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Internal Carotid Origins of the Middle Meningeal Artery

The Ophthalmic-Middle Meningeal and Stapedial-Middle Meningeal Arteries*

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Summary. The variations and inter-relationships between the middle meningeal artery and the ophthalmic and internal carotid arteries are discussed in terms of embryogenesis, roentgen-anatomical correlation and pathological significance. The pathological conditions cited include arterial occlusive disease, regional neoplasms and extradural hematomata. When the ophthalmic artery connection with the middle meningeal artery results in a large meningeal vessel, it is best called the *ophthalmic*-middle meningeal artery as opposed to the *conventional* middle meningeal artery. A less frequent variation in the middle meningeal artery origin is one in which this vessel arises from the petrosal portion of the internal carotid artery; this seems best named the *stapedial*-middle meningeal artery and occurs infrequently when compared with the ophthalmic middle meningeal artery.

Origines carotidiennes internes de l'artère méningée moyenne. Les artères méningées moyennes ophtalmique et stapédiale

Résumé. Les variations et les relations entre l'artère méningée moyenne et les artères ophtalmique et carotide interne sont discutées du point de vue embryologique, correlation radio-anatomique et valeur pathologique. La pathologie étudiée concernait les occlusions artérielles, les néoplasies régionales et les hématomes extra-duraux. Lorsque la jonction de l'artère ophtalmique avec l'artère méningée moyenne se fait sous forme d'un gros vaisseau méningé, il vaut mieux l'appeler artère méningée moyenne *ophtalmique* par opposition à l'artère méningée moyenne *conventionelle*. Une variation moins fréquente de l'origine de l'artère méningée moyenne est sa naissance à partir du segment pétreux de l'artère carotide interne; elle est alors appelée artère méningée moyenne *stapédiale* mais elle est peu fréquente par rapport à l'artère méningée moyenne ophtalmique.

Abgänge der A. meningea media von der A. carotis interna. Die A. ophthalmica meningea media und die A. stapedialis-meningea media

Zusammenfassung. Es werden die Variationen und die Beziehung zwischen der A. meningea media zu der A. ophthalmica und der A. carotis interna bezüglich der Embryologie, die Röntgenanatomie und pathologischen Veränderungen besprochen. Bei den pathologischen Veränderungen handelt es sich besonders um Gefäßverschlüsse, regionale Geschwülste und extradurale Hämatome. Wenn durch die Verbindung der A. ophthalmica zur A. meningea media ein großes meningeales Gefäß entsteht, so ist dieses Gefäß am besten A. ophthalmica-meningea media zu nennen, im Gegensatz zur konventionellen A. meningea media. Eine weniger häufige Variation der A. meningea media liegt vor, wenn dieses Gefäß vom Petrosa-Abschnitt der A. carotis interna entspringt. Dieses Gefäß sollte dann A. stapedialis-meningea media genannt werden.

The advent of *selective* catheterization or cannulation of branches of the common carotid artery has facilitated the angiographic demonstration of anomalous origins of the middle meningeal artery. Particular attention will be drawn here to the origin of the middle meningeal artery from the ophthalmic artery (ophthalmic-middle meningeal artery, OMMA) and from the petrosal portion of the internal carotid artery (stapedial-middle meningeal artery, SMMA). This communication deals with anatomical and roentgenological aspects of these anomalies and considers their hemodynamic and radiodiagnostic value in pathological states.

Embryology

In the region of the middle ear and orbit, the multiple variations in connection between the internal and external carotid arteries have been clarified by the classical studies of Padget [21] and summarized by Lie [18]. In the embryo these intercarotid anastomoses are large. During the 24 mm to 40 mm stage of development, contributions from the first and second aortic arches form the stapedial artery; this is pivotal in establishing external and internal carotid domains.

The *conventional* middle meningeal artery originates from the dorsal ramus of the stapedial artery; arborizations of the ventral ramus become the maxillary and mandibular arteries. During regression of the trunk of the stapedial artery, the middle meningeal artery usually becomes linked to the external carotid artery. When this transition of the middle meningeal from the internal to the external carotid artery fails, the stapedial-middle meningeal artery results [13].

Another branch of the dorsal ramus of the primitive stapedial artery accompanies the ophthalmic nerve into the orbit and anastomoses with the ophthalmic ramus of the internal carotid artery. A twig from this anastomosis supplies the developing cranium and may later remain connected to the middle meningeal artery constituting an internal to external carotid communication termed the supraorbital branch of the middle

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meningeal artery [18] or merely a branch (unnamed) of the lacrimal artery [17]. When this connection is dilated, it can be recognized angiographically as the *ophthalmic-middle meningeal artery*.

Persistence of the trunk of the stapedial artery may also give rise to a variety of other rare anomalies in the region of the middle ear [1, 15].

Anatomy

The origin of the middle meningeal artery from the ophthalmic artery has long been well illustrated by anatomical dissection [4, 7, 14, 19, 26, 27]. The lacrimal branch of the ophthalmic artery follows a sinuous course laterally and superiorly in the orbit (Fig. 1). It usually provides a twig to the temporal dura (Fig. 1a) after traversing the superior orbital fissure [11, 14] or the foramen lacrimals [12] (synonym: the meningo-orbital foramen [17]). Enlargement of this vessel passing through either bony canal may result in an "anomalous" origin of the middle meningeal artery (OMMA) (Fig. 1b) from the internal carotid circulation. The proximal portion of the OMMA arises from the lacrimal branch of the ophthalmic artery and can be differentiated from the recurrent meningeal branch of the ophthalmic artery which originates more proximally and divides early into several terminal twigs [17].

The "anomalous" OMMA has also been shown angiographically [5, 8, 9, 18]. This variant circulation appears to be reasonably common; we have observed this anastomosis in over 15 selective internal carotid angiograms from our departments in the last few years. Gabrielsen and Seeger [10] have estimated a 10% incidence of middle meningeal artery visualization on selective internal carotid angiographies.

Discussion

I. Ophthalmic-Middle Meningeal Artery

Selective internal carotid angiography, subtraction and radiographic magnification increase the likelihood of OMMA demonstration. It would appear that a small anastomosis between the lacrimal and middle meningeal arteries is present in most humans [11] but is seldom corroborated by angiography. Its visualization and angiographic appearance are often related to associated structural abnormalities or disease.

OMMA in the Presence of Tumor. Previous angiographic identification of a communication between the ophthalmic and middle meningeal arteries has been related principally to its enlargement in cases of regional tumor [2, 6, 25]. However, our study of a patient

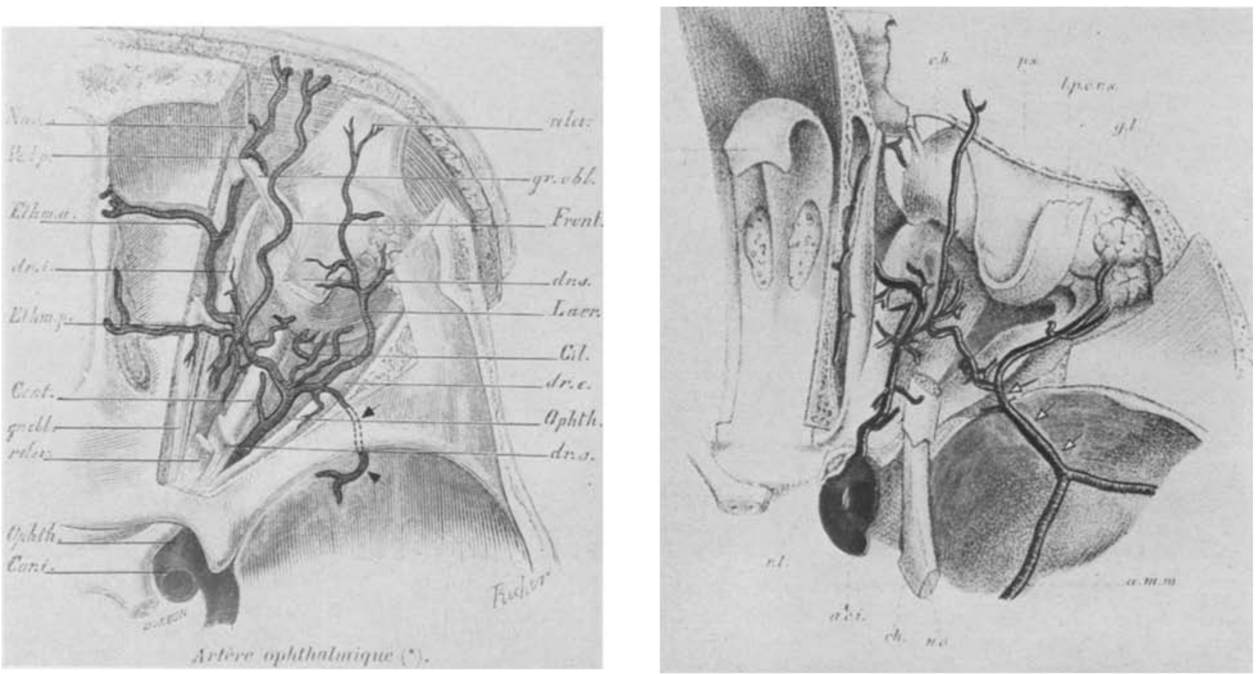

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Fig. 1. Anatomical dissections of ophthalmic artery connections with the middle meningeal artery. a) Cruveilhier [4]: Dissection showing superior view of orbit. A twig (arrows) from the lacrimal branch of the ophthalmic artery courses through a foramen in the sphenoid wing to supply the dura mater of the anterior extreme of the middle cranial fossa. b) Meyer [19]: Orbital dissection similar to Fig. 1a; exposure enhanced by anterior reflection of the superior rectus muscle. The communication between the lacrimal branch of the ophthalmic artery and the middle meningeal artery is well developed here (arrows = OMMA) showing discrete divisions within the dura

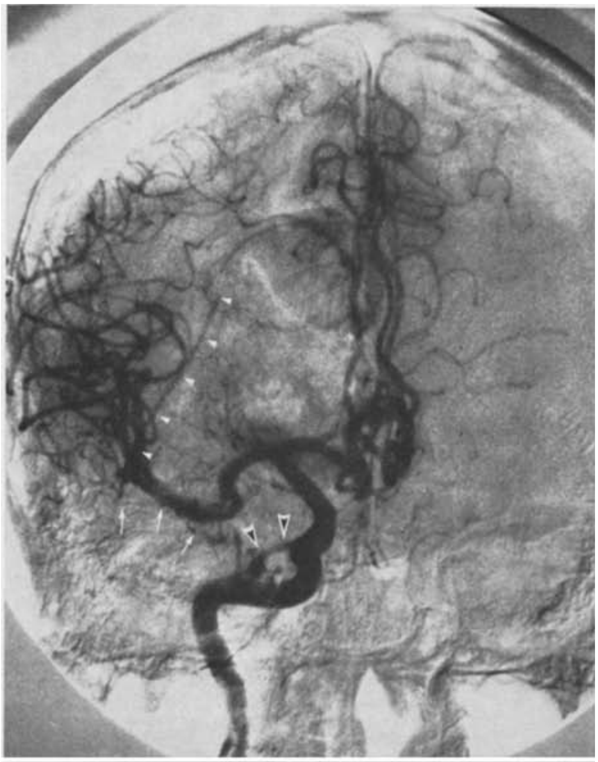

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Fig. 2. Smaller ophthalmic-middle meningeal artery (OMMA) on the side of an extracerebral vascular tumor (meningioma). a) Preoperative right internal carotid arteriogram, frontal projection: A small OMMA (arrows) courses laterally from the ophthalmic trunk (large arrowheads). The OMMA sends a small feeding vessel into the capsule of a right frontal meningioma supplied principally by the anterior and middle cerebral arteries. b) Postoperative left internal carotid arteriogram, frontal projection: The presence of a laterally and inferiorly located subdural hematoma affords better visualization of the larger OMMA present on the side contralateral to the tumor; the size of the OMMA is unchanged from the preoperative study. This larger OMMA (large black arrowheads) divides into two branches: an anterior ramus (white arrows with black centers) visualized in relief against the inner table of the skull and a smaller posterior ramus (small arrowheads). c) Normal common carotid arteriogram to demonstrate the course of a conventional middle meningeal artery in frontal projection: Note that in contrast to the OMMA (Fig. 2a and b), the proximal portion of a conventional middle meningeal artery is extracranial and parallels the ascent of the internal carotid artery; after it penetrates the base of the skull via the foramen spinosum, the conventional middle meningeal artery lies more laterally; however, the peripheral portion of the OMMA and conventional MMA are identical in frontal projection (Fig. 4). The position of an ophthalmic-middle meningeal artery may simulate a subtemporal epidural hematoma

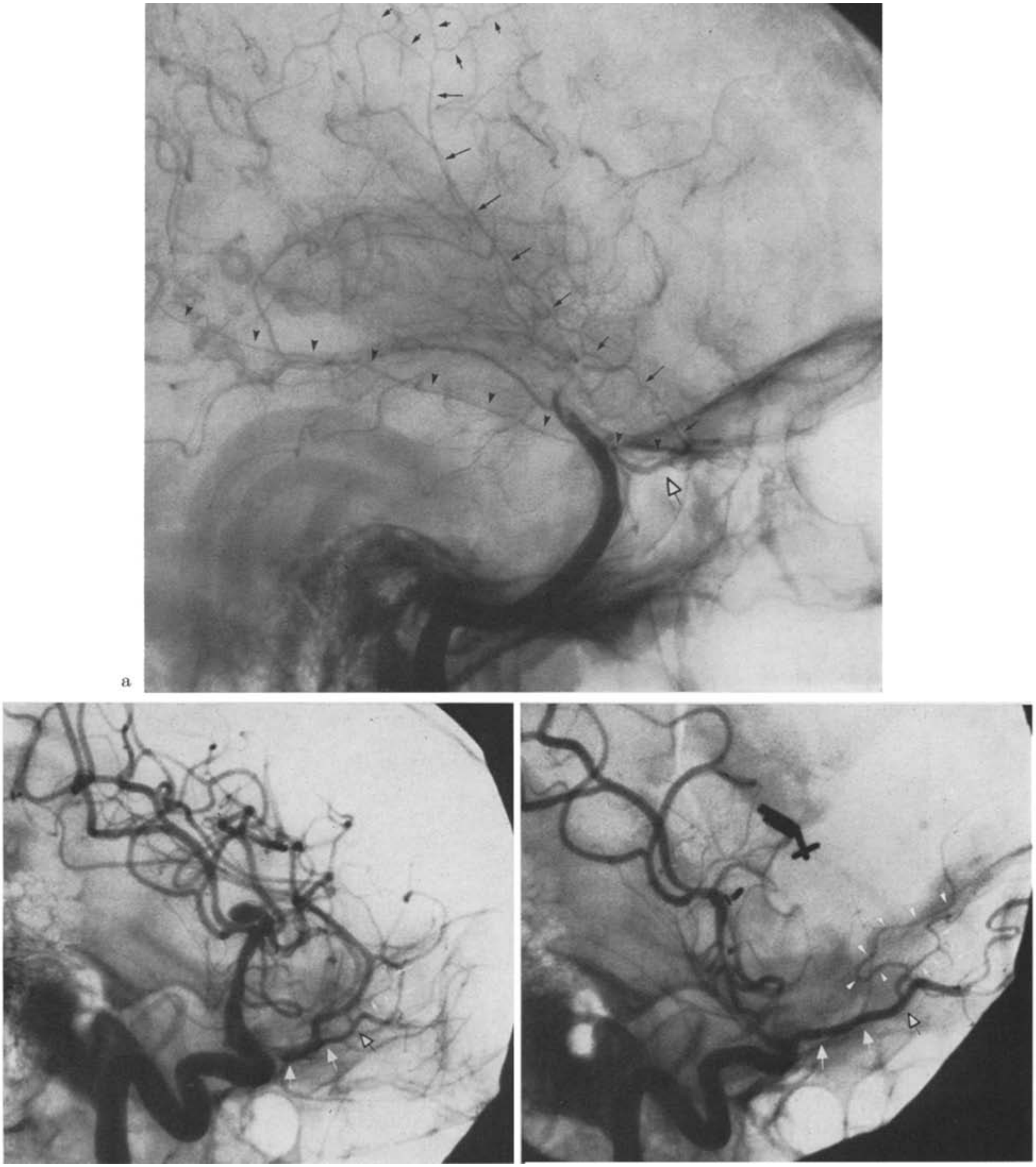

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Fig. 3. Ophthalmic-middle meningeal artery and enlarged ophthalmic dural branches in supraclinoid carotid occlusions. a) Internal carotid arteriogram, lateral projection. This patient had subtotal supraclinoid obstruction of the internal carotid artery due to a meningioma involving the middle cranial fossa. Supraclinoid carotid narrowing has facilitated ophthalmic artery flow (open arrow) and opacification of the OMMA with its anterior (solid arrows) and posterior (arrowheads) branches. With carotid occlusion at this site, the proximal course of the OMMA in lateral projection becomes optimally visualized (region between the open arrow and the arrowheads and solid arrows). The proximal position of the OMMA normally lies relatively higher than the conventional MMA which grooves the middle cranial fossa by its basal position. b) Preoperative internal carotid angiogram (oblique-lateral projection) showing a middle cerebral trifurcation aneurysm. The ophthalmic artery (large white arrows) gives rise (open arrow) to several small dural branches (small arrows). c) After clipping (lowest metallic clip) the neck of the aneurysm shown in Fig. 3b, severe spasm of the internal carotid artery resulted, causing marked dilatation of the ophthalmic artery (large white arrows), its dural trunk (open arrow) and the dural branches shown in the previous figure (small white arrows); there is also filling of a new branch (arrowheads), but no middle meningeal branches became opacified (OMMA). (This figure is slightly magnified over that of Fig. 3b; the projection is similar.)

with a large right frontal meningioma showed bilateral OMMAs (Figs. 2a and b). The smaller OMMA contributed slightly to the vascular supply of the extracerebral tumor (Fig. 2a); indeed, the larger OMMA was present contralateral to the tumor (Fig. 2b). A *conventional* middle meningeal artery in frontal projection (Fig. 2c) is compared with these ophthalmic-middle meningeal arteries.

Fig. 4. The position of an ophthalmic-middle meningeal artery may simulate a subtemporal epidural hematoma in frontal projection. Left internal carotid arteriogram, frontal projection. There is superomedial displacement of the middle cerebral artery (arrowheads) with "commensurate dislocation" of the middle meningeal artery; however, the very proximal portion of this vessel is transversely rather than vertically orientated, and as it courses more laterally, it ascends with the sphenoidal wing. This vessel therefore represents an OMMA which normally projects well above the floor of the middle cranial fossa simulating displacement of the conventional middle meningeal artery from the floor. At operation, subtemporal, subdural and intratemporal hematomata were found; no epidural abnormality was present

OMMA Enlargement in Vascular Occlusive States. Denny-Brown [5] noted an enlarged OMMA serving as a collateral pathway for cerebral blood flow in proximal internal carotid artery occlusive disease. Opacification of the OMMA might be expected to occur frequently when the internal carotid is occluded distal to the ophthalmic artery (Fig. 3); nonetheless, we found no visualization of an OMMA in 6 other patients with partial and total supraophthalmic internal carotid artery obstruction in whom the ophthalmic artery and its usual branches were well filled. Figs. 3b, c show pre- and postoperative carotid angiograms of a patient with subarachnoid hemorrhage from a ruptured middle cerebral artery aneurysm; after clipping the aneurysm, marked spasm of the supraclinoid portion of the internal carotid artery occurred and was followed by dilatation (Fig. 3c) of the previously small (Fig. 3b) dural branches of the ophthalmic artery.

OMMA in Frontal Projection — Simulation of Subtemporal Epidural Hematoma. The angiographic identification of an epidural mass in the temporal region is based on an extra-axial bare space and medial displacement of the middle meningeal artery [23]. Anteroposterior projections of the OMMA do not appear to have been analyzed previously in either normal or abnormal angiograms. Radiodiagnostically, the *distal* portions of the OMMA and the *conventional* middle meningeal artery are of identical angiographic value in differentiating extradural from subdural processes. Unlike the conventional middle meningeal artery, the *proximal* or *paraorbital* portion of the OMMA normally projects high along the greater sphenoid wing, thus simulating upward dislocation by a subtemporal epidural mass (Fig. 4). Little variation in position appears to occur in this paraorbital portion of the OMMA despite mass lesions involving the floor of the middle cranial fossa. Decreasing the cephalocaudad tube angulation may project an upward curvature to this segment of the vessel, further simulating a mass effect. Fig. 5 demonstrates a patient with a huge frontal acute epidural hematoma which did not displace the OMMA despite extension of the clot posteriorly along the sphenoid wing. Therefore, the position of the *proximal* OMMA is of doubtful diagnostic aid even in the presence of a large epidural mass.

Enlargement of the OMMA with Dural Angiomas. The OMMA may also be expected to contribute to dural arteriovenous malformations as described by Newton and Cronqvist [20]. Congenital circulatory aberrations may be associated with enlargement of this vessel as well [18].

Relationship of the Basal Foramina to the OMMA and SMMA. Absence of the foramen spinosum often accompanies aplasia of the *conventional* middle meningeal artery (Fig. 6) [24]. Substitution of the middle meningeal artery by the OMMA (Fig. 4) or persistent stapedial artery would also be expected to result in the absence of this foramen (Fig. 7). A small foramen spinosum suggests hypoplasia of the conventional middle meningeal artery (Fig. 7a); when the calvarial grooves of the middle meningeal artery are normal or large, but the foramen spinosum is small, a second source of meningeal blood supply such as the OMMA (Fig. 7b) should be sought. This can be compared with

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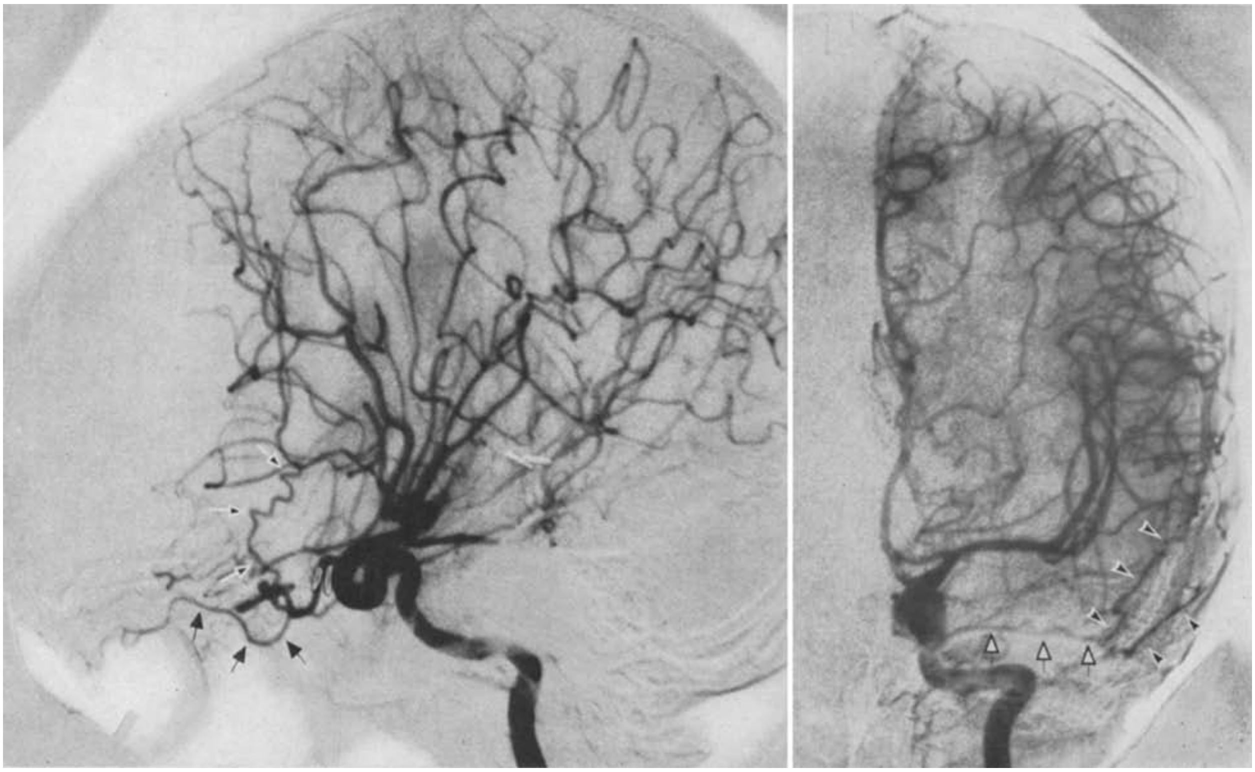
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Fig. 5. Massive frontal epidural hematoma fails to affect the position of the OMMA. a) Arterial phase, lateral projection: the ophthalmic artery (black arrows) gives rise to an OMMA which pursues a near normal course (white arrows). It is only slightly affected by the massive epidural clot (level of the uppermost white arrow). b) Frontal projection: proximal portion of the OMMA (arrows) and its anterior and posterior divisions (arrowheads) appear normal despite the large frontal epidural mass

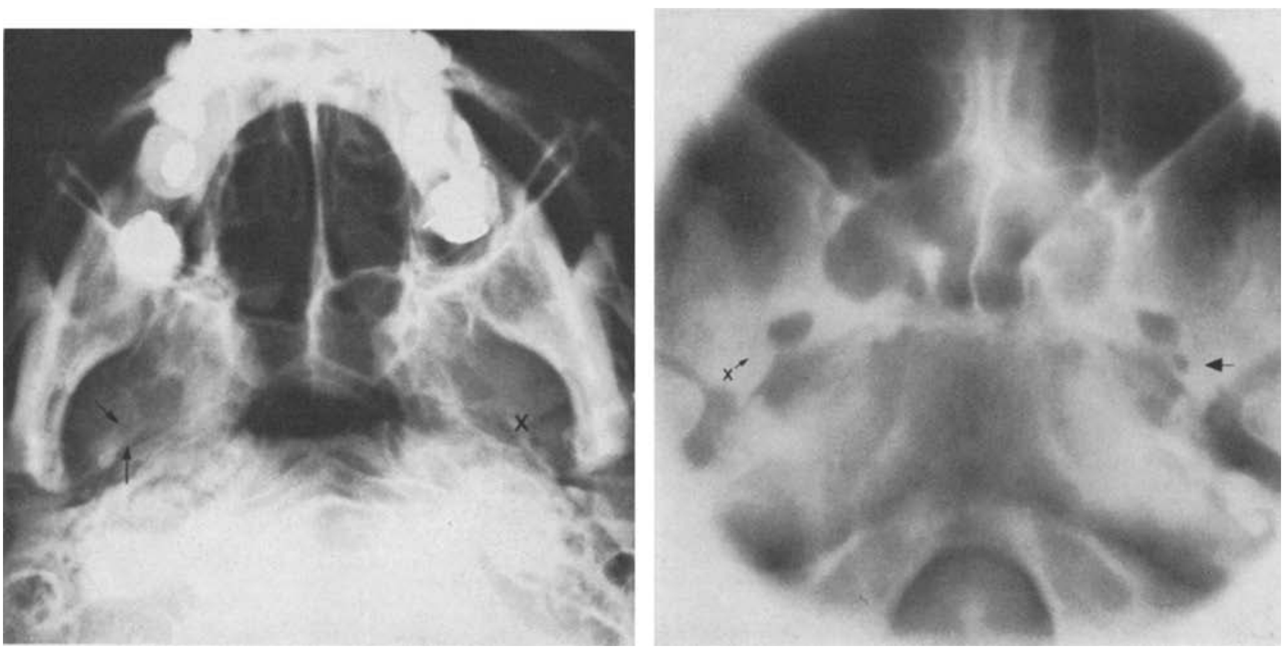

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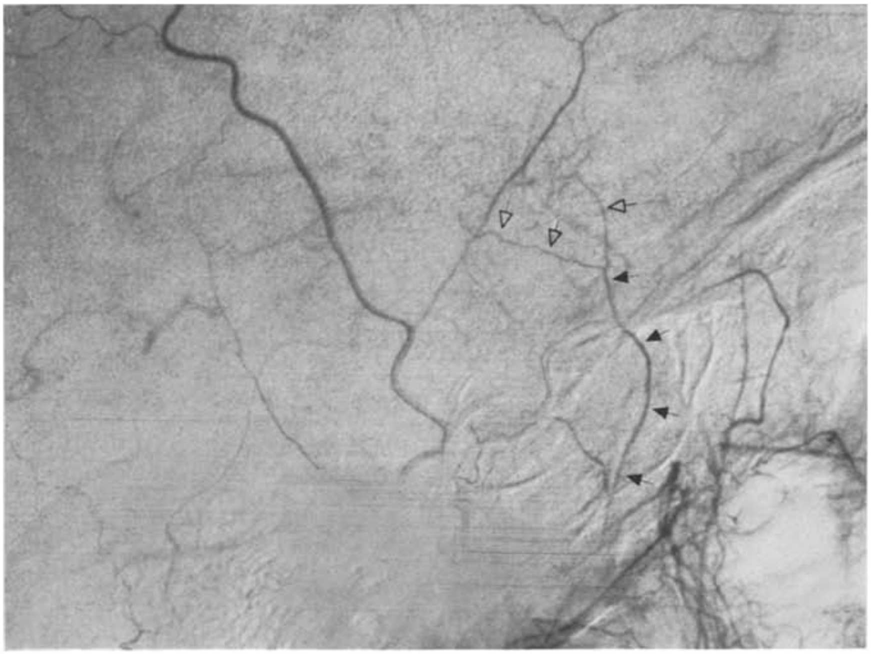
Fig. 6. Absence of foramen spinosum with anomalous meningeal vascular supply. a) Axial projection of skull (Case Report) showing normal right foramen spinosum (arrows) and absence of the left foramen (X) in the presence of an OMMA. b) Axial tomogram of skull in patient with a stapedial-middle meningeal artery (Fig. 9) shows absence of right foramen spinosum (X) and normal left foramen (arrow)



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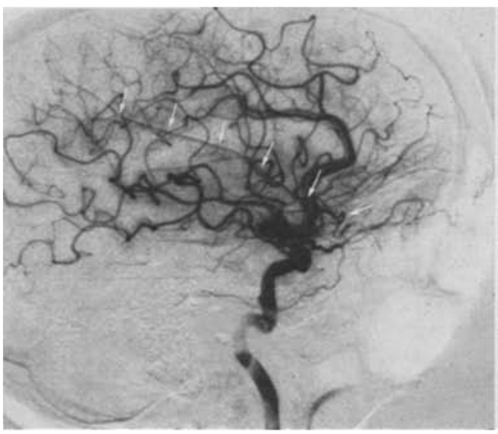

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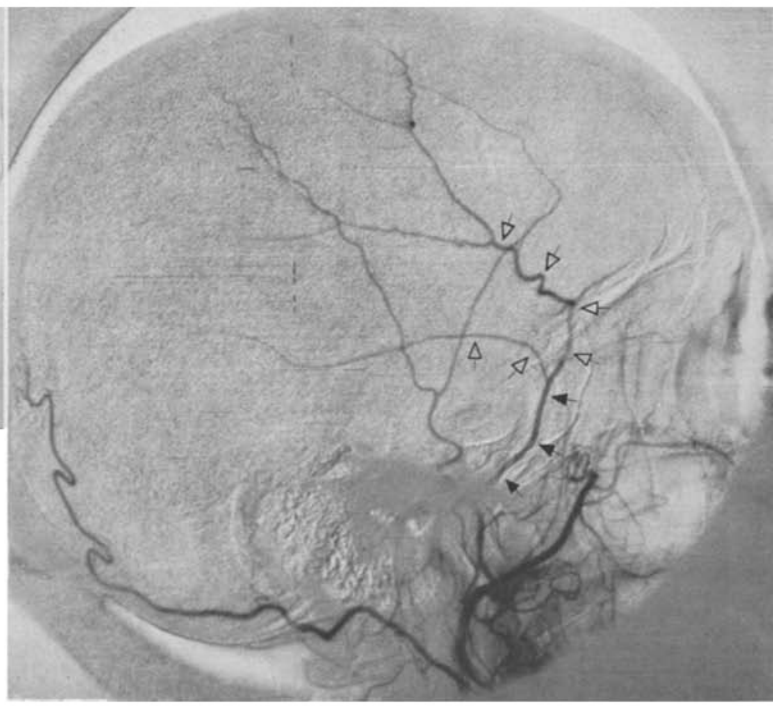

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Fig. 7. Unilateral hypoplasia of foramen spinosum and conventional middle meningeal artery with large clvarial meningeal grooves implying supplemental meningeal arterial supply. a) Selective external carotid arteriogram, lateral view: hypoplastic middle meningeal artery with superior and inferior branches (open arrows) (2 × magnification). b) Selective internal carotid arteriogram, lateral view. The OMMA occupies most of the middle meningeal vascular grooves. c) Contralateral selective external carotid arteriogram, lateral view: normal-sized conventional middle meningeal artery (solid arrows) and branches (open arrows)

the normal position and morphology of the conventional MMA (middle meningeal artery) on the opposite side in the same patient (Fig. 7c).

Our examination of 108 dried skulls in the Warren Museum of the Harvard Medical School disclosed one specimen with bilateral absence of the foramen spinosum and another with unilateral absence of the foramen. Both of these skulls had foramina lacrimale (Fig. 8a and b). It seems that prominent middle meningeal artery grooves emanating from the foramen acrimale in the sphenoid wing may be less frequent than the arterial anomaly itself (OMMA). This would be due to a dual source of meningeal arterial supply in many cases of OMMA. Royle and Motson [22] described "a very rare anomaly", identical to our Fig. 8b. They corroborate this with a survey of 1200 skulls [3] which disclosed no case of middle meningeal artery grooves emanating from the orbit.

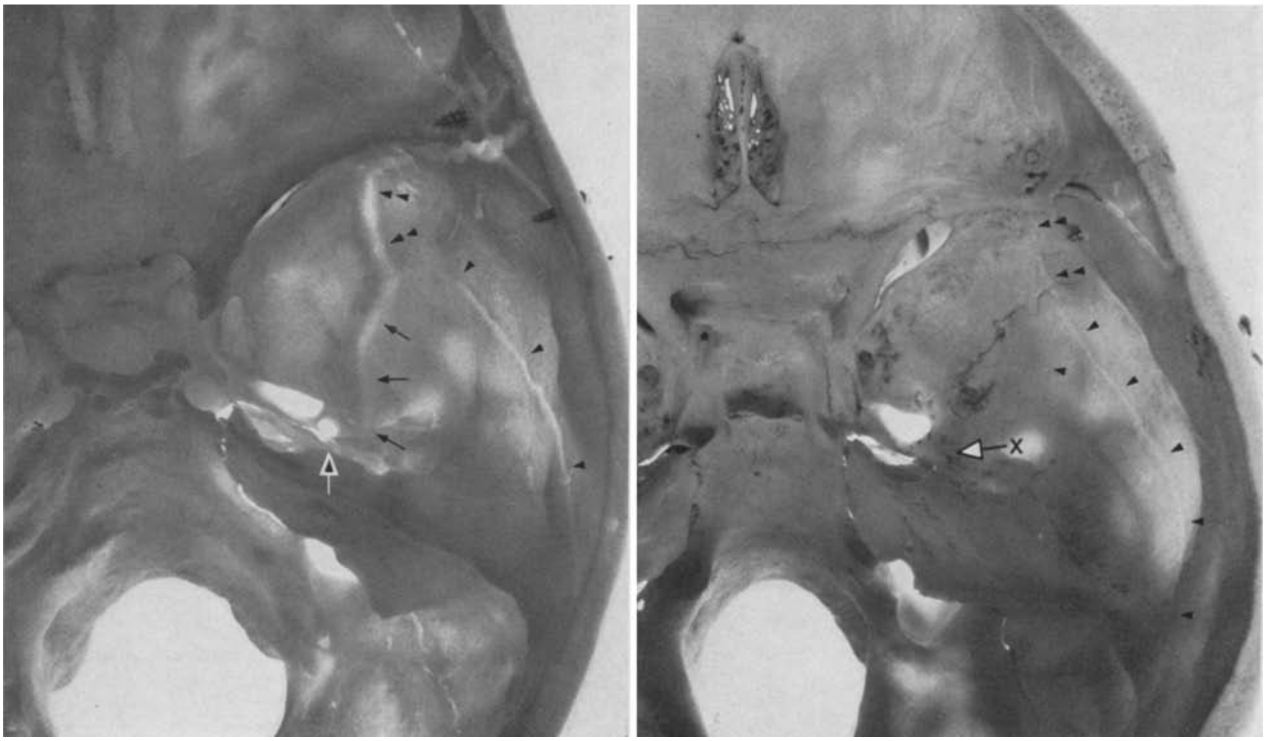

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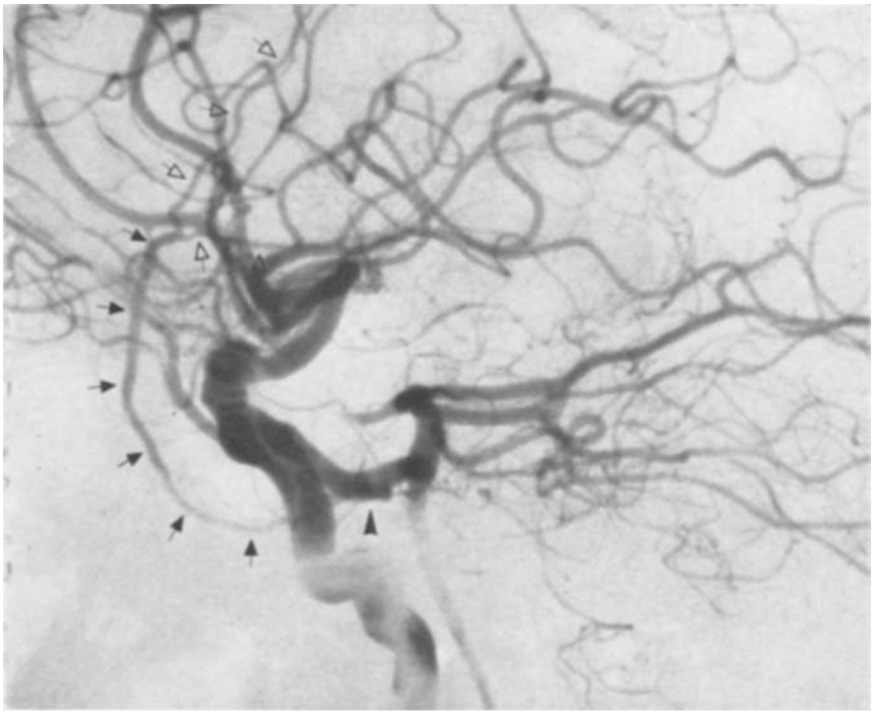
Fig. 8. Correlation of foramen spinosum and middle meningeal vascular grooves of transilluminated dried skulls. a) View of the base of the skull from above showing a normal foramen spinosum (large arrow) and grooves related to the conventional middle meningeal artery. The grooves course forward (small arrows) and divide into frontal (double arrowheads) and parietal (single arrowheads) rami. b) Unilateral absence of the foramen spinosum (X-arrow) with OMMA (double arrowheads) arising from the region of the foramen lacrimale in the greater sphenoid wing; the OMMA groove continues posteriorly forming two divisions (single arrowheads)

II. Stapedial-Middle Meningeal Artery

Persistence of a primitive stapedial connection between the internal carotid and middle meningeal arteries (SMMA) is uncommon. Variations in the development of the primitive stapedial artery were first well documented by Altmann [1]. An insufficient number of cases of the SMMA has been encountered angiographically or clinically to indicate its role under pathological circumstances.

It would appear that the SMMA is usually of little clinical relevance except for the otological surgeon. House and Patterson [16] found a stapedial artery in only 2 of 8000 middle ear operations, wherein passage of the anomalous vessel through the *os stapes* dictated termination of the procedure. Hogg *et al.*, [15] theorized that ligation of the stapedial artery in the middle ear might result in ischemia of vital neurological structures.

We have recently encountered 2 cases of SMMA, both in patients with other significant intracerebral pathology (Figs. 9, 10). The distal portion of the SMMA, like the OMMA, can be used to diagnostic advantage on selective internal carotid angiography to assess the presence of extradural processes.



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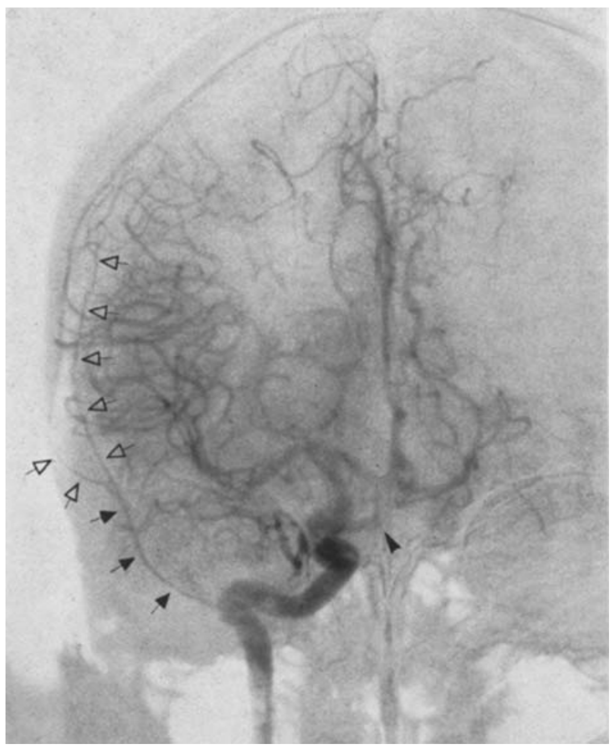

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Fig. 9. Persistent stapedial-internal carotid-middle meningeal artery (SMMA) (arrows) coexisting with primitive trigeminal artery (arrowhead). a) Selective internal carotid arteriogram, lateral view: anterior and posterior divisions (open arrows) of the SMMA (solid arrows) are clearly visible. b) Frontal view: origin of SMMA from the petrosal portion of the internal carotid artery is visualized after subtraction. Main trunk (solid arrows); divisions (open arrows)

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Fig. 10. Stapedial-middle meningeal artery in an infant with a Dandy-Walker cyst in the posterior fossa and absent corpus callosum. a) Lateral view: the SMMA origin (large arrowhead) from the internal carotid artery, its petrosal portion (arrows) and branches (small arrowheads) are well demonstrated. b) Frontal view: origin of the SMMA is shown at the catheter tip (arrowhead); proximal petrosal portion (arrows); dural portion (arrowheads)

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