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Variations of the Ophthalmic and Middle Meningeal Arteries: Relation to the Embryonic Stapedial Artery

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Recognition of the anatomic variations of the ophthalmic and middle meningeal arteries may be pertinent in tailoring the angiographic study to resolve a given clinical problem. An understanding of these anomalies is based on knowledge of the normal embryology. Unfortunately some early aspects of vascular development remain obscure. Fragmentary observations gleaned from the embryologic literature were correlated with selective and/or subselective angiography performed in 42 patients with such anomalies. This analysis has provided the basis for a tenable scheme for development of the ophthalmic and middle meningeal arteries as they relate to the embryonic stapedial artery. A classification for anomalies of these arteries is proposed based on deviation from this normal embryologic mechanism.

The evolution of selective and even subselective cerebral angiography, coupled with continued refinement in angiographic imaging apparatus and subtraction technique, has permitted remarkable progress in ability to resolve vascular anatomy. Furthermore, the advent of computed tomography (CT), rather than diminishing the role of angiography, has served to accentuate the need for angiographic evaluation of the highest quality. In this regard, some vascular anomalies are still poorly understood. Based on review of 42 cases of major anomalies of the ophthalmic and middle meningeal arteries, a classification is proposed which serves to facilitate recognition of these anomalies and the tailoring of the angiographic study to resolve the clinical question.

Embryology

Our research of the available embryologic literature and observations from our angiographic case material suggest a fundamental relationship between the development of the ophthalmic and middle meningeal arteries, and the embryonic stapedial artery. Knowledge of the arterial development in the human embryo from the branchial to the postbranchial stage is incomplete, and consequently the very early development of the stapedial artery remains obscure [1]. Nevertheless, an analysis of certain fragmentary observations by Padget [1], Evans [2], and Tandler [3] permits assumption that as an initial step, the stapedial artery is formed when primitive remnants of the first branchial arch, via a caudal migration, unite with the embryonic hyoid artery arising from the petrous segment of the internal carotid artery (i.e., at the level of the second branchial arch) (fig. 1).

The initial segment of the stapedial artery is, in fact, represented by this hyoid branch which after having penetrated the ring of the rudimentary stapes (middle ear) unites with the plexiform network residual of the degeneration of the first

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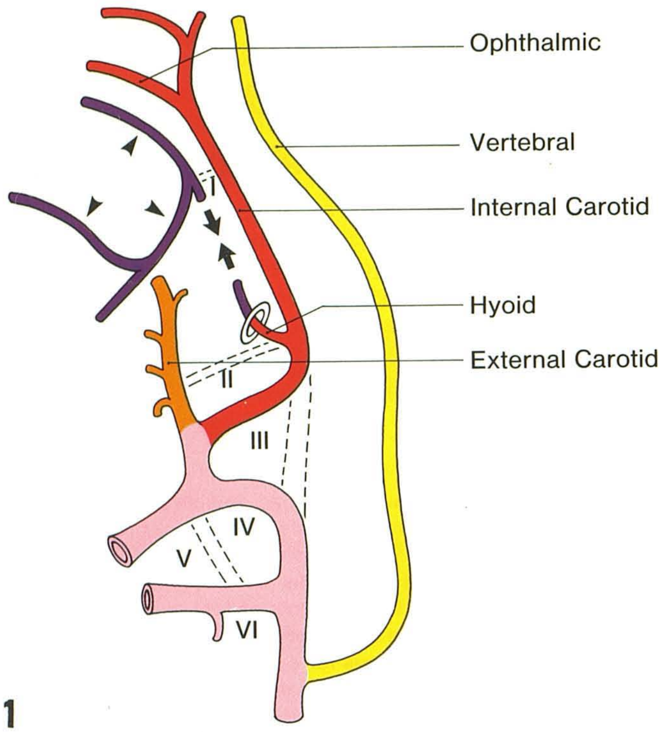

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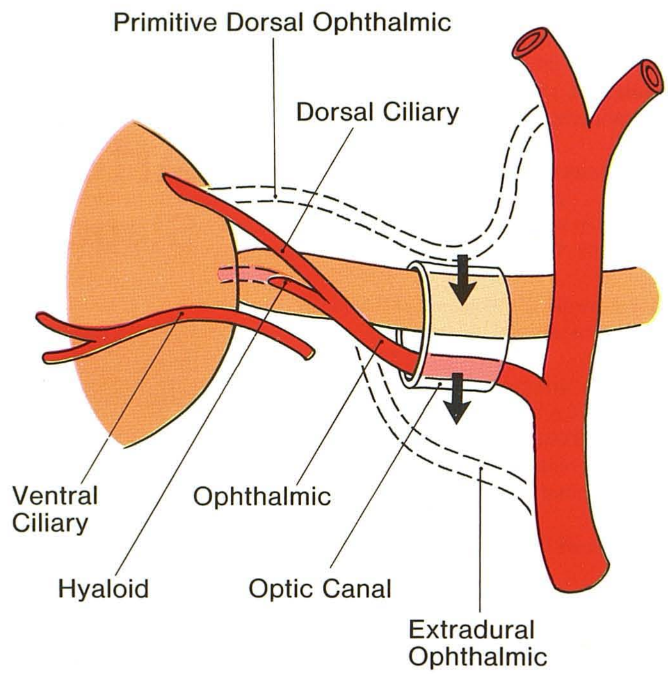

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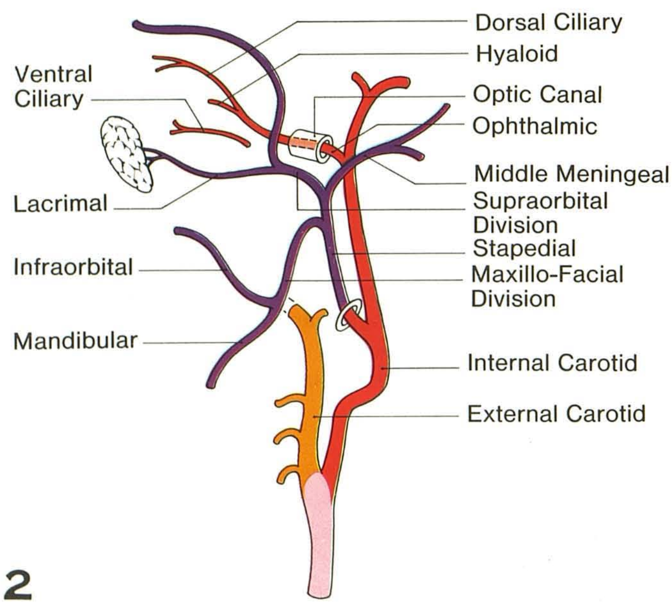

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Fig. 1.—15 mm embryo stage. Relation of vascular residua of first branchial arch (*arrowheads*) to second branchial arch is apparent. Closely related to second branchial arch is branch of internal carotid artery (hyoid artery), which penetrates ring of stapes and provides connection (*arrows*) with vascular residua of first branchial arch. In this way, stapedial artery is formed. I–VI = primitve aortic arches. (Modified from [3].)

Fig. 2.—20 mm embryo stage: division of stapedial artery. Branches of maxillofacial division will be assimilated by external carotid artery to form internal maxillary artery and provide extracranial segment of middle meningeal artery. Supraorbital division gives rise to intracranial segment of middle meningeal artery and enters orbital cavity, where it is assimilated by primitive ophthalmic artery and supplies all structures exclusive of globe.

Fig 3.—Development of ophthalmic artery. Caudal migration of primitive dorsal ophthalmic artery along internal carotid artery to site of developing optic canal, which ultimately will surround both ophthalmic artery and optic nerve. Ophthalmic artery will divide into dorsal ciliary branch and hyaloid branch (precursor of central retinal artery). Network will join primitive ventral ophthalmic artery (precursor to ventral ciliary arteries) and provide branches that will supply globe exclusively. If "migration" of primitive dorsal ophthalmic artery continues more caudally, its origin from internal carotid artery will be extradural and will enter orbit via superior orbital fissure rather than through optic canal. (Modified from [1].)

branchial arch. In the region of this union is the site of origin of one of the two definitive divisions of the stapedial artery—the maxillofacial division. The second definitive division of the embryonic stapedial artery is the supraorbital.

Essentially then, the stapedial artery in a 20 mm embryo (fig. 2) consists of: (1) a *main trunk* derived from the hyoid artery, at the level of the stapes, which divides into (2) a *maxillofacial* division consisting of an infraorbital (maxillary) branch and a mandibular branch; and (3) a *supraorbital* division consisting of branches destined to supply the orbit and provide for the intracranial segment of the middle meningeal artery.

The intracranial segment of the middle meningeal artery develops not only in a different manner from, but also at an earlier stage than, its extracranial part. Later the branches of the maxillofacial division of the stapedial artery are assimilated by the developing external carotid artery and form the internal maxillary artery (including the extracranial segment of the middle meningeal artery). At this stage the proximal part (trunk) of the stapedial artery involutes, and its remnant then becomes the tympanic branch of the middle meningeal artery. The remnant of the segment of the hyoid artery at the level of, and proximal to, the stapes (fig. 1) eventually differentiates into the caroticotympanic branch of the definitive internal carotid artery.

Concurrently the primordial ophthalmic artery undergoes an evolutionary sequence of changes (fig. 3), including a caudal migration along the internal carotid artery so that in the 20 mm embryo, it reaches its final position and enters the orbit through the optic canal. At this stage, it consists of a series of branches (dorsal and ventral ciliary, and hyaloid arteries) which will ultimately become the temporal and nasal ciliary and central retinal arteries—all of which supply exclusively the globe. At about the 20 mm embryo stage, branches of the supraorbital division of the stapedial artery begin to anastomose with the primitive ophthalmic artery. This anastomosis between the stapedial and primitive (dorsal) ophthalmic artery networks continues slowly and is completed by the 40 mm embryo stage. As these branches of the supraorbital division of the stapedial artery are assimilated by the dorsal ophthalmic artery, they will ultimately supply the entire contents of the orbit, other than the globe itself, forming among others, the frontal, supraorbital, ethmoidal, and lacrimal artery branches of the definitive ophthalmic artery.

As mentioned earlier, the supraorbital division of the stapedial artery forms, in addition to the extraocular intraorbital arteries, the intracranial segment of the middle meningeal artery. After the intraorbital branches of the stapedial artery are assimilated by the ophthalmic artery, its proximal intra- and retroorbital branches involute and become resorbed by the intracranial segment of the middle meningeal artery. The lacrimal artery, one of the terminal branches of the supraorbital division of the embryonic stapedial artery assimilated by the ophthalmic artery, in some cases remains partly connected to the retroorbital stapedial branches and, as such, then becomes a branch of the middle meningeal artery.

Materials and Methods

Our study was based on the analysis of 42 cases of major anomalies (table 1) of the ophthalmic and middle meningeal arteries recognized during evaluation of about 3,500 cerebral angiograms performed, using either direct percutaneous or selective catheter methods, during the past decade. It must be recognized that the true anatomic incidence of these anomalies might vary significantly from the findings in this series which are based on an angiographic assessment only. The reason for this is related to the observer's skill as well as limitations inherent in the technical quality and method of the angiographic study. Some of these anomalies can only be recognized and confirmed when both selective internal and external carotid angiograms are available.

TABLE 1: **Anomalies of Ophthalmic and Middle Meningeal Arteries**

Anomaly	No.
Separation of ocular branches of ophthalmic artery from extraocular intraorbital branches	1
Ophthalmic artery arising from middle meningeal artery	3
Middle meningeal artery arising from ophthalmic artery	17
Accessory ophthalmic artery	1
Ophthalmic artery arising from extradural portion of carotid siphon	7
Middle meningeal artery arising from extradural carotid siphon	10
Middle meningeal artery arising from petrous segment of internal carotid artery	3
Total	42

Anomalies of Ophthalmic and Middle Meningeal Arteries

Anomalies Involving Connection of Stapedial Artery with Primitive (Dorsal) Ophthalmic Artery

Separation of the ocular branches of the ophthalmic artery from the extraocular intraorbital branches results from a defect in anastomosis that normally occurs in the 20 mm embryo between branches of the supraorbital division of the stapedial artery and the primitive ophthalmic artery. In this situation, the ophthalmic artery supplies only the globe (via its ciliary and central retinal branches) and remains separated from the remaining intraorbital branches derived from the supraorbital division of the stapedial artery. As a result, the ocular branches of the ophthalmic artery remain in the internal carotid system, while the remaining intraorbital branches arise from the middle meningeal system and are therefore opacified separately on selective internal carotid and external carotid angiograms, respectively. According to the literature, this anatomic condition is rare with only one published report [4]. This condition was definitively demonstrated on serial angiography in one case in our series (fig. 4).

Ophthalmic artery arising from the middle meningeal artery results when there is complete assimilation of the primitive ophthalmic artery by the supraorbital division of the stapedial artery. The normal involution of the retroorbital branches of the stapedial artery fails to occur, and instead there is involution of the proximal segment of the primitive (dorsal) ophthalmic artery at its origin from the internal carotid artery. This anomaly is also quite rare with only 12 (10 documented) cases reported [5–7].

To our knowledge, this anomaly has never been demonstrated by serial carotid angiography. We have had occasion to study this anomaly angiographically in three patients, but in only one was its presence demonstrated unequivocally. In this case (fig. 5), selective internal carotid angiography failed to disclose opacification of any intraorbital vessels, while selective external carotid injection demonstrated the entire intraorbital vascular network including the choroidal vessels.

Middle meningeal artery arising from the ophthalmic artery evolves after assimilation of branches of the supraorbital division of the stapedial artery (i.e., the intraorbital extraocular branches) by the primitive ophthalmic artery (which initially supplies only the globe) (fig. 6). Two separate processes are involved: (1) failure of the proximal intraorbital and retroorbital stapedial branches to involute so that the intracranial segment of the middle meningeal artery remains

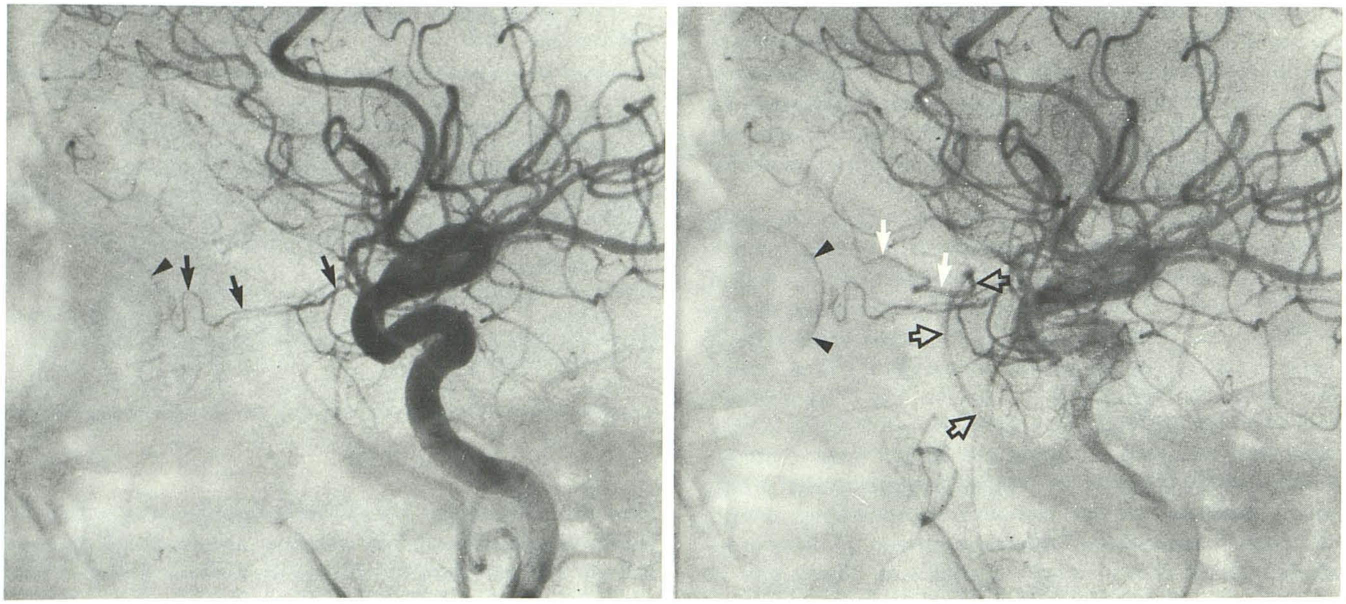

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Fig. 4.—Separation of ocular branches of ophthalmic artery from extraocular intraorbital branches. Selective internal carotid artery injection. **A**, Early arterial phase. Small caliber ophthalmic artery (*arrows*) with opacification of only ocular branches. Opacification of choroid (*arrowhead*) of globe. **B**, Late arterial phase. Transient reflux into external carotid artery, in addition, permits demonstration of faint opacification of middle meningeal artery (*open arrows*) and ultimate opacification of one orbital branch (*white arrows* = supraorbital artery).

connected with the intraorbital stapedial branches; and (2) defective involution of the maxillofacial division of the stapedial artery so that the extracranial segment of the middle meningeal artery is never formed. As a result, no connection forms between the internal maxillary artery and the intracranial segment of the middle meningeal artery.

Sometimes the extracranial segment of the middle meningeal artery forms normally and unites with the intracranial segment, with only partial involution of the retroorbital stapedial branches so that some connection with the middle meningeal artery is maintained. It is possible then for the anterior branch of the middle meningeal artery to fill from the internal carotid–ophthalmic artery circulation, while the posterior branch of the middle meningeal artery fills via the external carotid circulation (fig. 7).

The origin of the middle meningeal artery from the ophthalmic artery is a relatively frequent anomaly (0.5% incidence in our series) initially described anatomically by Zuckerkandl [8] (cited in [9]). Its angiographic features were described by Keller [10]. The intraorbital origin of the middle meningeal artery usually occurs at the point where the ophthalmic artery curves around the optic nerve, in close relation to the origin of the posterior ethmoidal arteries. As indicated above, the extracranial portion of the middle meningeal artery on the external carotid angiogram either may not be discernible or may exhibit a spectrum of hypoplasia. In this regard an association between lack of development of the extracranial segment of the middle meningeal artery and absence of the foramen spinosum has been described [11, 12].

Recurrent meningeal and accessory ophthalmic arteries. When incomplete involution of the proximal intraorbital and retroorbital segments of the supraorbital division of the stapedial artery occurs, the intraorbital vascular network retains partial connection with the intracranial middle meningeal artery. This connection provides the basis for the eventual development of unusual branches arising from the intraorbital vascular network, which return to the middle cranial fossa (recurrent arteries). Examples include the *recurrent meningeal* and *meningolacrimal* arteries [13–15]. The recurrent meningeal artery (fig. 8) is opacified directly from the ophthalmic artery trunk and returns to the middle cranial fossa via the superior orbital fissure where it directly vascularizes the dura or joins the middle meningeal artery. The meningolacrimal artery arises from the lacrimal branch of the ophthalmic artery and leaves the orbit, entering the middle cranial fossa via the meningoorbital foramen, a small opening in the medial aspect of the sphenoid bone just lateral to the superior orbital fissure. It eventually anastomoses with the middle meningeal artery.

These recurrent arterial branches are seldom identified even after subtraction. In general they are visualized arising from the opacified ophthalmic artery only when they enlarge in the context of occlusion of the external carotid artery, wherein they provide a means of collateral circulation, or in the presence of meningiomas of the sphenoid region [16]. The middle meningeal artery may maintain a major connection with the intraorbital vascular network via branches known as *accessory ophthalmic arteries* [17] (fig. 9). They anastomose with orbital branches of the ophthalmic artery and permit the middle meningeal artery, as well as the ophthalmic artery trunk, to actively supply the entire intraorbital circulation (including the globe). Consequently, the entire intraorbital vascular network may be equally well opacified by either selective external or internal carotid injection.

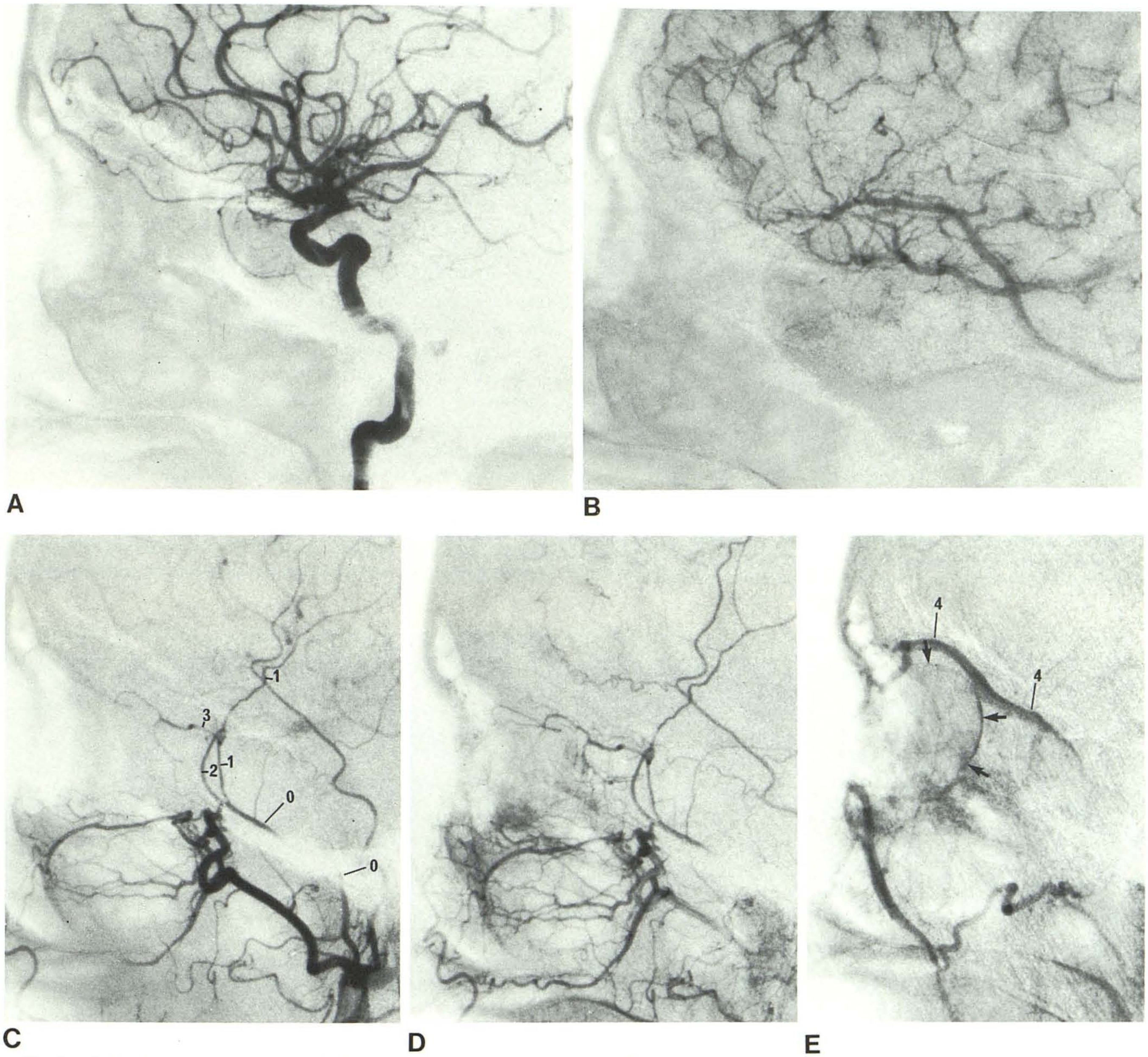

Fig. 5.—Ophthalmic artery network arising from middle meningeal artery. **A** and **B**, Selective internal carotid angiogram. No evidence of opacification of any intraorbital branches. **C–E**, External carotid angiogram. Opacification of middle meningeal artery and intraorbital vascular network, including choroid (*arrows*). 0 = middle meningeal artery trunk; 1 = lateral division of anterior branch of middle meningeal artery; 2 = medial division of anterior branch of middle meningeal artery; 3 = ophthalmic artery; 4 = superior ophthalmic vein.

Anomalies Involving Aberrant Origin of Ophthalmic and Middle Meningeal Arteries

Origin of the ophthalmic artery from the extradural part of the carotid siphon. An extradural origin of the ophthalmic artery which is only a few millimeters proximal to the dural boundary represents a rather frequent finding (7.5% according to Hayreh and Dass [5]). Such small variation generally reflects a particularly tortuous configuration of the cavernous part of the siphon. However, an extradural origin of the ophthalmic artery more than just a few millimeters proximal to the dura (fig. 10) is quite rare (0.2% in our series). Such an origin is characterized by a rather peculiar course of the ophthalmic artery as it aberrantly enters the orbit via the superior orbital fissure instead of passing through the optic canal. This anomaly entails a more caudal migration of the primitive (dorsal) ophthalmic artery along the course of the internal carotid artery prior to the 20 mm embryo stage (fig. 3). This migration normally terminates at the level of the mesenchymal plaque that develops into the optic canal, so that the definitive ophthalmic artery and optic nerve are enveloped by the osseous ring which constitutes the canal. If the primitive ophthalmic artery migrates more caudally, the developing optic canal surrounds only the optic nerve.

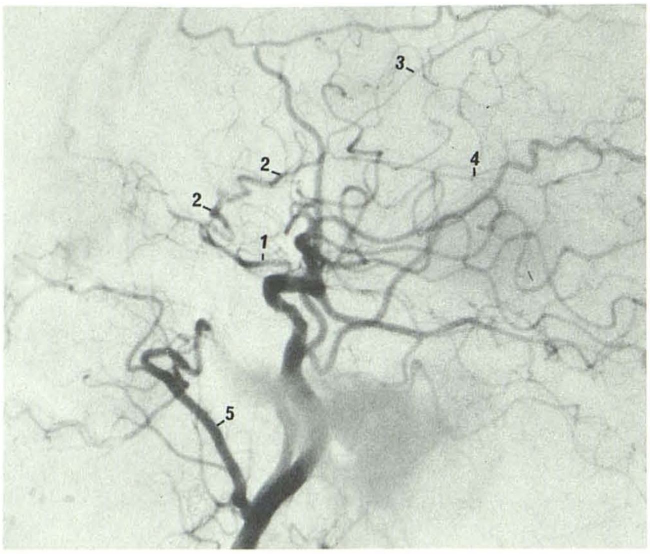

Fig. 6.—Middle meningeal artery arising from ophthalmic artery. Common carotid angiogram. Opacification of middle meningeal artery which arises from ophthalmic artery. Lack of extracranial segment of communication with internal maxillary artery. 1 = ophthalmic artery; 2 = middle meningeal artery; 3 = anterior branch of middle meningeal artery; 4 = posterior branch of middle meningeal artery; 5 = internal maxillary artery.

Origin of the middle meningeal artery from the extradural part of the carotid siphon is quite rare (0.3% in our series), especially in those cases in which the middle meningeal artery arises from the cavernous (siphon) (fig. 11) or high cervical (prepetrous) segments of the internal carotid artery. A possible embryologic mechanism relates to an aberrant origin (either more distal or more caudal) of the hyoid artery from the internal carotid artery, so that its union with remnants of the first branchial arch to form the stapedial artery either does not occur or occurs without any relation to the level of the stapes. The possibility of such a failure of formation of the stapedial artery has not been previously mentioned in the literature. With this anomaly the extracranial part of the middle meningeal artery remains either poorly developed or is absent.

Origin of the middle meningeal artery from the petrous segment of the internal carotid artery. The basis for this anomaly is persistence (failure of involution) of the embryonic stapedial artery. This artery has been the object of numerous anatomic dissections, and has been reported observed by chance, on three occasions, during middle ear surgery [18, 19]. Its rarity has been documented by House and Patterson [19] who noted such an anomaly only twice in 8,000 procedures on the middle ear. According to Alt-

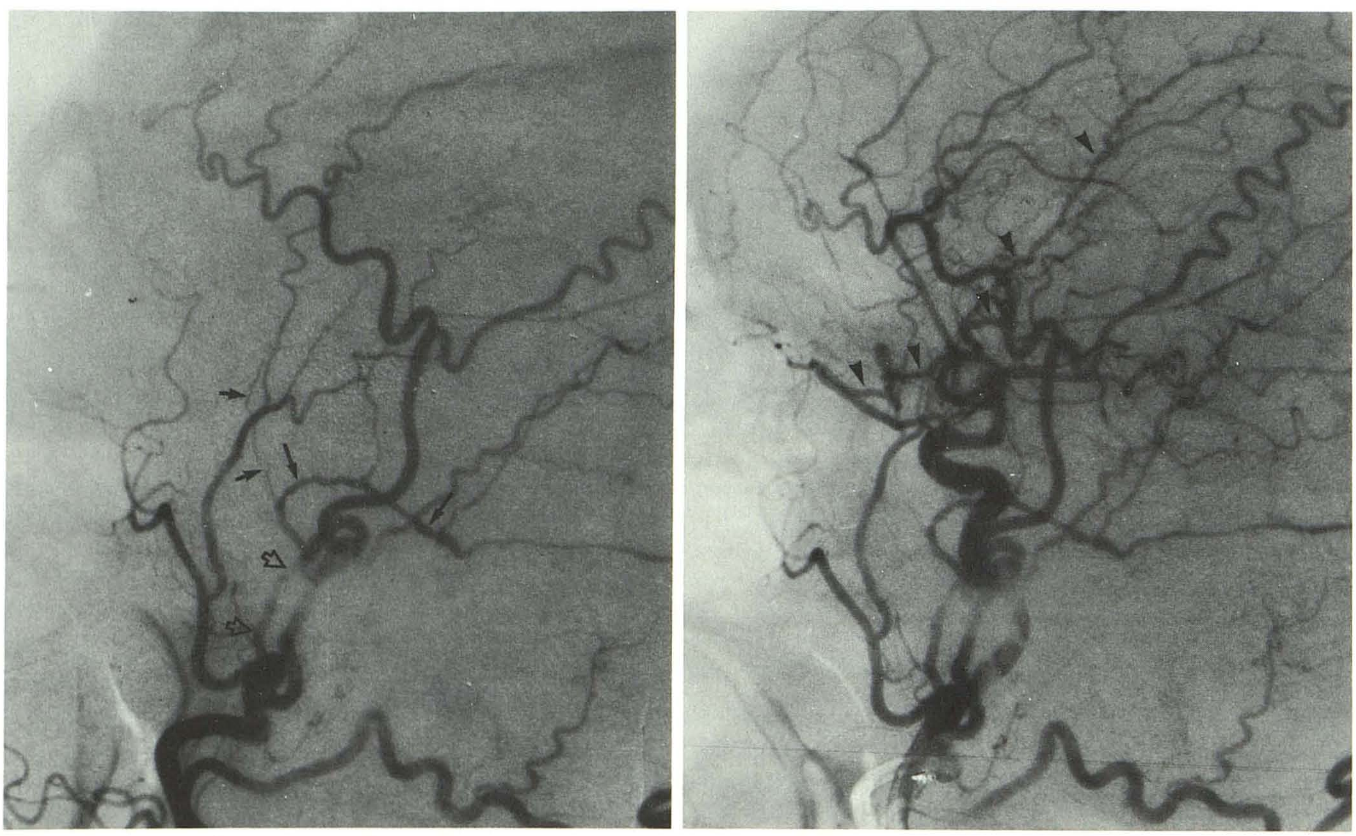

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Fig. 7.—**A**, Selective external carotid artery angiogram. Opacification of enlarged middle meningeal artery (*open arrows*) which otherwise appears normal in its extracranial segment. Intracranially, only its posterior division (*long arrows*) is well opacified. One branch (*short arrows*) may represent rudimentary anterior division. **B**, Common carotid angiogram. Filling of anterior division of middle meningeal artery (*arrowheads*) filling solely via ophthalmic artery.

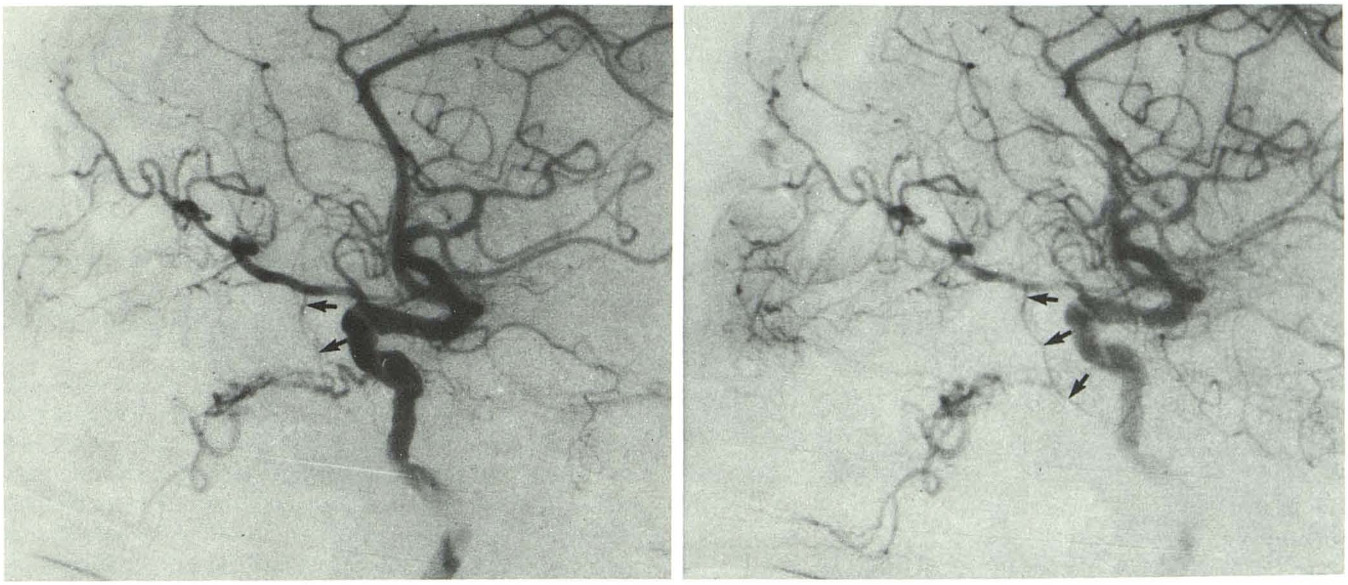

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Fig. 8.—Recurrent meningeal artery. Angiogram. Vessel (recurrent meningeal artery, *arrows*) arises from proximal intraorbital part of ophthalmic artery, which appears to follow retrograde course into middle cranial fossa where it anastomoses with middle meningeal artery. In this case, external carotid artery is occluded and recurrent meningeal artery provides means of collateral circulation to middle meningeal artery.

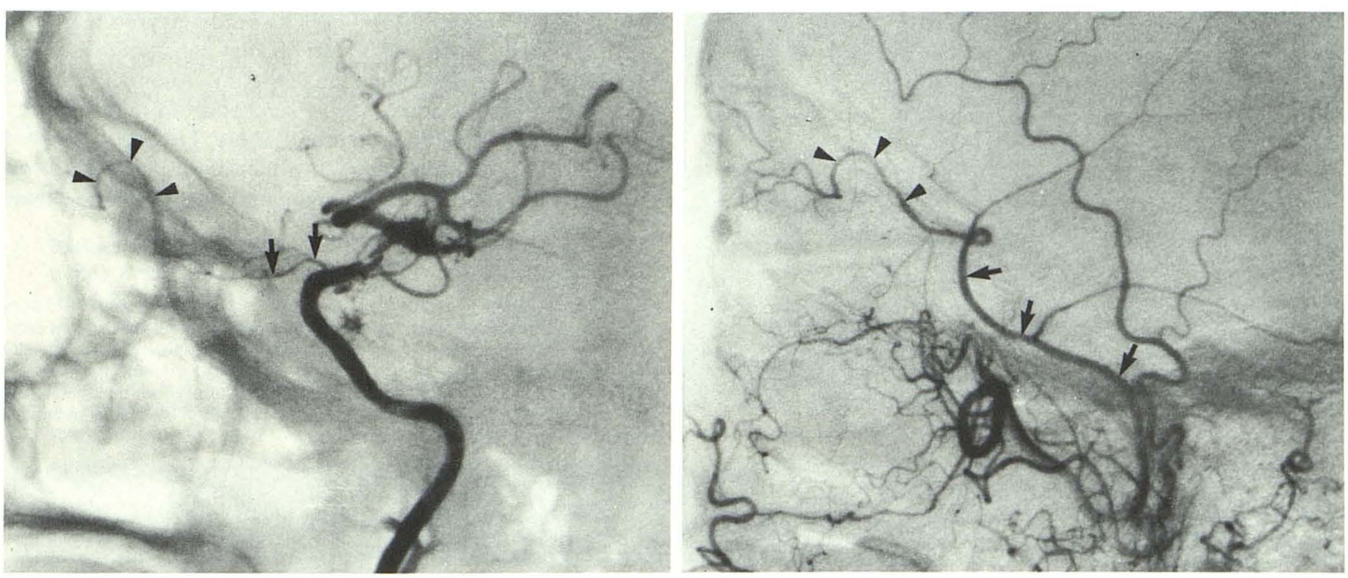

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Fig. 9.—Accessory ophthalmic artery. **A**, Selective injection of hypoplastic internal carotid artery. Opacification of small-caliber ophthalmic artery (*arrows*) including its ocular branches and (in contrast to Fig. 4) faint opacification of one of its orbital branches (*arrowheads* = supraorbital artery) as well. **B**, Selective external carotid angiogram. Better opacification of same orbital branch (*arrowheads*) via middle meningeal artery (*arrows*). Furthermore, in this case, orbital branches of ophthalmic artery are not separated from ocular branches, despite their different embryologic origins and their dual blood supply.

mann [20], it is a branch of the petrous segment of the internal carotid artery that enters the middle ear in close relation to the promontory. It passes through the stapes and then enters the facial canal, from which it exits via a small osseous foramen (stapedial foramen) near the geniculate ganglion. It finally continues between the dura and inner table of the middle fossa and anastomoses with the middle meningeal artery.

Without the use of subtraction technique, the osseous density of the temporal bone masks the presence of this vessel at angiography. Guinto et al. [21] reported for the first time such a case studied angiographically, but not confirmed anatomically. They described the stapedial artery as an anomalous branch of the petrous segment of the internal carotid artery, which in its intracranial course resembled the middle meningeal artery. This vascular network was associated with absence of the ipsilateral foramen spinosum, enlargement of the facial canal, and the presence

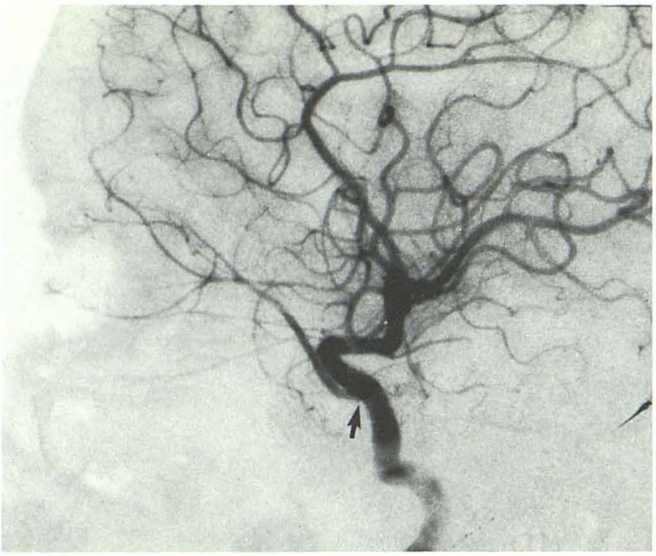

Fig. 10.—Example of ophthalmic artery (*arrow*) arising from extradural part of carotid siphon.

of a stapedial foramen.

But Steffen [22] reported a case in which angiography permitted visualization of an anomalous vessel arising from the petrous segment of the internal carotid artery, which in its proximal course appeared in close relation with the middle ear. At surgery, however, the stapes appeared normally developed and without apparent relation to this vessel. Therefore, it would not seem that this was an example of an authentic stapedial artery. However, since all the intracranial branches of this vessel were also in the distribution of the middle meningeal artery, the possibility of persistence of the stapedial artery must be considered.

We have observed such a vessel (fig. 12) in three cases. In one of these cases, selective external carotid angiography demonstrated a hypoplastic internal maxillary artery network. Selective internal injection opacified the middle meningeal artery as well as some pterygoid branches (anastomosed with the maxillofacial branches) that seemed to arise from the petrous carotid segment. These branches appeared to have a common origin, raising for consideration the persistence of an embryonic stapedial artery, which at a less well differentiated stage retained its connections with both meningeal and maxillofacial branches.

Other origins of the ophthalmic and middle meningeal arteries. The possibility of an ophthalmic artery arising from the external carotid artery, conceived by Hayreh and Dass [5] has never been confirmed to our satisfaction by any anatomic or angiographic observation. Anomalies of the ophthalmic artery origin have been reported in the context of agenesis of the internal carotid artery. Flemming [24] and Lowrey [25] reported cases in which the ophthalmic artery appeared as a branch of the middle cerebral artery. Fisher

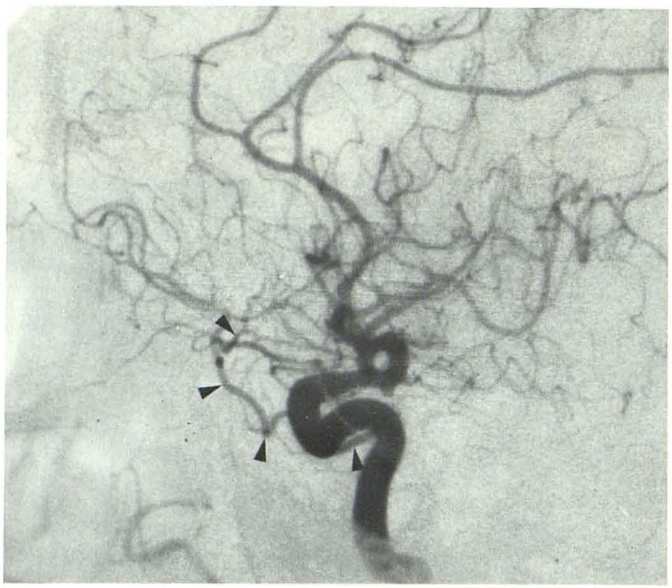

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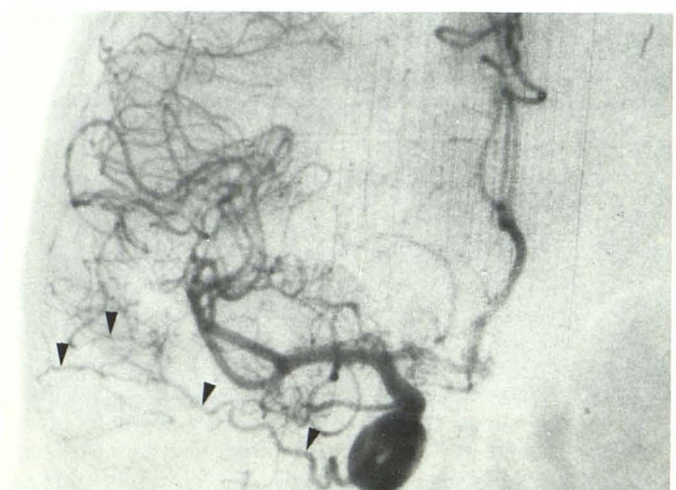
Fig. 11.—Origin of middle meningeal artery from extradural part of carotid siphon. Serial internal carotid angiogram. Course of middle meningeal artery (*arrowheads*) as it arises from precavernous segment is (**A**) initially juxtasellar, for short segment, then **B** and **C** are laterally toward side and top of cranial vault. Reflux of contrast into internal maxillary artery fails to opacify and demonstrate any evidence of extracranial segment of middle meningeal artery.



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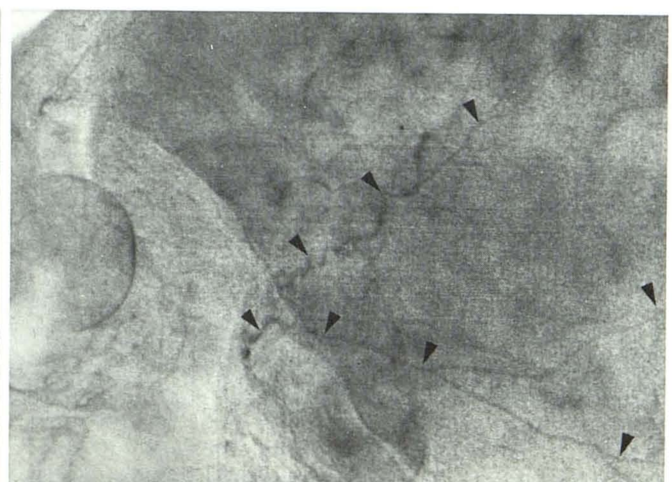

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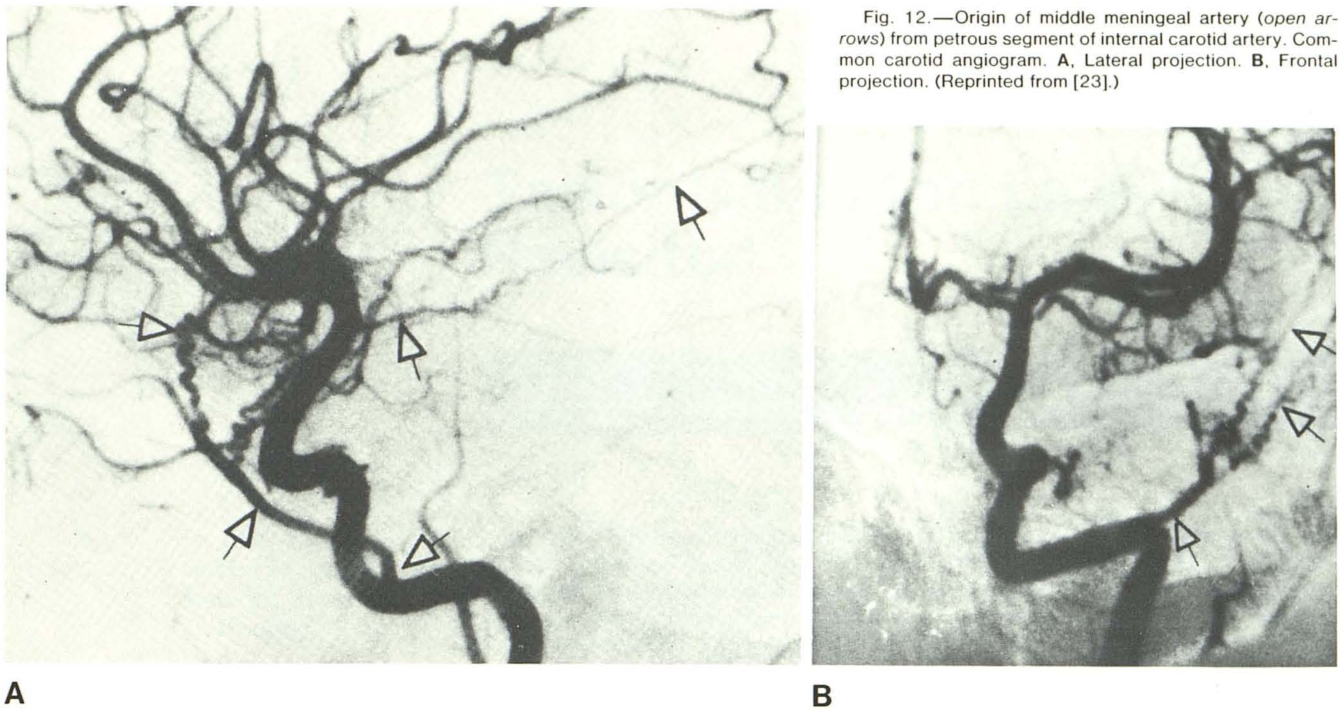

Fig. 12.—Origin of middle meningeal artery (*open arrows*) from petrous segment of internal carotid artery. Common carotid angiogram. **A**, Lateral projection. **B**, Frontal projection. (Reprinted from [23].)

[26] described a case in which the ophthalmic artery arose from the posterior communicating artery. These anomalies, unfortunately, are not satisfactorily documented despite their anatomic descriptions, and perhaps require confirmation.

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