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THE STUDY OF ANATOMY AND RADIOLOGY OF MIDDLE MENINGEAL ARTERIES, VARIATIONS AND ITS CLINICAL IMPLICATIONS

Dissertation submitted for M.Ch.,
(Neurosurgery)

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DEPARTMENT OF NEUROLOGY & NEUROSURGERY
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MADURAI.

CERTIFICATE

This is to certify that this dissertation titled **"The Study of Anatomy and Radiology of Middle Meningeal Arteries, Variations and its Clinical Implications"** is a bonafide record of work done by **Dr. K.S. Thirumurthy,** Postgraduate student in M.Ch., Neurosurgery, Madurai Medical College, Madurai.

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INTRODUCTION

The middle meningeal artery (MMA) is the largest of several meningeal arteries. It is also by far the most important branch of the maxillary artery. It is a common vessel encountered by neurosurgeons in their practice. There are considerable variations in the intracranial course and branching pattern of middle meningeal artery. Neurosurgeons need to know the variations in these vessels to understand varied clinical manifestations they present with and to avoid catastrophe during surgical or endovascular interventions.

Clinical importance of middle meningeal artery:

1. Injury to middle meningeal artery is the commonest cause of extra dural hematoma after injury to the skull, which might be associated with skull fracture in 65 to 90% of the cases. In children, extradural hematoma occurs due to injury to posterior branch of middle meningeal artery.
2. There are variations in the source of origin course and branching pattern of the middle meningeal artery which are of clinical significance in fractures of squamous and petrous temporal bones, in surgical interventions of skull base tumors and in endovascular

interventions in cases of intracranial neoplasms especially meningiomas and in dural arterio venous malformations.

Description of the course and relations of the middle meningeal artery to the endocranial surface of the bones of the cranial vault available in the text are scanty.

There are studies in the European, Japanese and American population on the middle meningeal artery course and its variation in branching pattern. Indian studies are few. This study is made as an attempt to understand the variations in the endocranial course of middle meningeal arteries and radiology of middle meningeal arteries in the population of this region and highlight the clinical implication due to such variations.

AIMS AND OBJECTIVES

AIMS

1. To study the course and relations of middle meningeal artery and variations of its branching pattern within the cranium.
2. To study the radiology of middle meningeal artery in normal individuals
3. An attempt to understand the significance of variations in course and branching pattern of middle meningeal artery.

OBJECTIVES

1. To emphasize the variations in endocranial course of middle meningeal artery and its branching pattern.
2. To enable the neurologists and neurosurgeons to understand and correlate the varied clinical manifestations which occur due to such variations.
3. To stress the importance of such variations which might be encountered during surgical and endovascular interventions in order to avoid major catastrophe.

REVIEW OF LITERATURE

The middle meningeal artery (MMA) is the largest of all the meningeal arteries supplying the dura of the cranium.

GROSS ANATOMY

Middle meningeal artery arises from the first part of maxillary artery and ascends between the sphenomandibular ligament and lateral pterygoid. It passes between the roots of auriculo-temporal nerve and lies lateral to tensor-veli- palatini before entering the cranial cavity through the foramen spinosum. It then runs in an anterolateral groove on the squamous part of the temporal bone dividing into frontal and parietal branches. The frontal (anterior) branch, the larger one, crosses the greater wing of sphenoid and reaches a groove or canal in the parietal's sphenoidal angle and divides into branches between the dura and the cranium, some ascending to the vertex and others to the occipital region. One ascending branch grooves the parietal bone about 1.5 cm behind the coronal suture, corresponding approximately to the precentral sulcus. The parietal (posterior) branch curves back on the squamous temporal bone reaching the lower border of the parietal bone anterior to its mastoid angle and dividing to supply the posterior parts of the dura matter and cranium. These branches anastomose with their fellows and with anterior and posterior meningeal arteries.

In the cranial cavity the artery has the following branches

1. Numerous ganglionic branches which supply the trigeminal ganglion and roots
2. A petrosal branch enters the hiatus for the greater petrosal nerve and supplies the facial nerve, ganglion and tympanic cavity anastomosing with the stylomastoid artery.
3. A superior tympanic artery runs in the canal for tensor tympani supplying both the muscle and the canal's lining membrane.
4. Temporal branches traverse minute foramina in the greater wing of sphenoid and anastomose with deep temporal arteries.
5. An anastomotic branch enters the orbit laterally in the superior orbital fissure anastomosing with the recurrent branch of lacrimal artery; enlargement of this anastomosis explains an occasional origin of the lacrimal artery from the middle meningeal artery.
6. Apart from this and supply to the dura matter the middle meningeal artery is predominantly periosteal, supplying bone and red bone marrow.
7. Accessory meningeal artery may arise from middle meningeal artery in 50% of cases.

Surface anatomy

The middle meningeal artery enters the skull medial to the zygoma's mid point dividing two centimeters above this. From here the frontal branch runs first up and forwards to the pterion and then up and back towards the point midway between the inion and nasion. The parietal branch runs up and back towards the lambda.

Guiffraida-Ruggeri (1913) has devised a classification of the branching pattern using the origin of the middle branch of as the criterion, which is not described in classical description of middle meningeal artery branches in the text books. Adachi simplified this in 1928, which is being followed nowadays.

Embryology

During embryonic development, the first and second aortic arch arteries begin to regress and a transient ventral pharyngeal artery grows from the aortic sac and terminates by dividing into mandibular and maxillary branches. Later the stapedial artery develops from the dorsal stem of the second arch artery and passes through the condensed mesenchymal site of the future ring of the stapes to anastomose with the cranial end of the ventral pharyngeal artery thereby annexing its terminal distribution. The fully developed stapedial artery possesses three branches, mandibular, maxillary and supraorbital, which follow the divisions of the trigeminal nerve. The mandibular and maxillary branches arise from a common stem. When the external carotid artery emerges from the base of third arch it incorporates the stem of the ventral pharyngeal artery and its maxillary branch. It communicates with the common trunk of the origin of the maxillary and mandibular branches of the stapedial artery and annexes these vessels. The proximal part of the common trunk persists as the root of the middle meningeal artery. More distally the middle meningeal artery is derived from the proximal part of the supraorbital artery.

The maxillary branch becomes the infraorbital artery and the mandibular branch forms the inferior alveolar artery.

When the definitive ophthalmic artery differentiates as the branch from the terminal part of the supraorbital branch of the stapedial artery distally this becomes the lacrimal artery. The later retains an anastomotic connection with middle meningeal artery.

Roentgenogram of the middle meningeal artery

Lateral view of x-rays skull will demonstrate two types of vascular markings:

1. Vascular grooves on the inner table of skull but occasionally on the outer table.
2. Diploic vascular channels

The vascular grooves usually seen on the inner table of the skull are depression \s produced by the middle meningeal arteries and veins and their branches as they course along the surface of the dura. The middle meningeal artery penetrates the skull through the foramen spinosum and directed forward and laterally in the middle fossa and shortly divides into anterior and posterior branches. The anterior branch continues its course forward and laterally to become visible in the lateral view as a groove at the lateral aspect of the sphenoid ridge. The artery actually produces a groove on the greater wing of sphenoid in its horizontal portion before ascending which can be visualized by oblique view obtained by rotating the skull on an antero-posterior axis, even then it may not be seen normally.

The trunk of the anterior subdivision of the middle meningeal artery ascends in a groove, which is almost always situated at or very near the coronal suture. The groove is usually wider than the middle meningeal artery because this vessel is normally accompanied by vein. The arterial grooves become smaller as they go distally. They are usually surrounded by a slight halo of increased density, which tends to differentiate them from fracture lines. Also the arterial grooves are not as radio lucent as fracture lines because they do not involve the entire thickness of the skull as a fracture does.

The posterior branch of the middle meningeal artery as it ascends upward and posteriorly over the inner table of the temporal bone sometimes casts a very straight shadow, which simulates a fracture.

Enlargement of the arterial grooves take place in those cases, that are associated with increased blood flow through these vessels. These include the meningiomas and the arteriovenous malformations of the brain, which have some blood supply by way of the external carotid branches. Some cases of fibrous dysplasia and Pagets disease present evidence of increase in size of the meningeal arterial channels. The relative sizes of these arterial grooves should be noted; if one branch of middle meningeal artery produces a wider groove than adjacent branches the possibility of meningioma should be suspected.

In normal patients, the arterial grooves of the middle meningeal artery are symmetrical, although occasionally one side may be slightly larger than the other. It might be mentioned that in lateral views magnification causes the middle meningeal grooves situated on the side against the film two appear smaller than those on the opposite side. If there is a question on a given lateral view, it is necessary to take stereoscopic lateral views in the other side against the film. When the middle meningeal grooves become enlarged they usually become tortuous in their proximal portion. Slight tortuosity is sometimes seen in normal cases but if the tortuosity extends up for several centimeters or if it is accompanied by an increase in the width of the grooves enlargement should be suspected.

Enlargement of the arterial branches of the middle meningeal artery was seen in a case of cephalhematoma deformans, a case where the meningeal arteries supplied the intracranial circulation through the rete mirabile following thrombosis of both internal carotid arteries.

Regarding foramen spinosum, it is radio graphically viewed by base of skull view. It is behind and lateral to foramen ovale. Enlargement of foramen spinosum is encountered when there is an increase in the size of middle meningeal artery as seen in meningiomas.

However because of the fact that normally one foramen may be larger than the other, this sign is not too reliable, unless it’s accompanied by enlargement of middle meningeal grooves on the inner table of the skull.

Absence or small foramen spinosum suggests aplasia or hypoplasia of the conventional middle meningeal artery under such circumstances a second source of meningeal blood supply must be sought.

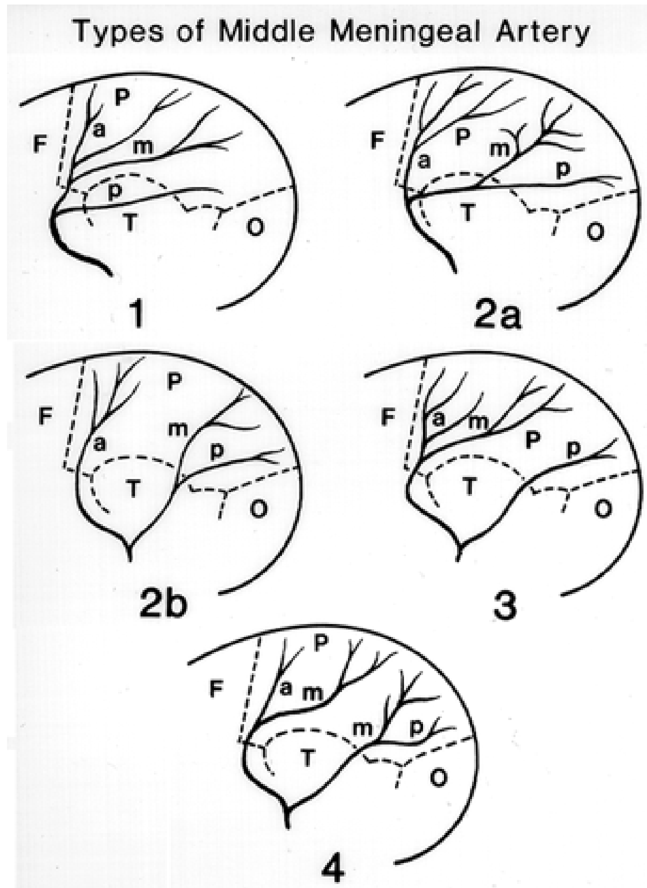
Guiffrida Ruggeri (1913) defined a classification of the branching pattern of middle meningeal artery using the origin of the middle branch as the criterion. According to their classification there were 4 types and two subtypes in type II.

Adachi (1928) simplified it into three types namely:

Type I - Middle branch arises from the frontal (anterior) ramus.

Type II - Middle branch arises from the parietal (posterior) ramus.

Type III - Middle branch arises from both frontal and parietal rami.



GUIFRRIDA-RUGGERI CLASSIFICATION

F - Frontal, P - Parietal, T - Temporal, O – Occipital.

a – anterior branch, p – posterior branch, m – middle branch .

Type 1 – middle branch arises from anterior ramus of middle meningeal artery, which is given at a higher level.

Type 2a – middle branch arises from posterior ramus of middle meningeal artery, which is given at a higher level.

Type 2b – middle branch arises from posterior ramus of middle meningeal artery, which is given at a lower level.

Type 3 – middle branch arises from anterior ramus of middle meningeal artery, which itself is given at a lower level.

Type 4 – middle branch arises from both anterior and posterior rami of middle meningeal artery.

Klisovic, Sikic, and Krmpotic – Nemanic (1993) have identified nine variations of the middle meningeal artery, the last two of which involve the origin of the middle meningeal artery from the ophthalmic artery.

Chandler and Derezinski (1935) described the presence of a bony canal of varying length usually for the anterior branch.

Rothmans (1937) reported on the presence of a bony canal for the posterior ramus in three cases.

Bartlett (1902) described that in the absence of the foramen spinosum the middle meningeal artery may enter the cranial fossa through the foramen ovale along with mandibular nerve.

Toida (1934) and Low (1946) reported about the origin of the middle meningeal artery from the third part of the maxillary artery (spheno-maxillary portion) and entry into the middle cranial fossa through the lateral end of the superior orbital fissure.

Curnow (1874) and Zukerkandel (1876) reported about the earliest case of ophthalmic origin of middle meningeal artery (OMMA). Under such circumstances the middle meningeal artery passes through the lateral end of the superior orbital fissure (SOF) or a foramen in the greater wing of sphenoid (foramen meningo-orbitale).

Hyrtl (1936) first reported about the persistent stapedial artery and origin of middle meningeal artery (SMMA) from it, which is a rare anomaly in human beings.

Altman (1947) described the course of the persistent stapedial artery and its association with other anomalies like anencephaly and Paget’s disease.

House and Patterson (1964) reported the presence of persistent stapedial artery in two cases out of 8,000 procedures done in the middle ear.

Stephen (1968) noticed only two cases of persistent stapedial artery in 10,000 middle ear operations.

Dilengne and Ascherl (1980) reported a rare instance of middle meningeal artery arising from the ascending pharyngeal artery.

Newton and Potts (1974) demonstrated that the middle meningeal artery may also arise as a branch of the intra cavernous portion (juxtasellar) of the internal carotid artery.

Tran-Dinh and Jayasinghe (1983) described a similar case of cavernous origin of middle meningeal artery.

Seeger and Hemmer (1976) and Waga, Okada, Yamamato (1978) have reported anomalous origin of the middle meningeal artery from the basilar artery.

Moret et al (1978) reported a rare instance of middle meningeal artery arising from the ascending pharyngeal artery.

David Sutton and John Stevens (2003) have mentioned that early filling of middle meningeal artery together with internal carotid artery branches can occur if these vessels are hyper vascular and supply the meningioma and angioma.

Richard Silbergleit (2000) wrote an excellent article on persistent stapedial artery.

Rumbaregh et al (1972) stressed that the most common injured vessel in trauma is the middle meningeal artery which may result in epidural hematoma, traumatic aneurysm, partial or total vascular occlusion, fistula between middle meningeal artery and meningeal veins or diploic veins or cortical veins.

Hamilton et al (1971) in their textbook of surface and radiological anatomy mention that the middle meningeal artery divides at or above the level of the zygomatic arch.

Guinto et al (1972) were the first to report on the angiographic features of the persistent stapedial artery.

Marion et al (1986) in the article on persistent stapedial artery cited various other authors regarding the association of various anomalies and thalidomide with the occurrence of persistent stapedial artery.

Pascual – Castroveijo (1983) reported the association of the persistent stapedial artery with first arch anomalies.

Royle and Motson (1973) have described a case of bilateral ophthalmic origin of middle meningeal artery in an adult skull of Asiatic origin. It is also probably the first photographic record of this anomaly.

Gabriale and Bell (1967) consider their report of three cases of ophthalmic origin of the middle meningeal artery as the first arteriographic demonstration of this anomaly.

Liu, Quingliang et al (2001) reported that the ophthalmic artery may infrequently arise from the anterior branch of the middle meningeal artery which places this artery at risk when the dura is elevated from the greater and lesser wing of sphenoid or sphenoid ridge is being removed and during embolization procedures involving the branches of the external carotid artery.

Kresimic Lucic et al (2001) from Zagreb, Croatia presented an article on extra-cranial branches of middle meningeal artery.

Gary J Wikie (2000) reported a case of temporary uniocular blindness and ophthalmoplegia associated with mandibular block injection.

Wood- Jones (1931) found foramen spinosum to be more or less incomplete in approximately 20% of cases and sometimes the foramen spinosum may be duplicated.

Lindblom (1936) reported that foramen spinosum to be absent in 0.4% of cases he studied and opined that it is especially true when the middle meningeal artery arises from the ophthalmic artery. In such cases the middle meningeal artery enters the cranium through the foramen ovale.

Yanagi. S (1987) have studied skull and recorded that foramen spinosum's diameter is at an average 2.63 mm and is round shaped. He did not observe any significant variation with age, side and sex of skull.

McLennan et al (1974) in their examination of 108 dried skulls found only one skull with bilateral and another with unilateral absence of foramen spinosum.

Ginsberg et al (1994) in their article in skull bone foramina of the middle cranial fossa recorded foramen spinosum to be absent in 3.2% of cases.

Hyae Young Kim et al (1997) in their article have highlighted that foramen spinosum was found to be asymmetrical in 25.8% of cases and small or absent in 2.5% of cases.

Falk and Nicholls (1992) opined that the anterior branch of the middle meningeal artery is homologous with the meningeal lacrimal artery of rhesus monkey, supporting the view of embryological basis of origin of middle meningeal artery from the ophthalmic artery.

Manjunath. K. Y. (2001) has reviewed about anomalous origin of middle meningeal artery and opined that unlike the middle meningeal artery of stapedial origin there have been no reports of ophthalmic origin presenting with clinical symptoms.

Low and Klisovic et al (1993) stress that anomalous origin of middle meningeal artery from the third part of the maxillary artery or the ophthalmic artery is of surgical interest because it would be difficult to ligate its main trunk since it not be found its normal position in comparison to the conventional middle meningeal artery located in the floor of the middle cranial fossa where it would be within easy access.

Vitek J.J (1988) opined that accessory meningeal artery is a branch of the middle meningeal artery and may arise from other branches of the maxillary artery and predominantly has extra-cranial supply.

Adachi (1928) reported in his series that type I branching pattern of the middle meningeal artery was predominant (51%) and in only 9% type III was seen.

Akiba (1925) in a study with 219 skulls recorded that type II variety being predominant pattern (43.8%) and type III was only 2.3%

Guiffrida – Ruggeri (1913) in their study in European skull noticed that type I pattern accounted for 59.6% and type III in only 2.3%

Rothman (1937) in his study on American white and black reported that type II variety was the predominant pattern, type III being the least.

Manjunath et al (2000) studied about the course, relations and branching pattern of middle meningeal artery in the south Indians and noted that type II was found to occur at high frequency (35.93) and type I and III variety was almost equal in frequency (31.73,32.33%)

Moret. J et al (1978) reported that the middle meningeal artery arose from the ascending pharyngeal artery vascularizing entire posterior fossa, which was of clinical and surgical interest.

Galligioni et al (1967) observed in angiogram a large meningeal branch originating from the lacrimal artery in cases of pterional meningiomas and they are pathological and serve as feeder vessel to the tumor.

Mandai S et al (2000) presented refractory chronic subdural in a 15 year old with coagulopathy due to liver cirrhosis who was treated by middle meningeal artery embolization.

Takahashi.K et al (2002) presented three cases of refractory chronic subdural hematoma treated by middle meningeal artery embolization.

Tsutsumi.M et al (2002) reported a case of traumatic middle meningeal artery pseudo-aneurysm and subsequent fistula formation with the cavernous sinus in a 23-year-old male following head injury. They have highlighted that the neurosurgeon should bear in mind the possibility of pseudo-aneurysm and dural arteriovenous fistula after blunt head injury to anticipate and prevent any hemorrhagic complication. The patient was treated with endovascular embolization with micro coils.

Bruneau.M et al (2002) reported in a 62-year-old patient who presented with fronto-temporal intracerebral hemorrhage was found to be due to traumatic false aneurysm of the middle meningeal artery.

Kinoshita.Y. et al (2004) reported a case of delayed epidural bleeding caused by traumatic pseudoaneurysm of the middle meningeal artery.

Koebe.C.J. et al (2004) reported a rare case of ruptured middle meningeal artery aneurysm causing intracerebral hematoma in a patient with moya moya disease who was treated with endovascular coil embolization.

Kobata H et al (2001) reported a case of 72-year-old lady presenting with loss of consciousness. On computer tomographic examination of the brain was found to have frontal lobe sub cortical hematoma with sub arachnoid hemorrhage. On angiographic study there was two saccular aneurysm of the left middle meningeal artery which was treated by endovascular embolization.

Kawaguchi .T et al (2002) reported a case with traumatic lesion of both middle meningeal arteries. The right middle meningeal artery had a dural arteriovenous fistula and the left one had a pseudoaneurysm. Transarterial embolization was done in this case.

Lama .M et al (2000) reported a rare case of meningioma associated with the middle meningeal artery aneurysm in a 62 year old female presenting with seizure and was managed by endovascular treatment. They highlighted that 30 cases of pseudoaneurysm of the middle meningeal artery were reported in literature and their case is the first reported case with pseudoaneurysm of the middle meningeal artery associated with meningioma.

Matsushige T et al (2004) from Japan reported a case of scalp arteriovenous malformation with intracranial feeders from the middle meningeal artery.

Matsomoto .K et al (2001) reported in a 65 year old female presenting with headache and delayed onset of left hemiparesis was to have vertex epidural hematoma associated with traumatic arteriovenous fistula of the middle meningeal artery.

Kokaogullar. Y et al (2003) from Turkey highlighted the course of middle meningeal artery in their study of extradural sub temporal keyhole approach to the sphenocavernous region.

Leiosin .F et al (1986) in their paper on orbitozygomatic malar bone flap approach highlighted the early isolation of the maxillary and the middle meningeal artery is needed to avoid vascular injury.

Djindjan .R (1976) suggests that super selective embolization of the middle meningeal artery in cases of meningioma and skull bone tumors obliterating the tumor vascular supply network and preservation of blood supply to the normal parenchyma helps in surgical outcome.

Neumaier Probst .E et al (1999) reported the importance of pre operative embolization of intracranial meningioma with fibrin glue for better surgical outcome.

Turner et al (2002) have reported sequential blockade of retinal artery branches following embolization of an intracranial meningioma following of sequential swelling of polyvinyl alcohol and also highlighted that sudden loss of vision occurring in cases of middle meningeal artery embolization due to anastomosis between middle meningeal artery and ophthalmic artery.

Manelfe C et al (1986) have reported the effectiveness of pre-operative embolization of intracranial meningiomas especially those with predominantly having external carotid artery supply as seen in meningiomas occurring in convexity, paracavernous and middle fossa and skull base locations.

MATERIALS AND METHODS

MATERIALS:

1. 14 skulls and 3 cadavers in the Department of Anatomy, Madurai Medical College was taken up for study. 6 corpses / cadavers subjected for postmortem was also taken up for surgery with the kind help obtained from the Department of Forensic Medicine. The course and branching pattern of middle meningeal arteries were observed in each.
2. Plain radiographs of skull right and left contact lateral x-rays with base of skull views were taken to study the middle meningeal artery and foramen spinosum.

METHOD OF STUDY

Skull and Cadaver Study

Fourteen dry skulls were taken up for study. There were 10 base of skull sections and 4 sagittal sections. Right and left sides were studied. Corresponding calvaria were available for only three bases of skulls studied.

Nine cadavers were taken up for study.

In total forty-six sides were studied.

In each case following parameters were studied.

1. Length of the stem and its relation to the a) squamous temporal bone b) spheno-squamosal suture c) greater wing of sphenoid.

The above-mentioned parameter was measured using sliding calipers

2. Origin of the middle branch by preparing sketch patterns, classified by using Adachi's classification.
3. Angle of the stem to a line drawn coronally through the foramen spinosum.
4. Angle of the anterior ramus to the stem.

   These angles were measured using protractor and the degrees were rounded to the nearest multiples of ten.

5. Presence of bony canal for the anterior ramus of middle meningeal artery.
6. Presence of orbital branch was identified by grooves leading to the orbit from the anterior ramus, which led either to the lateral end of superior orbital fissure or to a foramen in the lateral wall of the orbit which being named as foramen meningo-orbitale.

Radiology of Skull

20 healthy volunteers were subjected to plain radiography of skull. Lateral and skull base views were taken.

Lateral Projection

Both right and left contact lateral films were taken to avoid misinterpretation of apparent enlargement of middle meningeal vessels when compared with each other.

Technique

Patient in semi prone position with the side studied kept closer to the table. Head was kept in lateral position with external auditory meatus in midline of the table. Head was adjusted in such a way to keep the median sagittal plane (mid sagittal plane) parallel to the plane of the film and the inter-pupillary line perpendicular to the plane of the film. Finer adjustment of head was done by means of flexion of head in such a way to keep the infraorbito-meatal line (auricular line) parallel to the transverse axis of the table. Central ray was directed perpendicular to the plane of the film at a point 3 to 4 cm above the external auditory meatus. Patient was asked to suspend respiration during the exposure of X – rays.

Basal or Axial projection

Technique

Patient was placed in supine position on the table with firm support under patient's torso to achieve hyperextension of head. The film plate is kept at the level of vertex. The anthropologic plane should be parallel to the film. The central ray was directed midway between the angles of the mandible, in a line perpendicular to the anthropologic plane. Patient was asked to suspend the respiration during exposure of X – rays.

Table 1: Branching pattern of middle meningeal artery based on Adachi's classification

S.NO.	SPECIMEN STUDIED	RIGHT SIDE	LEFT SIDE
1.	Skull Base	Type I	Type I
2.	Skull Base	Type II	Type III
3.	Skull Base	Type III	Type III
4.	Skull Base	Type II	Type I
5.	Skull Base	Type III	Type II
6.	Skull Base	Type II	Type I
7.	Skull Base	Type III	Type I
8.	Skull Base	Type II	Type III
9.	Skull Base	Type I	Type II
10.	Skull Base	Type II	Type II
11.	Skull Sagittal	Type III	Type II
12.	Skull Sagittal	Type II	Type II
13.	Skull Sagittal	Type III	Type III
14.	Skull Sagittal	Type II	Type I
15.	Cadaver	Type I	Type III
16.	Cadaver	Type II	Type II
17.	Cadaver	Type I	Type I
18.	Cadaver	Type I	Type II
19.	Cadaver	Type III	Type I
20.	Cadaver	Type I	Type II
21.	Cadaver	Type II	Type III
22.	Cadaver	Type I	Type II
23.	Cadaver	Type II	Type III

Type I - Middle branch arising from Anterior branch.

Type II - Middle branch arising from Posterior branch

Type III - Middle branch arising from both branches

Of the 46 sides examined, 30.4% were type I, 41.3% were type II and 28.3 % were type III .On both the sides, type II was predominant.

<u>Table 2</u>: Length of Stem of Middle Meningeal Artery in mm

S.NO	SPECIMEN STUDIED	RIGHTSIDE	LEFT SIDE
1	Skull Base	7	10
2	Skull Base	40	25
3	Skull Base	50	32
4	Skull Base	42	33
5	Skull Base	18	25
6	Skull Base	15	15
7	Skull Base	5	3
8	Skull Base	3	3
9	Skull Base	23	30
10	Skull Base	35	9
11	Skull Sagittal	30	28
12	Skull Sagittal	27	24
13	Skull Sagittal	15	16
14	Skull Sagittal	40	15
15	Cadaver	30	30
16	Cadaver	40	20
17	Cadaver	20	20
18	Cadaver	4	3
19	Cadaver	12	16
20	Cadaver	6	7
21	Cadaver	7	6
22	Cadaver	8	10
23	Cadaver	4	3

MEAN LENGTH: 18.78 mm

In 15 sides (32.6%) the length of the stem of middle meningeal artery was less than 10mm.

Table 3: Angle between stem of middle meningeal artery and foramen spinosum (measured in degrees)

S.NO	SPECIMEN STUDIED	RIGHT SIDE	LEFT SIDE
1	Skull Base	40	40
2	Skull Base	30	40
3	Skull Base	40	30
4	Skull Base	40	40
5	Skull Base	30	40
6	Skull Base	30	20
7	Skull Base	20	20
8	Skull Base	20	10
9	Skull Base	40	30
10	Skull Base	40	60
11	Skull Sagittal	40	30
12	Skull Sagittal	30	20
13	Skull Sagittal	50	40
14	Skull Sagittal	50	40
15	Cadaver	30	40
16	Cadaver	20	30
17	Cadaver	30	30
18	Cadaver	30	20
19	Cadaver	30	20
20	Cadaver	10	20
21	Cadaver	20	30
22	Cadaver	20	30
23	Cadaver	20	20

Of the 46 sides studied, the stem of middle meningeal artery exits from foramen spinosum at an angle of 30º in 15(32.6%), 40º in 13(28.2%) and 20º in 13 (28.2%) sides. In total, 89% of the specimens studied, showed that the stems of the middle meningeal arteries exit from foramen spinosum at an angle between 20º and 40º.

Table 4 : Angle between stem and anterior branch of middle meningeal artery measured in degrees

S.NO	SPECIMEN STUDIED	RIGHT SIDE	LEFT SIDE
1	Skull Base	30	40
2	Skull Base	30	30
3	Skull Base	40	20
4	Skull Base	30	30
5	Skull Base	20	20
6	Skull Base	40	40
7	Skull Base	50	60
8	Skull Base	60	60
9	Skull Base	20	30
10	Skull Base	20	20
11	Skull Sagittal	30	30
12	Skull Sagittal	30	40
13	Skull Sagittal	20	20
14	Skull Sagittal	20	30
15	Cadaver	30	30
16	Cadaver	20	40
17	Cadaver	20	30
18	Cadaver	40	40
19	Cadaver	40	40
20	Cadaver	40	30
21	Cadaver	40	40
22	Cadaver	40	50
23	Cadaver	30	40

In 89% of the sides studied, the anterior branch of middle meningeal artery shoots off from the stem of middle meningeal artery at an angle between 20º and 40º. Only in 5 sides, the angle was more than 40º. In those occasions, the stems were short.

Table 5: Presence of bony canal for anterior ramus (branch) of Middle meningeal artery

S.NO	SPECIMEN STUDIED	RIGHT SIDE	LEFT SIDE
1	Skull Base	-	-
2	Skull Base	-	+
3	Skull Base	+	-
4	Skull Base	+	+
5	Skull Base	+	-
6	Skull Base	-	+
7	Skull Base	-	-
8	Skull Base	-	-
9	Skull Base	-	+
10	Skull Base	+	+
11	Skull Sagittal	+	+
12	Skull Sagittal	+	-
13	Skull Sagittal	+	+
14	Skull Sagittal	+	+
15	Cadaver	+	-
16	Cadaver	+	+
17	Cadaver	-	-
18	Cadaver	+	-
19	Cadaver	-	+
20	Cadaver	+	+
21	Cadaver	+	+
22	Cadaver	-	-
23	Cadaver	+	+

Presence of bony canal for anterior branch of middle meningeal artery was noted in 27 sides (58.6%), of which 14 were on the right and 13 on the left.

Table 6: Presence of orbital branch from anterior ramus of middle Meningeal artery

S.NO	SPECIMEN STUDIED	RIGHT SIDE	LEFT SIDE
1	Skull Base	-	-
2	Skull Base	-	-
3	Skull Base	-	-
4	Skull Base	+	+
5	Skull Base	-	+
6	Skull Base	+	-
7	Skull Base	+	+
8	Skull Base	+	+
9	Skull Base	-	-
10	Skull Base	+	+
11	Skull Sagittal	+	+
12	Skull Sagittal	-	+
13	Skull Sagittal	+	-
14	Skull Sagittal	+	+
15	Cadaver	-	-
16	Cadaver	-	-
17	Cadaver	-	-
18	Cadaver	+	+
19	Cadaver	-	-
20	Cadaver	+	-
21	Cadaver	+	+
22	Cadaver	-	-
23	Cadaver	-	-

21 out of the 46 sides had orbital branches. In 8 specimens they were found bilaterally.

Table 7: Relation of stem of middle meningeal artery to bony parts of Middle cranial fossa

S.NO	SPECIMEN STUDIED	RIGHT SIDE	LEFT SIDE
1	Skull Base	SQT, GWS	SQT, GWS
2	Skull Base	GWS	GWS
3	Skull Base	GWS	SQT, GWS
4	Skull Base	GWS	GWS, SQT
5	Skull Base	GWS, SQT	SQT, GWS
6	Skull Base	GWS	GWS
7	Skull Base	GWS	GWS
8	Skull Base	GWS	GWS
9	Skull Base	SQT, GWS	SQT, GWS
10	Skull Base	GWS, SQT	GWS
11	Skull Sagittal	GWS	GWS, SQT
12	Skull Sagittal	GWS, SQT	GWS
13	Skull Sagittal	SQT, GWS	GWS
14	Skull Sagittal	SQT, GWS	SQT, GWS
15	Cadaver	GWS	GWS
16	Cadaver	GWS, SQT	GWS
17	Cadaver	GWS	GWS
18	Cadaver	GWS	GWS
19	Cadaver	SQT, GWS	SQT, GWS
20	Cadaver	GWS	GWS
21	Cadaver	GWS	GWS
22	Cadaver	GWS	GWS
23	Cadaver	GWS	GWS

GWS - Greater Wing Of Sphenoid

SQT - Squamous Temporal Bone

29 / 46 (63%) specimens studied had the stem of middle meningeal artery related purely to greater wing of sphenoid. The rest had a variable amount of relation to both squamous temporal bone and greater wing of sphenoid.

Table 8: Radiology of skull. Age-Sex Distribution

Age group (in yrs)	Male	Female	Total
0 – 10	0	0	0
10 – 20	1	1	2
20 – 30	5	1	6
30 – 40	1	5	6
40 – 50	3	3	6
50 – 60	0	0	0
Total	10	10	20

Of the 20 healthy volunteers, 10 were males and 10 were females.

Table 9: Relation of anterior branch of middle meningeal artery to the Coronal Suture

Relation of anterior branch of MMA to coronal suture	Male	Female	Total
Just anterior to coronal suture	-	2	2
At the level of coronal suture	3	4	7
Behind the coronal suture	8	3	11

In 90% of the volunteers studied, the anterior branch of middle meningeal artery was either just at the level or just behind coronal suture.

<u>Table 10</u>: Foramen Spinosum visualization in Base of skull view

Foramen spinosum	Male	Female
Bilaterally visualized	9	9
Unilaterally visualized	1	1
Total	10	10

In 90% of cases foramen spinosum was visualized bilaterally

<u>Table 11</u>: Symmetrical nature of Foramen Spinosum

Foramen spinosum	Male	Female	Total
Symmetrical	7	7	14
Asymmetrical	1	3	4

In 4 out of 20 volunteers, foramen spinosum was found to be asymmetric.

RESULTS

Skull: Anatomical Study:

14 skulls and 9 cadavers were studied. Totally 46 sides were studied.

Type II pattern of Adachi's classification of branching pattern of middle meningeal artery was seen predominantly; noted in 41.3%of the cases studied. Types I and III were noted in the rest.

Mean length of the stem of middle meningeal artery was found to be 18.78 mm. 50% of the sides studied showed that the stems of the middle meningeal arteries were between 10 and 30 mm in length.

In 41/ 46 (89%) studied the stem of the middle meningeal artery exited from the foramen spinosum at an angle of 20º and 40º.

In 41 out of the 46 (89%) sides studied, the anterior branch of the middle meningeal artery shoots off from the stem of the middle meningeal artery between 20º and 40 º.

In the present study the bony canal for the anterior ramus of the middle meningeal artery was found in 58.6% of cases. In 39.13% (9/23) it was found bilaterally.

Orbital branch arising from the anterior ramus of middle meningeal artery was found in 45.66% of specimens studied. 34.8% (8 / 23) had bilateral orbital branches.

In 63% of the sides studied, the stems of the middle meningeal arteries were related to greater wing of sphenoid alone.

There was no instance of middle meningeal artery entering the cranium through the foramen ovale in present study.

We have not encountered orbital origin of anterior ramus of middle meningeal artery.

Radiology:

20 healthy volunteers who were neurologically stable were taken up for study.

90% of the healthy volunteers subjected to plain radiograph of skull were between 20 and 50 years of age with equal sex distribution.

In 55% of the subjects studied, the anterior branch of middle meningeal artery was just posterior to the coronal suture and in 35% of cases it was found along the coronal suture.

Foramen spinosum was visualized unilaterally in 2 cases.

In 20% of the subjects studied foramen spinosum was found to be asymmetrical. More commonly, it was found in female subjects. Left side was larger than the right side foramen spinosum.

DISCUSSION

In the present study, type II branching pattern of middle meningeal artery (based on Adachi’s classification) was predominant which was found in 41.3%.

Manjunath et al (2000) in their study on the endocranial course of middle meningeal artery and its variations in South Indian population had reported that type II variety was predominant in their series (35.93%). Type I and III were almost of equal frequency (31.73% and 32.33%).

In European and American studies, type III was the least.

Branching pattern	**Present study (2005)**	**Manjunath et al (2000)**
Type I	30.4%	31.73%
Type II	41.3%	35.93%
Type III	28.3%	32.33%

In the present study, we were not able to study the sex of the skull and hence sex predominance was not applied to the parameters studied.

The branching distance, in other words the length of the stem of the middle meningeal artery in present study varied between and 3 and 50mm; 50% were between 10 – 30 mm in length.

Study	Stem length variations
Present study (2005)	3 – 50 mm
Manjunath et al (2000)	3 – 54 mm
Rothman (1937)	1 – 46 mm

Present study results are comparable to that of Manjunath et al.

In present study, the angle between the stems of the middle meningeal artery to that of foramen spinosum was found to be between 20º and 40º in 89% of cases.

The angle between the anterior branches of middle meningeal arteries to that of their stems were found to be between 20º and 40º in 89% of cases.

In the present study, the bony canals for the anterior ramus of middle meningeal artery were found in 58.6% of cases.

Study	Percentage of the bony canal for the anterior ramus of middle meningeal artery
Present study (2005)	58.6 %
Manjunath et al (2000)	64.22%

Orbital branches from the anterior ramus of middle meningeal arteries were found in 45.66% of our cases.

Study	Percentage of orbital branches arising from Anterior ramus of middle meningeal artery
Present study (2005)	45.66%
Manjunath et al (2000)	48.71%
Chandler and Derenzinski (1935)	14.2%

The present study results are comparable to that of Manjunath et al who have reported the incidence of orbital branches in 48.71% of their cases.

In the present study, there were no instances of middle meningeal artery entering the cranium through the foramen ovale. Manjunath et al have also have not reported such instances in their study.

In the present study, the stems of the middle meningeal arteries were solely related to the greater wing of sphenoid in 63%. Their relation to the squamous temporal bone were variable.

Regarding the plain radiograph of the skull, in present study, the anterior branches of the middle meningeal arteries were found to be along or just posterior to the coronal suture in 90% of the subjects studied.

Foramen spinosum was unilaterally visualized in 2 subjects.

In 20% of the subjects studied, foramen spinosum was found to be asymmetrical.

Hyae Young Kim et al (1997) in their study of skull base foraminae of middle cranial fossa using high resolution Computer Tomography had highlighted that the foramen spinosum was asymmetrical in 25.8% of cases. Foramen spinosum was either or small in 2.5% of the cases.

Clinical Implications

In the present study orbital branches were found in 45.66% of population studied and there were significant variations in the length of stem and branching pattern of middle meningeal artery. Neurosurgeons have to be cautious in performing skull base procedure especially when using endoscope, to avoid injury to the middle meningeal artery to avoid intractable hemorrhage. During endovascular interventions especially when micro-fractioned gel foam, polyvinyl alcohol or N- butyl methacrylate have been used to embolize the feeder vessels in cases of meningioma or vascular lesions or tumors, careful planning and positioning of the endovascular catheter has to be practiced in this population, inorder to avoid unilateral blindness or neurological deficit.

Foramen spinosum have been found to be asymmetrical in 20 % of normal individuals and it signifies that asymmetric foramen spinosum alone has no clinical significance unless it is associated with dilated middle meningeal vessels in order to suspect pathological condition like meningioma.

LIMITATIONS OF PRESENT STUDY

1. In the present study, the number of skulls and cadavers studied are in small numbers (N=46).

2. The lengths of the anterior and posterior rami were not studied since most of the skull base specimens did not have corresponding calvaria to study in detail.

3. Computer Tomography of the skull base or angiographies of middle meningeal artery were not done due to ethical, medical and economic constraints.

CONCLUSION

From present study following conclusions are made:

1. Type II pattern of middle meningeal artery branching is the common pattern (based on Adachi's classification).

2. There are considerable variations in the length of the stem of the middle meningeal artery ranging from 3 – 50 mm.

3. In most occasions it is related to the greater wing of sphenoid and to a variable extent with squamous temporal bone.

4. Bone canals for the anterior branches of the middle meningeal artery have been found in 58.6 %.

5. Orbital branches from the anterior rami of middle meningeal arteries have been found in 45.66%.

6. In X-ray skull, the anterior branches of the middle meningeal arteries have been found adjacent to or just behind the coronal suture in 90% of the subjects.

7. Foramen spinosum have been found to be asymmetric in 20% of the subjects.

Presence of orbital branches in 45.66% of population studied and significant variations in the length of stem and branching pattern of middle meningeal artery indirectly signify that the neurosurgeons have to be cautious in performing skull base procedure and endovascular interventions in these population studied.

Foramen spinosum have been found to be asymmetrical in 20 % of normal individuals which signifies that asymmetric foramen spinosum alone has no clinical significance until it is associated with dilated middle meningeal vessels in order to suspect pathological condition like meningioma.

In the present study, an attempt has been made to understand and highlight the endocranial course of middle meningeal artery, its branching pattern and variations in its relationship to the middle cranial fossa base. These variations in the middle meningeal arteries have a significant effect in the outcome of procedures done either by conventional and endoscopic surgeries or by radiological intervention.

Mother Nature always provides surprise to us by subtle but significant variations in the environment and within our own self. Nature does not follow hard and fast rules we lay. It is our duty and pleasure to understand and appreciate Her intricacies in order to avoid catastrophe and reap the benefits of the bounty She provides.

MASTER CHART FOR RADIOLOGICAL STUDY

S.No	Name	Age/ Sex	Location of Middle meningeal artery anterior branch	Foramen spinosum
1.	Shyam	29/M	Just behind the coronal suture	Bilaterally normal
2.	Thirumurthy	30/M	At the level of coronal suture	Bilaterally normal
3.	Sethu	37/M	1 cm behind the coronal suture	Bilaterally normal
4.	Parameswari	14/F	Just behind the coronal suture	Bilaterally normal
5.	Shanthi	35/F	At the level of coronal suture	Left > Right
6.	Olariammal	50/F	1 cm behind the coronal suture	Bilaterally normal
7.	Rakkammal	40/F	Just at the level of coronal suture	One side not seen
8.	Kottiammal	45/F	Just behind the coronal suture	Bilaterally normal
9.	Varalakshmi	38/F	At the level of coronal suture	Bilaterally normal
10.	Olathuraja	22/M	Just behind the coronal suture	Bilaterally normal
11.	Sivaswamy	35/M	Just behind the coronal suture	Bilaterally normal
12.	Nachiappan	51/F	Just in front of coronal suture	Right > Left
13.	Maruthupandi	50/F	At the level of the coronal suture	Right > Left
14.	Ramar	30/M	Just behind the coronal suture	Bilaterally normal
15.	Ayyavoo	50/M	Behind the coronal suture	Left not visualized
16.	Palanichamy	50/M	Just behind the coronal suture	Left > Right
17.	Kalpagam	24/F	At the level of the coronal suture	Bilaterally normal
18.	Arumugam	40/M	Just behind the coronal suture	Bilaterally normal
19.	Mariammal	35/F	Just behind the coronal suture	Bilaterally normal
20.	Pandian	58/M	At the level of the coronal suture	Bilaterally normal

MASTER CHART FOR SKULL STUDY

S.No	SPECIMEN STUDIED	Side	A	B	C	D	E	F	G
1.	Skull Base	Rt.	I	7	40	30	-	-	S, T
		Lt.	I	10	40	40	-	-	S, T
2.	Skull Base	Rt.	II	40	30	30	-	-	S
		Lt.	III	25	40	30	+	-	S
3.	Skull Base	Rt.	III	50	40	40	+	-	S
		Lt.	III	32	30	20	-	-	S, T
4.	Skull Base	Rt.	II	42	40	30	+	+	S
		Lt.	I	33	40	30	+	+	S, T
5.	Skull Base	Rt.	III	18	30	20	+	-	T, S
		Lt.	II	25	40	20	-	+	S, T
6.	Skull Base	Rt.	II	15	30	40	-	+	S
		Lt.	I	15	20	40	+	-	S
7.	Skull Base	Rt.	III	5	20	50	-	+	S
		Lt.	I	3	20	60	-	+	S
8.	Skull Base	Rt.	II	3	20	60	-	+	S
		Lt.	III	3	10	60	-	+	S
9.	Skull Base	Rt.	I	23	40	20	-	-	S, T
		Lt.	II	30	30	30	+	-	S, T
10.	Skull Base	Rt.	II	35	40	20	+	+	T, S
		Lt.	II	9	60	20	+	+	S
11.	Skull Sagittal	Rt.	III	30	40	30	+	+	S
		Lt.	II	28	30	30	+	+	S, T
12.	Skull Sagittal	Rt.	II	27	30	30	+	-	S, T
		Lt.	II	24	20	40	-	+	S
13.	Skull Sagittal	Rt.	III	15	50	20	+	+	S, T
		Lt.	III	16	40	20	+	-	S
14.	Skull Sagittal	Rt.	II	40	50	20	+	+	T, S
		Lt.	I	15	40	30	+	+	T, S
15.	Cadaver	Rt.	I	30	30	30	+	-	S
		Lt.	III	30	40	30	-	-	S
16.	Cadaver	Rt.	II	40	20	20	+	-	S, T
		Lt.	II	20	30	40	+	-	S
17.	Cadaver	Rt.	I	20	30	20	-	-	S
		Lt.	I	20	30	30	-	-	S
18.	Cadaver	Rt.	I	4	30	40	+	+	S
		Lt.	II	3	20	40	-	+	S

19.	Cadaver	Rt.	III	12	30	40	-	-	S, T
		Lt.	I	6	20	40	+	-	S, T
20.	Cadaver	Rt.	I	6	10	40	+	+	S
		Lt.	II	7	20	30	+	-	S
21.	Cadaver	Rt.	II	7	20	40	+	+	S
		Lt.	III	6	30	40	+	+	S
22.	Cadaver	Rt.	I	8	20	40	-	-	S
		Lt.	II	10	30	50	-	-	S
23.	Cadaver	Rt.	II	4	20	30	+	-	S
		Lt.	III	3	20	40	+	-	S

MASTER CHART FOR SKULL STUDY – LEGEND.

Rt. – Right side.

Lt. – Left side.

A- Branching pattern of middle meningeal artery based on Adachi's classification .

B- Length of stem of middle meningeal artery measured in millimeters.

C- Angle of stem of middle meningeal artery to Foramen spinosum measured in degrees.

D- Angle between stem and the anterior branch of middle meningeal artery measured in degrees.

E- Presence of bony canal for the anterior branch of middle meningeal artery.

F- Presence of orbital branch from anterior ramus of middle meningeal artery.

G- Relationship of stem of middle meningeal artery to the bony parts of middle cranial fossa.

A - Adachi's Classification

I - Type I branching pattern

II - Type II branching pattern

III - Type III branching pattern

\+ - Present.

\- - Absent.

S - Greater wing of sphenoid.

T - Squamous temporal bone.