁸ |
| 8° | Variations of the ophthalmic and middle meningeal arteries: relation to the embryonic stapodial artery. | Dilenge D <i>et al</i> (1980) | To analyze the relationship between the stapodial embryonic artery and the development of variations of the ophthalmic and MMA. ⁹ | Several anomalies were identified in the MMA and ophthalmic artery, proving the importance of knowledge of these structures for medical practice. ⁹ |
| 9° | Normal craniovascular variation in two modern European adult populations. | Eisová, S <i>et al</i> (2019) | To analyze the set of craniovascular impressions in two populations of European dried cranium with different morphological characteristics. ¹⁰ | Geographic and genetic factors may influence macroanatomic characteristics (e.g., anteroposterior vascular distribution). Endocranial foramina is influenced by morphology. Among the functional applications of these variations, the involvement with endocranial thermal regulation is highlighted. ¹⁰ |
| 10° | The foramen spinosum: a landmark in middle fossa surgery. | Krayenbühl N <i>et al</i> (2008) | To analyze the anatomical and vascular relationships of the foramen spinosum and define an external framework for its early identification. ¹¹ | The spinous foramen, through which the MMA, middle meningeal veins, and other structures flow, is an important anatomic landmark in surgeries of the cranial fossa. Knowledge of the anatomical variations of this structure may help to identify and preserve important neurovascular structures during surgeries. ¹¹ |

Source: the authors. MMA: middle meningeal artery.

DISCUSSION

Many authors highlight the clinical importance of understanding the anatomy, variations, and morphometrics of the MMA.^{2,3,4} Studies included different perspectives, such as the approach and relationships of MMA with nearby structures (e.g., foramen spinosum) and its complex embryological origin, widely discussed in the literature.^{3,11}

Natali *et al.* (2021) showed the importance of knowing the angioarchitecture of MMA for treating pathologies of the dura mater and for access in otorhinolaryngological surgeries. Anomalous origins of the MMA (origin from the basilar artery, internal carotid artery, and occipital artery) may have clinical implications and complex embryological explanations.¹

From its origin in the internal maxillary artery, the MMA enters the cranial fossa through the spinous foramen, crosses the bone crest laterally, and curves anteriorly above the superior wing of the sphenoid. Before bifurcating into anterior and posterior divisions, the MMA emits the petrous and cavernous branches that irrigate the dura mater of the temporal fossa. The petrous branch runs through the petrous apex and irrigates the dura mater of this region and the upper part of the tympanic cavity. The cavernous branch irrigates the lateral wall of the cavernous sinus. In addition, the MMA supplies most of the dura mater of cranial convexity, and its anterior and posterior divisions still contribute to vascularizing the superficial half of the sickle of the brain.¹

Bonasia *et al.*, (2020) reported the origin of the MMA, which develops similarly to other vessels via angiogenesis and is influenced by vascular endothelial growth and other growth factors. During MMA development, it is closely related to the stapedia system, which is present in the embryonic phase and usually

degenerates in the tenth week of embryonic development.

Because of this complex origin, many anatomical variations and anastomoses may be observed. Surgical considerations involving MMA highlight the formation of epidural hematomas due to the close relationship of the meningeal vessels with the cranial vault, which may fragilize them in situations of injury.²

Ellwanger *et al.* (2013) described a case of morphological abnormality of the spinous foramen resulting from variations in the MMA course and showed the prevalence of anatomical variations of the blood vessel. Clinical repercussions related to the MMA highlight that 85% of the bleeding sources causing epidural hematomas are due to this vessel.³

Hartmann da Silva *et al.* (2013) studied morphometric aspects of the MMA and showed the scarcity of morphometric data in the literature. No significant differences were found between the morphometric measurements of the left and right sides of the MMA, except for the length of the parietal branch. The study highlights the importance of statistical analysis of these data, which may elucidate approaches in surgery and radiology. Among the clinical considerations, the study shows that MMA might be related to the development of pain in migraine crises, resulting either from neurogenic inflammation or cranial vasodilation.⁴

When analyzing the morphometric organization of the MMA, Page *et al.* (2021) identified significant differences between left and right-side parameters (extension of the frontal branch, length of the parietal branch, and length of the bone tunnel). Also, no variations were identified in the measurements of the angle and dimension of the main trunk of the artery and between the angle formed by the frontal and parietal branches. The study

evidenced the lack of information related to the morphometry of the MMA.⁶

Kumar *et al.* (2012) reported an anomalous origin of the MMA from the basilar artery and the importance of this arterial segment in various devascularization neoplastic processes of the dura mater and the healing of dural arteriovenous fistulas. Some factors of the MMA genesis were addressed.⁷

The stapedia artery, from which MMA originates, has three branches distributed around the divisions of the trigeminal nerve: mandibular, maxillary, and supraorbital. The internal maxillary artery, originating from the external carotid artery, is incorporated into the trunk of the maxillary and mandibular branches of the stapedia artery. The proximal part of this union forms the root of the MMA, and the distal part derives from the supraorbital artery mentioned above.

During embryological development, the stapedia artery regresses and its remnants contribute to the formation of other branches, which predisposes to variations in the angioarchitecture of the MMA. In addition, anomalous origin from the basilar artery is extremely rare. Knowledge of this anatomical variation is crucial for planning neuroendovascular procedures.⁷

Campos *et al.* (2018) reported a rare formation of a bony path related to the distal segment of the frontal branch of the MMA, revealing higher predominance on the left side (5.88% of the cranium studied) than the right side (1.18%). The lack of anatomical knowledge about this arterial segment, which is predominantly periosteal, might be a hindering factor during surgeries due to its location and anatomical relationships.

A correlation between the morphologi-

cal characteristics of the MMA and the shape of the cranium was described in the literature, which makes the study a possible tool to predict variations in the MMA. In addition, a lack of information regarding the anatomical variation studied was identified in the literature.⁸ Dilenge *et al.* (1980) reaffirmed the importance of knowledge of the anatomy of arteries, such as the MMA and ophthalmic artery, in angiographic studies for the resolution of clinical problems.⁹

Vascular trait analysis may be useful in forensic science, biological anthropology, evolutionary studies, and medicine. MMA development increases in the first and second years of life and reaches a stable morphology around the fifth and sixth years; however, MMA becomes fully functional only in adult life. The main branches of these vessels divide into smaller branches, apparently following geometric patterns, which may be partially identified in the cranial impressions.¹⁰

Krayenbühl *et al.* (2008) studied the spinous foramen, an important anatomic landmark in microsurgery, and showed that understanding its anatomical variations and the surrounding areas is crucial for preserving neurovascular structures during procedures in the median fossa. The spinous foramen size varies greatly and may be attached to the sphenomandibular ligament, a remnant of the first brachial arch. Variations in this site might be important for the vascular supply of the dura mater due to its close relationship with the MMA, and in anomalous cases, the artery may travel through different locations.¹¹

CONCLUSION

The knowledge of the angioarchitecture of the MMA in the clinical, surgical, and scientific environment is important. A relationship

was observed between the aspects of this arterial segment and various clinical conditions, with anatomical variations being the most widely documented in the literature. Also, a lack of information regarding the morphometric data of MMA may hinder the planning of surgeries and reinforce the importance of further studies to understand this vessel, which is essential for dural irrigation.

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