Anat Clin (1982) 3:243–261

ANATOMIA CLINICA

Original Papers

The Internal Carotid Arteries

JP Francke[1], A Macke[1], J Clarisse[2], JC Libersa[3], and P Dobbelaere[2]

[1] Laboratory of Anatomy and Organogenesis, Faculty of Medicine, 1, place de Verdun, F-59045 Lille Cedex, France
[2] Neuroradiology Unit, CHU, 1, Place de Verdun, F-59037 Lille Cedex, France
[3] Department of Dental Pathology and Therapeutics, Faculty of Dental Surgery, place de Verdun, F-59000 Lille, France

Summary. Anatomical characteristics of the internal carotid arteries are detailed in 50 anatomical preparations of frontal, sagittal and transversal sections from subjects aged between 42 and 76 years. The results obtained are compared with those reported in the literature and the following points are emphasized:

Dimensions of the vessels (for the right internal carotid artery, the external diameter in the region of the neck was found to be 5 ± 0.8 mm, the mean length 154.9 ± 13.8 mm. There was no significant difference between left and right arteries).

The variations in its course, with tortuousities at fixed points appearing relatively early in life, and their importance to arterial pathologies.

The principal relationships of the cervical portion (C1), the petrous portion (C2), with the different parts of the ear and the cavernous portion of the artery (C3) in particular, and with the pituitary.

Les artères carotides internes

Résumé. Les caractères des artères carotides internes sont précisés sur 50 préparations anatomiques de sujets âgés de 42 à 76 ans et sur des coupes frontales, sagittales et transversales. Les données recueillies sont confrontées aux observations rapportées dans la littérature en insistant sur:
- la biomètrie des vaisseaux (pour l'artère carotide interne droite, diamètre externe dans la région cervicale moyenne: 5 ± 0.8 mm, longueur moyenne: $154{,}9 \pm 13{,}8$ mm, il n'existe pas de variation significative entre les artères droites et gauches);
- les variations de trajet avec sinuosités fixées relativement précocément et leur importance dans la pathologie artérielle;
- les rapports principaux de la portion cervicale (C1), de la portion pétreuse (C2), notamment avec les différentes parties de l'oreille et de la portion caverneuse (C3), avec l'hypophyse.

Key words: Internal carotid artery – Cervical region – Petrous bone – Cavernous sinus – Pituitary

Although it may appear difficult to shed any original light on existing knowledge of the internal carotid artery (arteria carotis interna) such is the immense number of studies already published, we would like to draw attention to certain points, in particular:

The dimension of the vessels, these measurements having important relevance to the insertion of a coaxial catheter used for the hyperselective injection of the internal carotid system and its branches (Clarisse et al. 1977) with a therapeutic rather than a diagnostic aim in mind.

The variations in dimensions, explaining, together with atherosclerotic lesions, such as those of senescence generally (Clarisse et al. 1979) the dangers and failures of this technique.

The relationships of different portions of the arteries likely to shed light on certain syndromes, or to guide surgery, not only of the cervical portion (Natali et al. 1973; Thevenet 1979), but also of the petrous portion (Paullus et al. 1977) and the cavernous portion (Parkinson 1973).

This study does not concern itself with the collaterals or terminal arteries.

Phylogeny and Ontogeny

The importance of the contribution of the carotid artery to the arterial system of the brain is variable. De Vriese (1905) divided the mammals into those

Offprint requests to: JC Libersa, Laboratoire d'Anatomie et Organogénèse, Faculté de Médecine, 1, place de Verdun, F-59045 Lille Cedex, France

0343-6098/82/0003/0243/$03.80

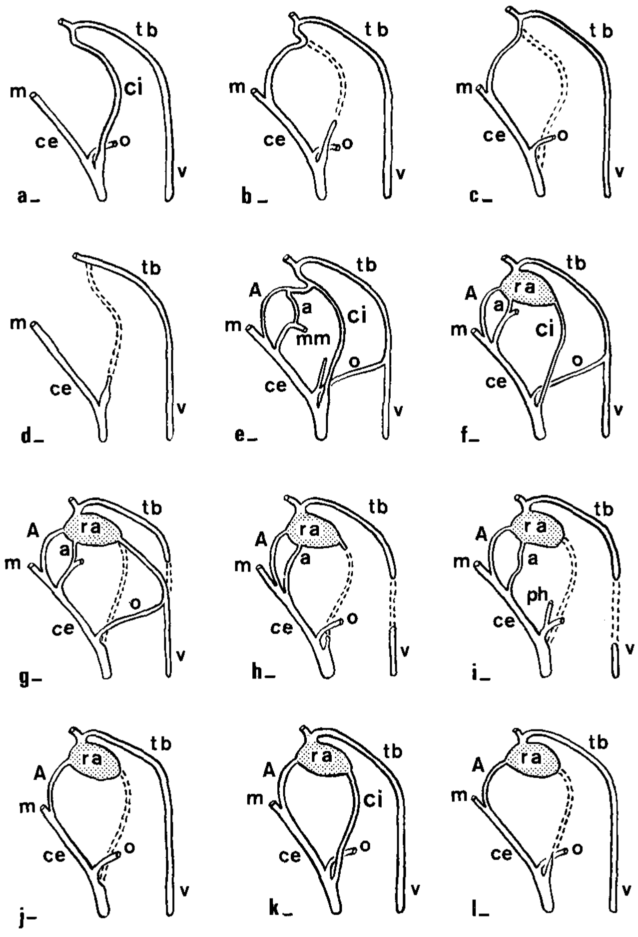


Fig. 1a–l.
The blood supply to the brain in a selection of mammals (modified after Ask-Upmark 1935)

Les voies artérielles d'apport *encéphalique* chez quelques mammifères (d'après Ask-Upmark 1935; modifié)
a Oryctolagus cuniculus; **b** Arctomys marmotta; **c** Cavia porcellus; **d** Rhinolophus hipposideros; **e** Canis familiaris; **f** Sus scrofa; **g** Bos taurus; **h** Ovis aries; **i** Capra hircus; **j** Panthera tigris; **k–l** Felis catus

ra rete mirabile, *ci* a. carotis interna, *ce* a. carotis externa, *ph* a. pharyngea ascendens, *o* a. occipitalis, *m* a. maxillaris, *mm* a. meningea media, *a* ramus anastomoticum, *A* a. anastomotica, *v* a. vertebralis, *tb* a. basilaris

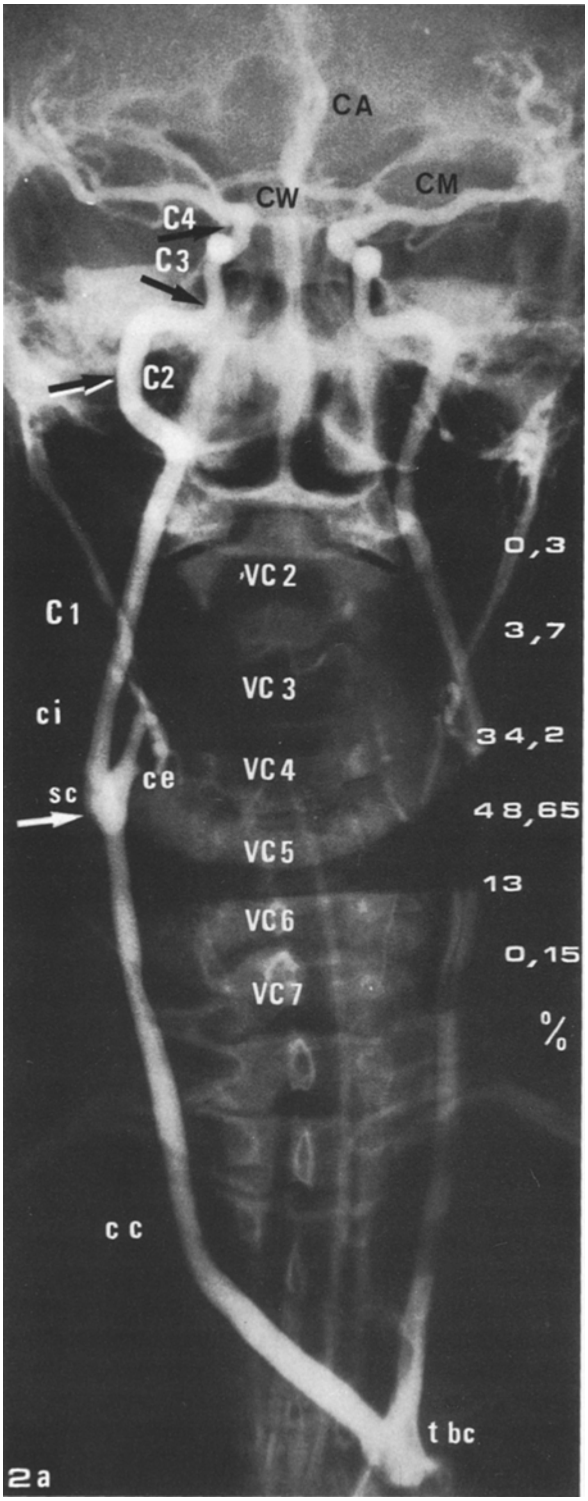
whose carotid supply was predominant (group II), those whose vertebro-basilar supply was predominant (group III), and those in which the contribution of each was about equal (group I). Legait and Racadot (1949) suggested that a third supply might also be important; that of the external carotid system. Furthermore, there is sometimes present in the cavernous recess, a complex arterial formation, that of the rete mirabile caroticum. Whether such a formation exists or not (Fig. 1), two carotid columns always emerge from the roof of the cavenous sinuses. They immediately divide to a rostral and caudal trunk from which the circle of Willis takes its origin in a manner which we have already described in some domestic mammals (1974, 1977). Certainly, as Lazorthes et al. (1976) have recently pointed out, 'the blood supply to the cerebral circulation in man differs from that of the quadruped mammals'. However, comparative anatomy brings to light several situations which bear analogy to the human carotid system, such as internal carotid hypoplasia, atresias, even total absence of the carotids with the development of anastomoses with the external carotid system or even the rete mirabile (Arnould et al. 1967; Du Boulay et al. 1973).

Such arrangements do not seem to occur during human embryogenesis (Lazorthes and Gouaze 1968). As the elegant studies of Streeter (1918), Condon (1922) and Padget (1948) have shown, the carotid system is laid down very early in the embryo. From the 2 mm stage onwards, the ventral plexiform capillary network is in continuity with the rostral extremities of the dorsal aortae. These presegmentary branches form, at a point below the first aortic arch, the primitive internal carotid arteries. The successive development of the first aortic arches and their subsequent involution leads to a lengthening of these branches which, at around the 30th day (4 to 5 mm), appear to arise from the third aortic arches. At this stage, the internal carotid arteries are jointed to the posterior longitudinal neural arteries by the primitive trigeminal acoustic and hypoglossal arteries whose regression begins with the next stage of development. The disappearance of the dorsal aortic segment lying between the third and the fourth aortic arches (ductus caroticus) gives the internal carotid artery its definitive appearance with its first segment formed by the third arch. The complete or partial involution (dorsal or ventral) of the third aortic arch explains, according to Lie (1968), the variations in origin of the internal carotid arteries and certain tortuousities or loops in its cervical portion.

Origin

The internal carotid artery is usually the posterolateral branch of the bifurcation of the common carotid artery (arteria carotis communis).

Although a classical finding (Malacarne 1784), variations in site of origin of the artery are rare. Twenty-nine cases, of which two are bilateral, are to be found in the literature, in which the origin of the aortic arch (arcus aortae) may be either to the left or right or that of the subclavian artery (arteria subclavia) is found on the right side only. The origins of the arteries on the right and the left side in the same subjects are thus always different. They



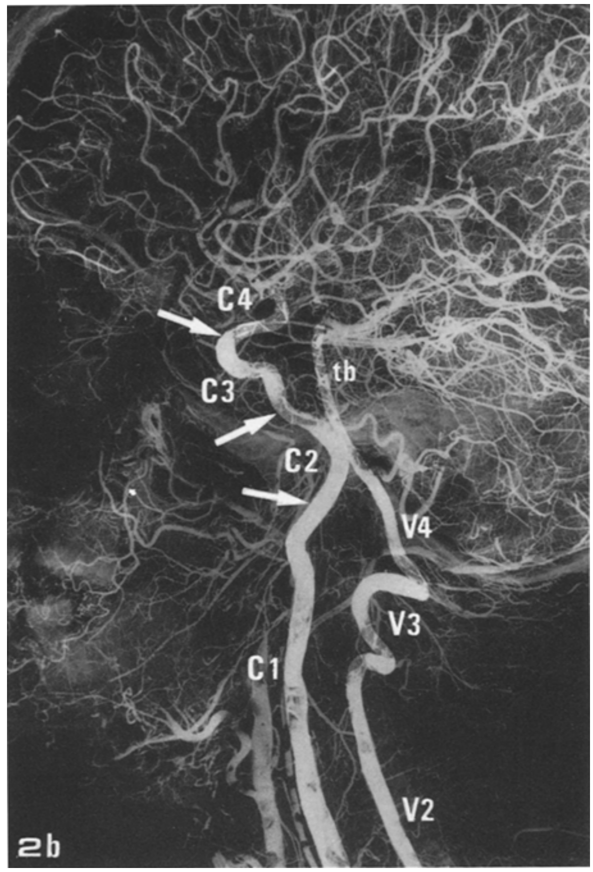


Fig. 2a–b.
Origin and course of the internal carotid arteries (*ci*): **a** in vivo arteriography, frontal view; **b** anatomical preparation, profile

Origine et trajet des artères carotides internes (*ci*): **a** artériographie in vivo de face; **b** préparation anatomique de profil

tbc truncus bicaroticus; *cc* a. carotis communis; *sc* sinus caroticus; *ce* a. carotis externa; *ci* a. carotis interna, *C1* pars cervicalis, *C2* pars petrosa, *C3* pars cavernosa, *C4* pars subarachnoideale; *V2-V3-V4* a. vertebralis; *tb* a. basilaris; *CW* circulus arteriosus cerebri; *CA* a. cerebri anterior; *CM* a. cerebri media; *VC* vertebrae cervicales, *VC2* axis

are frequently accompanied by major abnormalities of the aortic arch.

Again, Smith and Larsen (1979) recently confirmed the level of this bifurcation, already pointed out by numerous authors, among which the following studies in adults are worth noting; Adachi (1928), who found 68% in relation to the fourth cervical vertebra, Lazorthes (1961), who found 48.5% at the same level with 31% above and 20.5% below C4, and Krayenbuhl and Yasargil (1965) whose findings in 658 angiograms are summarised in Fig. 2a). It should be noted that the bifurcation is frequently asymmetrical and that in the child it appears to be slightly higher than in the adult. A few cases of intrathoracic bifurcations have been noted at the level of T1–T2 and even T3 (Vitek and Reaves 1973).

The relationships with the proximal segment of the external carotid artery (arteria carotis externa) are also variable: the initial part of the carotid artery may lie frankly posterior or postero-medially.

The point of bifurcation is often marked by a dilatation, the carotid sinus (sinus caroticus), involving either the whole of the termination of the common carotid artery and the origin of the external and internal carotid arches (type I of Adachi 1928), situated on two of these vessels (type II, III and IV), or simply on one of them (types V, VI and VII). The existence of the sinus modifies the general anatomy of the bifurcation which may make an acute angle, or take on the form of a trident, or may sometimes be intermediate. These different arrangements are important because they may facilitate catheterization or conversely, make it more difficult; furthermore, they determine the channelling of blood through the bifurcation and explain the frequency of particular types of circulatory impairment.

Course and Divisions

Before joining the circle of Willis, the internal carotid artery crosses successively the cervical region, the petrous bone (os temporale pars petrosa), the cavernous sinus and the chiasmatic cistern (cisterna chiasmatis) of the sub-arachnoidal cisterns (cisternae subarachnoideales) Further, the artery may be divided into four segments (Fig. 2) in the same way as may be done for the vertebral arteries (Argenson et al. 1979; Francke et al. 1980). The cavernous (C3) and subarachnoid (C4) portions together correspond to the carotid siphon described by Egas Moniz (1927).

Biometrics

Caliber

The measurements carried out on 50 anatomical specimens at different levels (Fig. 4) show that there is no significant variation between the external diameter of the left and right arteries. The dimensions obtained are similar to those given by Abraham (1973) but smaller than those (7 to 8 mm) of Lazorthes et al. (1976). There is no clear diminution in caliber until after the origin of the ophthalmic artery (arteria ophthalmica). The study in relation to age confirms that arterial aging is accompanied by a tendency for the vessel to enlarge.

The published literature underlines the presence of anomalies such as agenesis, aplasia, hypoplasia and very recently duplication (Killien et al. 1980). Aplasia and agenesis are frequently confused angiographically because both are characterized by absence of opacification. The term agenesis should not be applied (Lancien 1971) except in the absence of vascular vestiges of the carotid canal and stapedian branch. In the case of total or partial aplasia, anatomical examination reveals a vestige in the form of a thin chord without lumen (Lie 1968), and the persistence of a carotid canal of subnormal or minimum caliber (Tondury 1934). These findings seem to confirm the secondary nature of aplasia and are very similar to the findings in mammals. Where hypoplasia is concerned however, there is undoubtedly a major reduction in caliber, although the primary or acquired nature of the anomaly is often difficult to establish (Michel 1972). In all reported cases, the origin of the artery and its initial segment are normal. The anomaly may be bilateral. The most likely mechanism in most cases of agenesis, aplasia and hypoplasia is embryological. Such anomalies are, moreover, frequently accompanied by other malformations. Thus Servo (1977) noted that in 25% of angiographically absent vessels contralateral or basilar aneurysm were present.

Length

We have also detailed the length of each portion of the artery (Fig. 4). The mean length of the whole artery is in the region of 150 mm. There is significant variation with age.

Cervical Portion (C1)

The cervical portion of the internal carotid artery crosses first the bicarotid region, then the posterior sub-carotid space in the retrostyloid region, before reaching the base of the cranium and the carotid canal (canalis caroticus). The principal relationships are illustrated in Fig. 5 and Fig. 9a and b.

The course of the artery in this region is only exceptionally straight, and tortuousities of variable degree are frequently encountered. Thus Lazorthes (1961) described three types: *type A* (30.5%) straight or a little sinuous; *type B* (48.5%) S shaped to a greater or lesser degree (Fig. 6a) with a bend low down in the substyloid region, with an anterior concavity and a bend with posterior concavity, higher up in the retro-styloid, in relation to the lateral mass (massa lateralis) of the atlas; *type C* (21%) with irregular curvature (Fig. 7). The age-related study of 2453 carotid angiographies performed by Krayenbuhl and Yasargil (1965) shows progressive increase in the

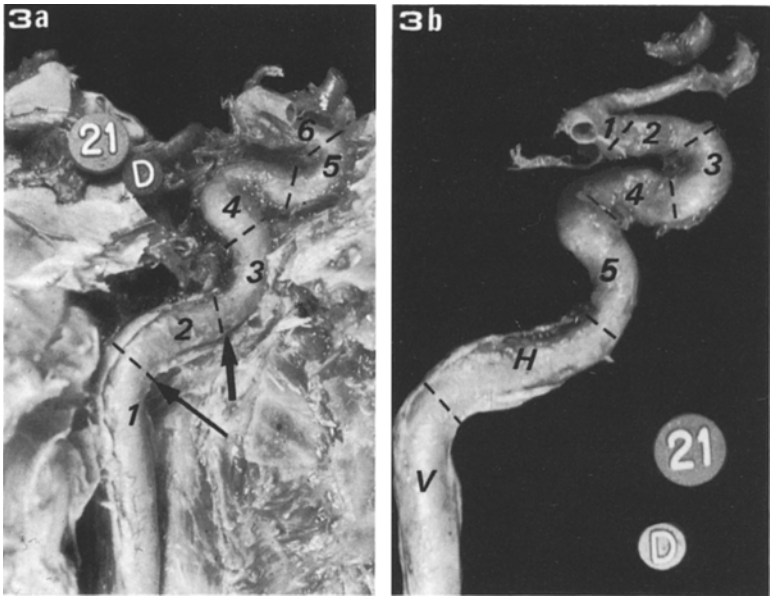
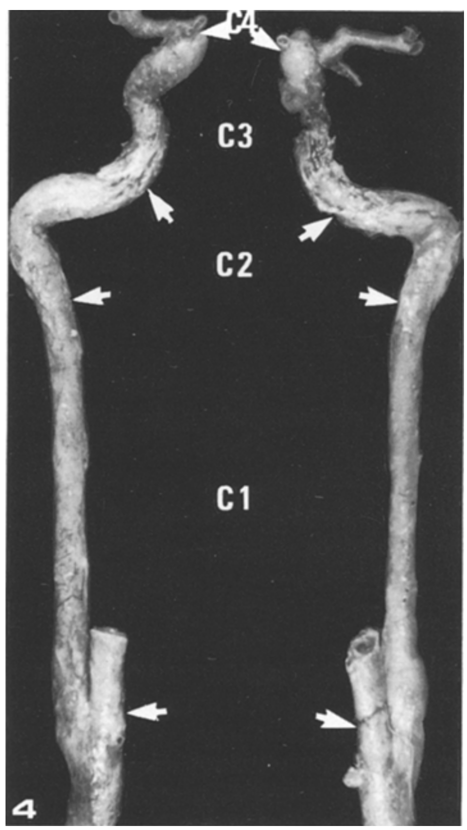


Fig. 3a–b.
Division into segments of the cranial portion of the carotid artery: **a** according to Lazorthes (1961); **b** according to Fisher (1938)

Segmentation de l'artère carotide interne crânienne: **a** selon Lazorthes (1961); **b** selon Fischer (1938)

Left ci		
Length	Diameter	
42.7 ± 4.3	3.7 ± 0.5 4.6 ± 0.6	C4
	5.5 ± 0.5	C3
29.6 ± 2.6	5.8 ± 0.7 5.7 ± 0.7	C2
80.2 ± 10	5.6 ± 0.7 5.1 ± 0.8 6.2 ± 1.4	CI
152.5 ± 12.7		



	Right ci	
	Diameter	Length
C4	3.8 ± 0.5 4.5 ± 0.6	42.4 ± 4
C3	5.6 ± 0.6	
C2	5.9 ± 0.6 5.7 ± 0.8	30.4 ± 2.3
CI	5.8 ± 0.8 5 ± 0.8 6.7 ± 1.3	82.2 ± 11.6
		154.9 ± 13.8

Fig. 4.
External diameter and length of the different portions of the internal carotid arteries (in mm)

Diamètre extérieur et longueur des différentes portions des artères carotides internes (en mm)

C1 pars cervicalis, *C2* pars petrosa, *C3* pars cavernosa, *C4* pars subarachnoideale

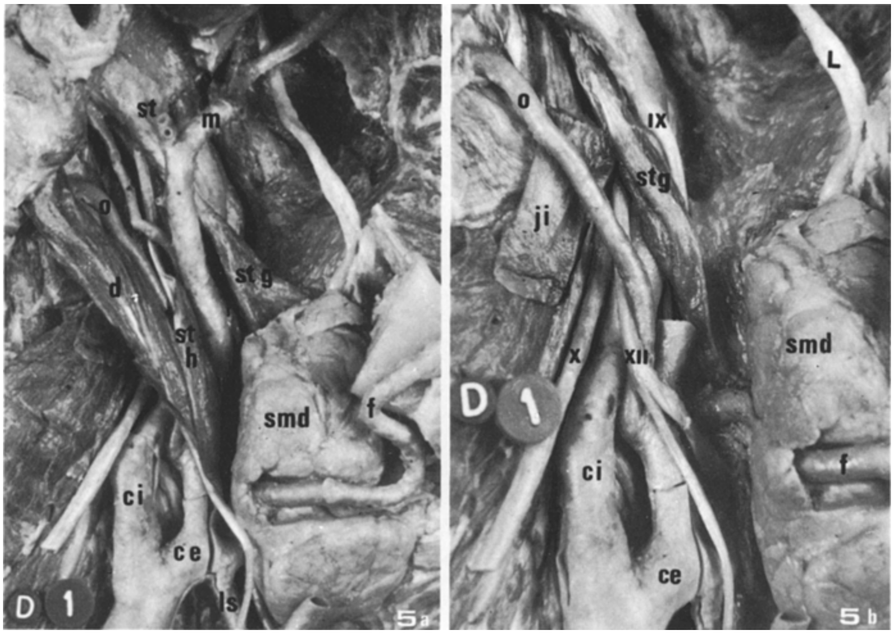


Fig. 5a–b
Relations of the cervical portion of the internal carotid artery (right-sided preparation, profile)

Rapports de la portion cervicale (Préparation droite en vue latérale)

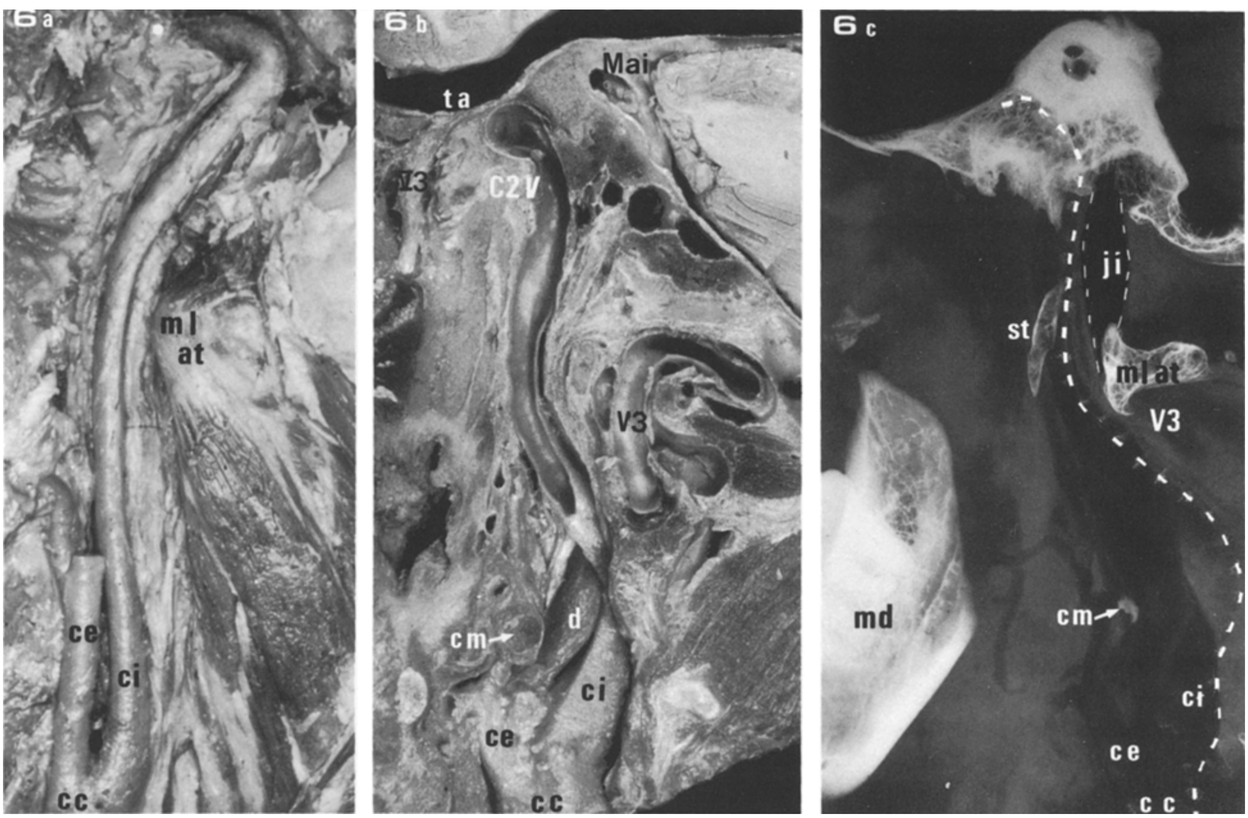
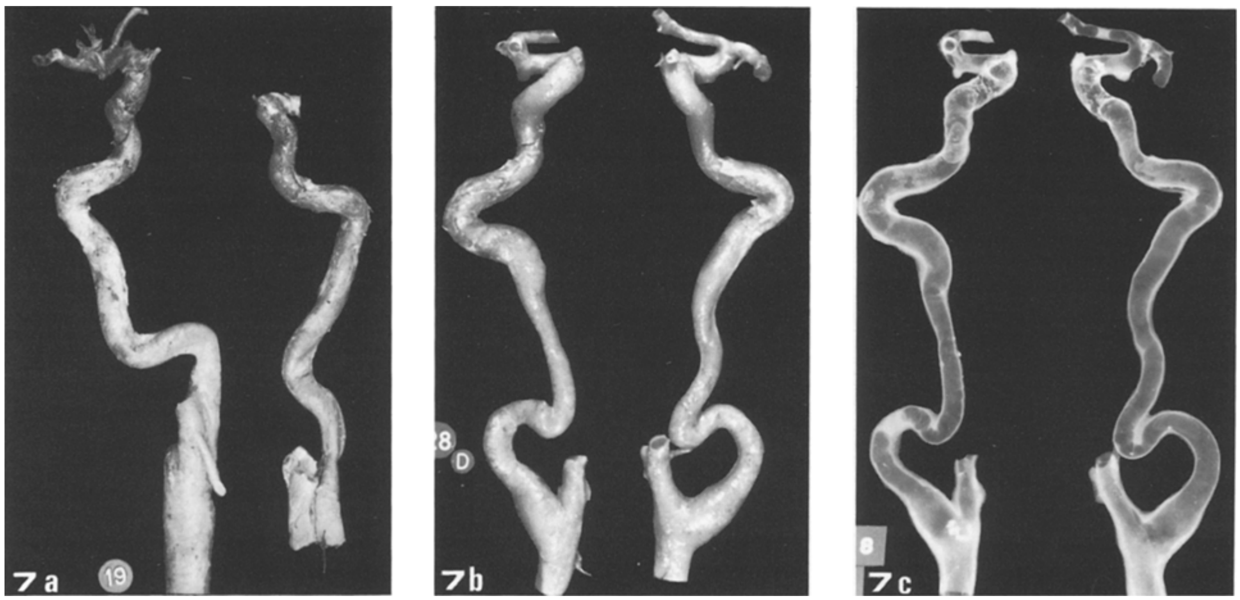


Fig. 6a–c
Relationship with the digastric muscle (*d*), the styloid process (*st*) and the transverse process of the lateral mass of the atlas (*ml at*): **a** left lateral view; **b** medial view of a right sagittal section; **c** microradiography of the preceding section, the internal jugular vein (*ji*) and the posterior border of the internal carotid artery being indicated by a dotted line

Rapports avec le muscle digastrique (*d*), l'apophyse styloïde (*st*) et l'apophyse transverse de la masse latérale de l'atlas (*ml at*): **a** vue latérale gauche; **b** vue médiale d'une coupe anatomique sagittale droite; **c** microradiographie de la coupe, la veine jugulaire interne (*ji*) et le bord postérieur de l'artère carotide interne étant marqués par une ligne pointillée

ci a. carotis interna; *ce* a. carotis externa, *ls* a. laryngea superior, *f* a. facialis, *o* a. occipitalis, *m* a. maxillaris; *V3* a. vertebralis; *ji* v. jugularis interna; *V3* n. mandibularis, *L* n. lingualis, *IX* n. glossopharyngeus, *X* n. vagus, *XII* n. hypoglossus; *smd* glandula submandibularis; *st* processus styloideus; *ml at* atlas, massa lateralis; *md* mandibula, *cm* os hyoideum, cornu majus; *sth* m. stylohyoideus; *stg* m. styloglossus, *d* m. digastricus; *ta* tuba auditiva



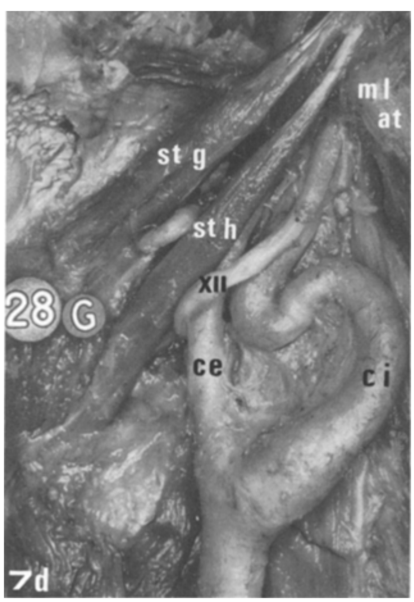


Fig. 7a–d
Variations in the cervical portion of the internal carotid artery: **a** retropharyngeal sinuosity particularly marked on the right; **b, c, d** symmetrical looping of the prestyloid segment

Variations de la portion cervicale de l'artère carotide interne: **a** tortuosité rétropharyngée surtout marquée à droite; **b, c, d** boucles symétriques du segment préstylien

ci a. carotis interna; *ce* a. externa; *sth* m. stylohyoideus, *stg* m. styloglossus; *XII* n. hypoglossus; *ml al* atlas, massa lateralis

curvature of the artery and increase in its length. These changes result from an adaptation to movements of rotation of the head. Thus, as Lazorthes et al. (1971) have shown, the artery is held firmly in its initial portion by the sterno-cleido-mastoid muscle (m. sternocleidomastoideus) and above all by the anterior belly (ventor anterior) of the digastric muscle (m. digastricus), which may compress the artery during ipsilateral movements (Fig. 6b and c). The artery is subsequently tethered laterally by the styloid diaphragm (Figs. 5 and 6c) and the styloid process (Figs. 8 and 9b) and it may be trapped by the transverse process (ala atlantis) of the lateral mass of the atlas during the controlateral movements of rotation. This latter movement tends to compress the internal carotid artery and squeeze the internal jugular vein (v. jugularis interna).

Weibel (1965) distinguished amongst the more obvious deformations three types which have since been confirmed by Thevenet (1979): type I 'tortuosity' type II 'coiling or buckling', either of congenital origin or secondary to aging of the artery with atherosclerosis often bilateral and symmetrical, sometimes incomplete and situated in the proximal sub-styloid segment of the artery (Fig. 7b and d), frequently complete and situated high up; type III: 'kinking' (Fig. 8)

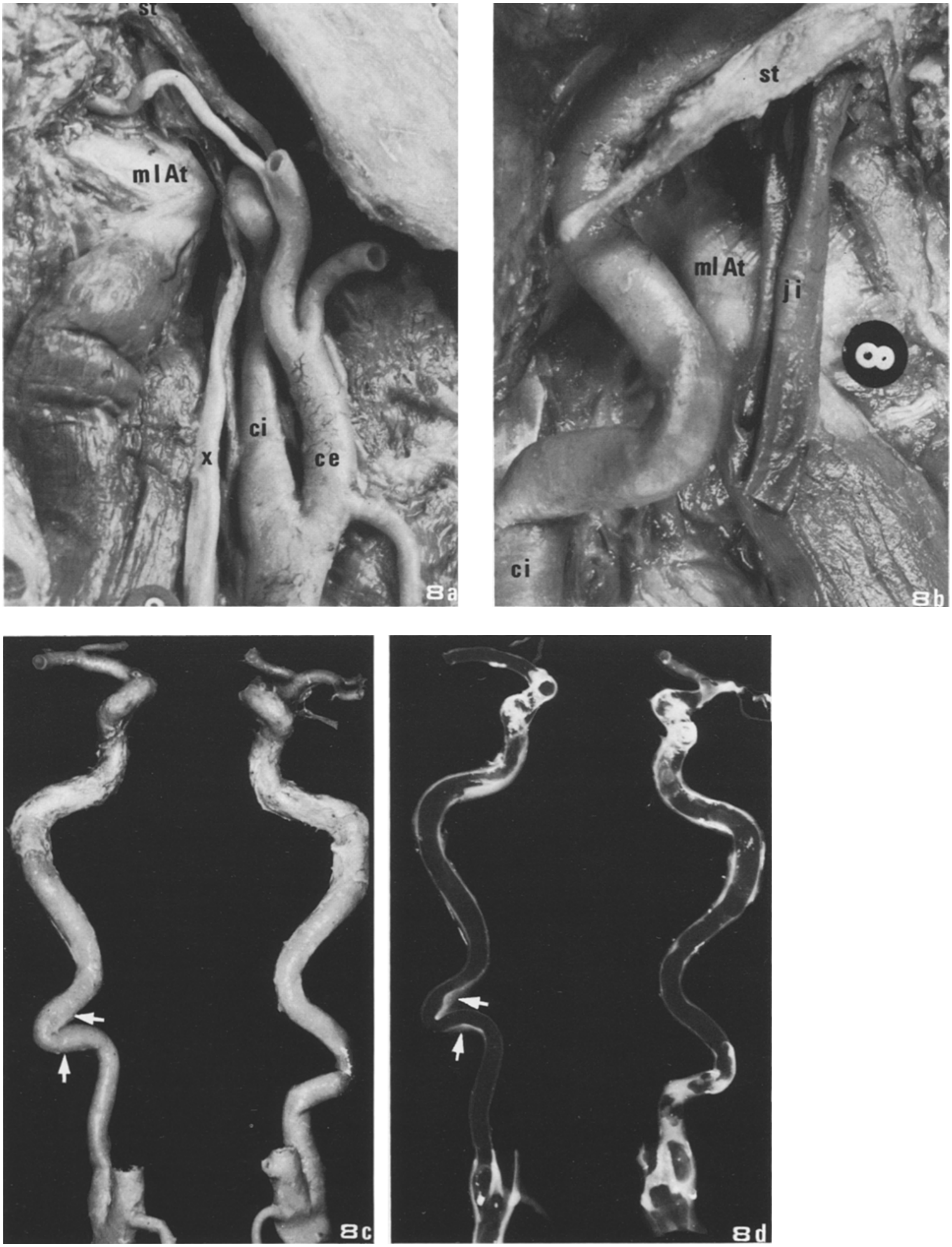


Fig. 8a–d
Kinking of the cervical portion of the right (**a**) and left (**b**) internal carotid arteries, relationships with the lateral mass of the atlas and the styloid process after ablation of the stylo-digastric fascia

Plicatures de la portion cervicale des artères carotides internes droite (**a**) et gauche (**b**), rapports avec la masse latérale de l'atlas et l'apophyse styloïde après ablation du rideau stylo-digastrique

ci a. carotis interna ; *ce* a. carotis externa ; *ji* v. jugularis interna ; *st* processus styloideus ; *ml at* atlas, massa lateralis ; ↗ dépots athéromateux

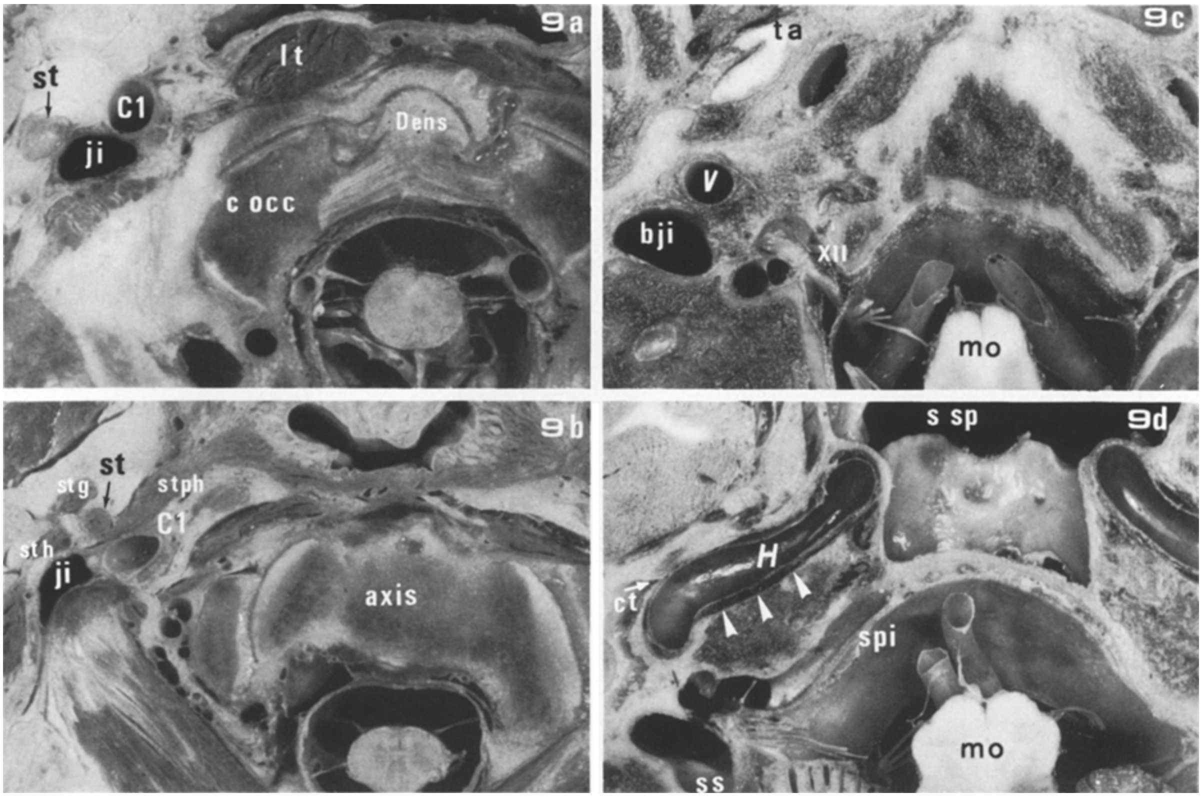


Fig. 9a–d
Transverse sections of the atlanto-axial junction (**b** inferior view), of the craniovertebral junction (**a** inferior view), through the vertical segment (*V*) of the carotid canal and through the canals of the hypoglossal nerves (**c** superior view), through the horizontal segment (*H*) of the carotid canal (**d** superior view)

Coupes transversales de la jonction atlanto-axoïdienne (**b** vue inférieure), de la jonction craniovertébrale (**a** vue inférieure), par le segment vertical (*V*) du canal carotidien et par les canaux des nerfs hypoglosses (**c** vue supérieure), par le segment horizontal (*H*) du canal carotidien (**d** vue supérieure)

C1 a. carotis interna, pars cervicalis; *ji* v. jugularis interna, *ss* sinus sigmoideus, *bji* bulbus venae jugularis superior, *spi* sinus petrosus inferior; *st* processus styloideus;; *c occ* condylus occipitalis; *s sp* sinus sphenoidalis; *c t* cavum tympani, ↗ ostium tympanicum tubae auditivae; *mo* medulla oblongata; *XII* n. hypoglossus; *lt* m. longus capitis, *sth* m. styhyoideus, *stg* m. styloglossus, *stph* m. stylopharyngeus

Intermediate and mixed forms are likewise encountered. The anatomical and microradiographical studies of Macke-Ribet (1978) confirm the lengthening and the progressive dilatation of the artery throughout life, often accompanied by a thinning of its walls. We have also recently studied the contribution of aging and of atherom to arterial anomalies, and their accentuation with age (Clarisse et al. 1979).

The surgical approach to the carotid bifurcation and cervical (C1) portion is undertaken by a "pre-sternocleidomastoid route in which the skin incision curves up and behind the base of the mastoid process (processus mastoideus) and, according to Thevenet (1979), is to be preferred to the retro-sternomastoid route 'which does not provide access to the base of the cranium'. The retro-styloid space is reached by a temporary section of the digastric muscle and of the base of the styloid process which together with the styloid stumps is inclined backwards.

The Petrous Portion (C2)

The petrous portion of the internal carotid artery has a mean length of approximately 30 mm and external diameter of around 5.8 mm (Fig. 4). It joins the carotid canal. It has two portions, the first vertical and ascending (V) the second horizontal (H), oblique forwards and medially, and separated by a right angled bend. In the petrous bone, the arterial wall is poor in elastic fibers and the tunica muscularis is classically very thin. The artery is surrounded by a periostial sheath which is adherent to the periphery of the opening of the carotid canal and in continuity at the apex of the petrous bone with the periosteal

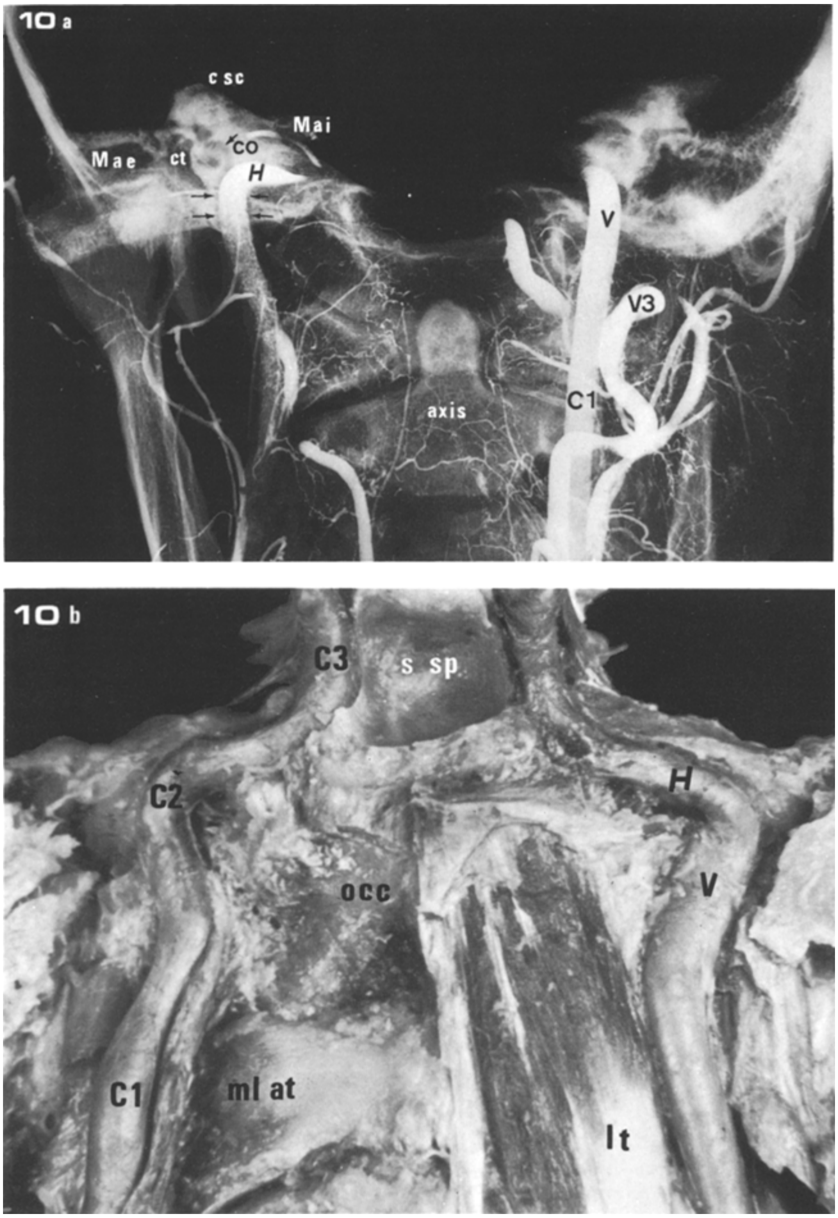


Fig. 10a–b
Course of the internal carotid artery at the base of the cranium: **a** relationship with the different parts of the ear radiographically in the frontal plane; **b** anterior view of a preparation of the cranio-vertebral junction

La traversée de la base du crâne: **a** rapports avec les différentes parties de l'oreille sur la radiographie d'une coupe frontale; **b** vue antérieure d'une préparation de la jonction cranio-vertébrale

C1 pars cervicalis, *C2V* et *C2H* pars petrosa, *C3* pars cavernosa; *V3* a. vertebralis; *Mae* meatus acusticus externus, *ct* cavum tympani, *csc* ductus semicirculares, *co* cochlea, *Mai* meatus acusticus internus; *ml at* atlas, massa lateralis, *occ* os occipitale, *s sp* sinus sphenoidalis; *lt* m. longus capitis

tissue covering the floor of the cavernous sinus and with the fibrous collar of the Princeteau. This sheath, which carpets the walls of the canal, adheres to the vertical segment of the artery (C2V). The artery is likewise protected from the walls of the canal by a venous plexus; the plexus of Mellinger, in continuity endocranially with the cavernous sinus and exocranially with the inferior petrosal sinus (sinus petrous inferior) and the jugular bulb (bulbus venae jugularis superior). It does not, however, inpede the surgical approach. On the surface of the artery runs the carotid branch, which divides in the region of the acute angle into two trunks.

In this portion, the artery lies in close relation with the cavities of the middle ear, the facial nerve (n. facialis) and the trigeminal nerve (n. trigeminus). The recent publication by Paulus et al. (1977) provides a remarkably detailed description of these structures. The vertical segment is related anteriorly to the Eustachian tube (tuba auditiva) (Fig. 6b) and laterally to the hypotympanic recess (Fig. 10). The internal carotid artery is separated from the tympanic cavity (cavum tympani) by a bony plate of variable thickness. This plate may however be incomplete or even absent, the artery thus projecting into the tympanic cavity and simulating a tumor of the middle ear. The artery in such cases is thus very vulnerable during surgical trepanation of the middle ear, or may be

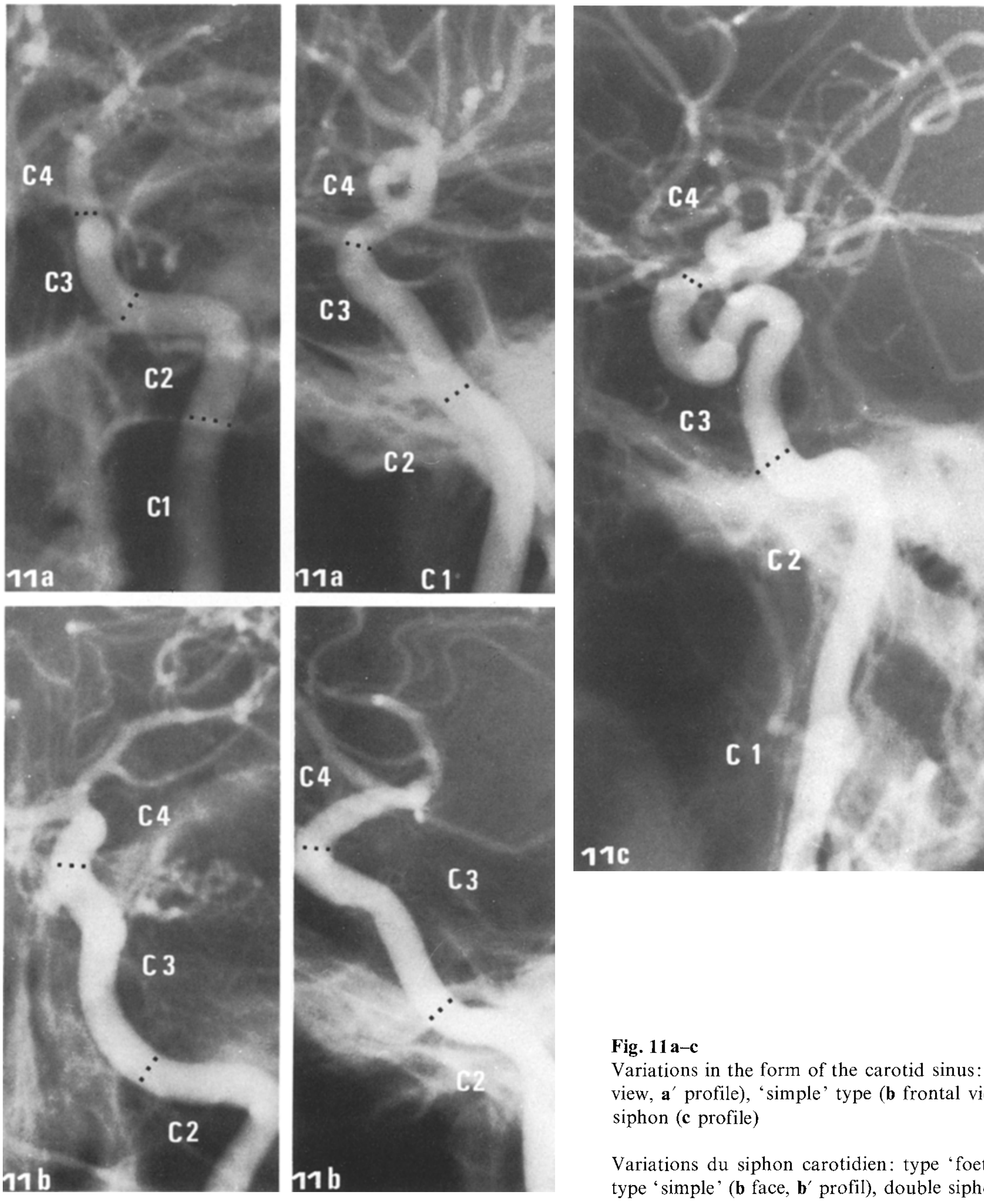


Fig. 11a–c
Variations in the form of the carotid sinus: 'fetal' type (**a** frontal view, **a′** profile), 'simple' type (**b** frontal view, **b′** profile), double siphon (**c** profile)

Variations du siphon carotidien: type 'foetal' (**a** face, **a′** profil), type 'simple' (**b** face, **b′** profil), double siphon (**c** profil)

damaged by extension of an otitis media. Lapayowker (1971) emphasized the need to localize the course of the artery very carefully. On X-rays taken in the frontal plane, the vertical segment of the artery always lies medial to a perpendicular drawn laterally to the vestibule. On the other hand, when it projects into the middle ear (auris media), the line of the artery crosses this perpendicular as confirmed by Glasgold (1972). The Eustachian tube and the canal of the tensor tympani muscle are situated anteriorly, parallel to the horizontal segment (Fig. 9c). The Eustachian tube is separated from the carotid canal by a fine bony lamella (0.1 to 0.3 mm in 56% of the dissections reported by Paullus et al. 1977), replaced by a simple connective tissue wall in 6%, so that catheterization of the artery at this point must be undertaken with utmost care. The cochlea is situated postero-superiorly (Figs. 6c and 10a) to the bend in the artery, at a mean distance of 2.1 mm, while the geniculate ganglion is more frequently situated postero-laterally, at a distance of between 3 and 13 mm. As far as the middle cranial fossa (fossa cranii media) is concerned, Paullus et al. (1977) point out that the artery may be exposed over some 10 mm in its horizontal segment by simple trepanation, the bony lid often being papery thin, or even absent with the artery in this case lying immediately sub-durally. The great superficial petrous nerve (n. petrosus major) is an important landmark during such an operation. It runs parallel to the anterior margin of the horizontal segment and above it. In its terminal segment, the internal carotid artery lies in relation to Meckel's diverticulum (cavum trigeminale), which it crosses (Fig. 12a) and lies medially (Fig. 12a) before joining the cavernous sinus at the apex of the petrous bone, in relation to the foramen lacerum.

Following its discovery by Paullus et al. (1977), Fish (1980) has reaffirmed the importance of the petrous portion of the artery when an arterial bridge is being constructed or when the middle cerebral fossa or even the clivus is to be approached surgically. The latter operation necessitates resection of the mandibular condyle (processus condylaris) or its displacement to one side, and trepanation of the middle ear and redirection of the facial nerve. It is also relevant to cases of aneurysm of the vertical segment or more rarely of the horizontal segment (Anderson 1972).

Intracranial Portion of the Internal Carotid Artery

Moniz (1927) applied the term carotid syphon to the part of the internal carotid artery lying within the cavernous sinus (C3) and its subarachnoid termination (C4). It normally has two elbow bends (Figs. 11 and 15a) which occur not only in the sagittal plane but transversally as well (Figs. 12f and 14a): a bend situated posteriorly concave antero-inferiorly is related medially to the quadrilateral lamina (dorsum sellae) and to the floor of the sella turcica; the second bend is anterior, has a postero-superior concavity and laterally lies in contact with the anterior clinoid process (processus clinoideus anterior). The varying acuteness of these bends give rise to many different types of siphons, their form having been studied in greatest detail by Lazorthes et al. (1961) in 224 arteriographies, by Dilenge (1961), Jovanocic (1971) in 270 preparations from adults, infants, and fetuses and by Harwood (1976) in the child. We would like to emphasize the fundamental types (Fig. 11): the 'fetal' type is rare in the adult but was present in 80% of the fetuses described by Jovanovic (1971); the 'simple' type is the classic form found in the adult (70%); the 'double siphon' which is only except ionally found in the fetus (4%) (Jovanovic 1971). These variations only serve to confirm the observations of Krayenbuhl and Yasargil (1965), who remarked upon the increasing complexity which occurs with age, and the description of the siphon by Hasso (1975) who stressed the notion of evolving complexity.

The Cavernous Portion (C3)

We only have space to look at the overall descriptions in the literature concerning this portion of the artery which is associated both with the cavernous sinus and the sella turcica. Among the principal published studies are those of Taptas (1949), Bonnet (1955), Bedford (1966) and Patouillard (1969). In addition, the work of Rabischong and Vignaud (1974) and of Harris and Rhoton (1976) bring into perspective the particular problems associated with this region.

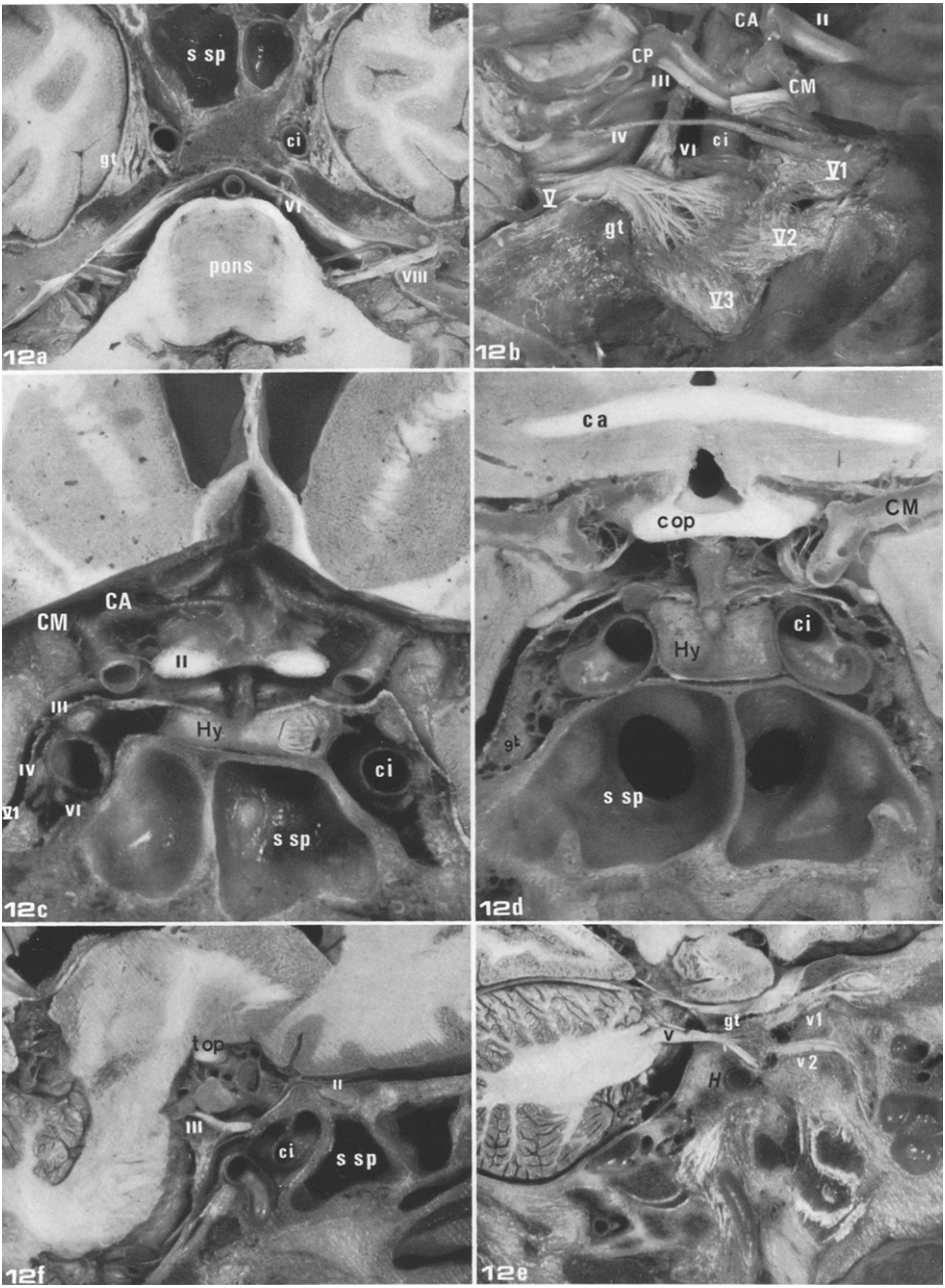
The Venous Relationships

The cavernous sinusses are in continuity posteriorly with the carotid canals, lead forward into the orbital cavities (orbitae) and circumscribe the sella turcica. The internal carotid arteries occupy the major part of these dural recesses (Figs. 12c, d, f and 15a). The cavernous sinus is a 'venous plexus lined with epithelium which penetrates the interstices of the sinus and its various arterial and nervous structures' (Rabischong et al. 1974b). There are within it three venous spaces (Harris and Rhoton 1976): an antero-inferior space in the concavity of the first bend in the carotid artery, which is crossed by the 6th cranial nerve (n. abducens) and which leads to the anterior venous confluents and sphenoidal fissure (fissura orbitalis superior); a postero-superior (Fig. 15a) and medial

Fig. 12a–f
The carotid siphon: **a** transverse cut as the artery enters the cavernous sinus; **b** relationship to nerves; **c, d** sections in the frontal plane; **e, f** sections in the sagittal plane

Le siphon carotidien: **a** coupe transversale à l'entrée dans la loge caverneuse; **b** rapports nerveux; **c, d** coupes frontales; **e, f** coupes sagittales

ci a. carotis interna, *CA* a. cerebri anterior, *CM* a. cerebri media, *CP* a. cerebri posterior; *II* n. opticus, *c op* chiasma opticum, *III* n. oculomotorius, *IV* n. trochlearis, *VI* n. abducens; *V* n. trigeminus, *gt* ganglion trigeminale, *V1* n. ophthalmicus, *V2* n. maxillaris, *V3* n. mandibularis; *ca* commissura anterior, *Hy* hypophysis; *ssp* sinus sphenoidalis


s sp
ci
gt
VI
pons
VIII
12a
CA
II
CP
III
CM
IV
VI
ci
V1
V
gt
V2
V3
12b
CA
CM
II
III
Hy
IV
ci
V1
VI
s sp
12c
ca
CM
cop
ci
Hy
gt
s sp
12d
top
II
III
ci
s sp
12f
gt
v1
v
v2
H
12e

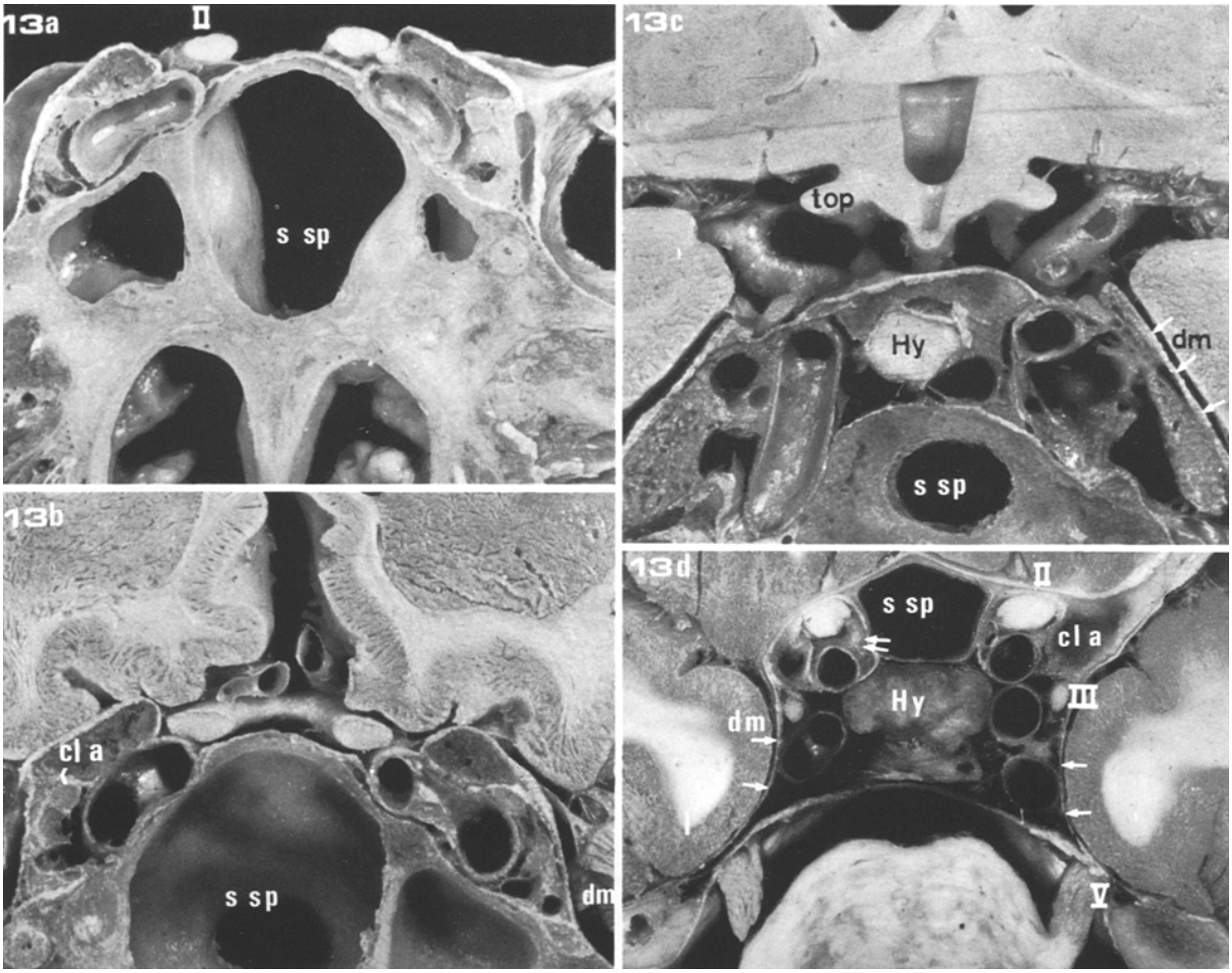


Fig. 13a–d
Sections of the cavernous sinus: **a, b** frontal rostral cuts through the anterior bend of the internal carotid artery, **c** frontal caudal cut showing the subarachnoid (supracavernous) portion, **d** transverse cut

Coupes de la loge caverneuse: **a, b** coupes frontales rostrales par le coude antérieur de l'artère carotide interne; **c** coupe frontale caudale et mise en évidence de la portion supracaverneuse subarachnoïdienne; **d** coupe transversale

dm dura mater; *cla* processus clinoideus anterior; *ssp* sinus sphenoidalis; *Hy* hypophysis, *II* n. opticus, *top* tractus opticus, oculomotorius, *trigeminus*, ↗ ↗ a. ophthalmica

space (Fig. 12c, d) of variable size determined by the relationships of the internal carotid artery with the pituitary gland and sphenoidal sinus. In hemodynamic terms, the existence of two venous channels is important; an anterior which drains the ophthalmic and cortical areas, and a posterior which drains into the superior and inferior petrosal sinuses. Theron (1974) believes that there are two parallel flows between these channels, from the internal carotid artery on both sides: ophthalmic flow and the external cortical flow. The two cavernous sinuses are joined by the intercavernous sinus (sinus intercavernosi) and the anterior, inferior and posterior transverse sinuses (Delvert et al. 1979).

Classically, the arrangement of the sinuses as a group forms a kind of shock absorbing system around the internal carotid artery, which not only absorbs the arterial pulsation but also favors venous return by the pulsating action of the artery on the veins (Bellocq 1925), Rabischong et al. (1974a) have confirmed this arrangement experimentally, and shown that the venous drainage is preferentially ophthalmic.

Relationships to the Nerve

Apart from the external ocular motor nerve, which is in contact with the artery, and has the appearance

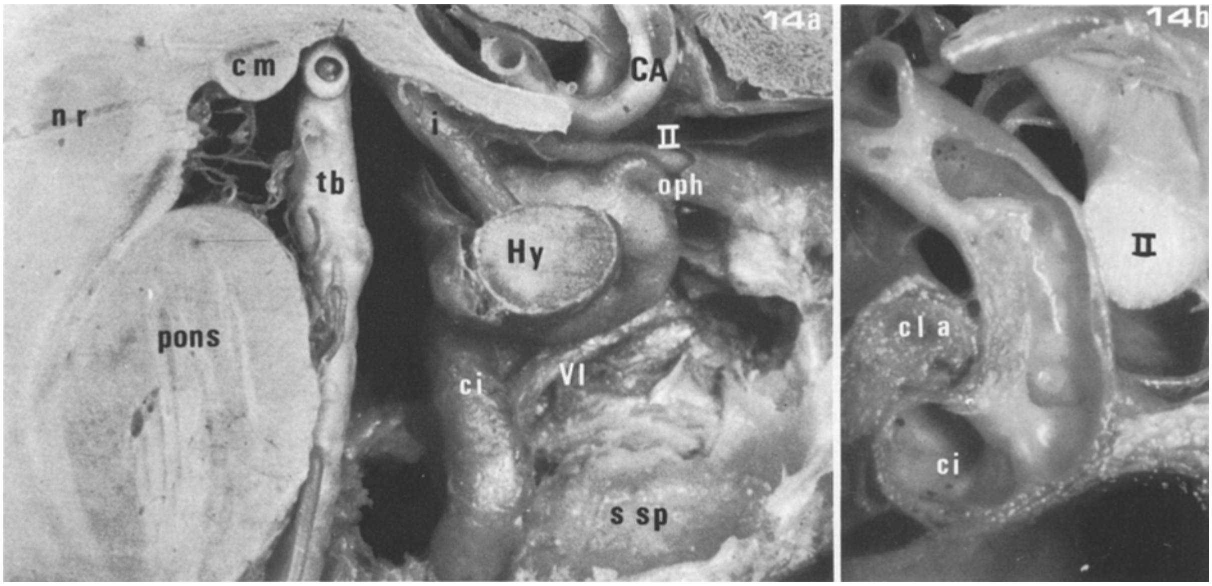
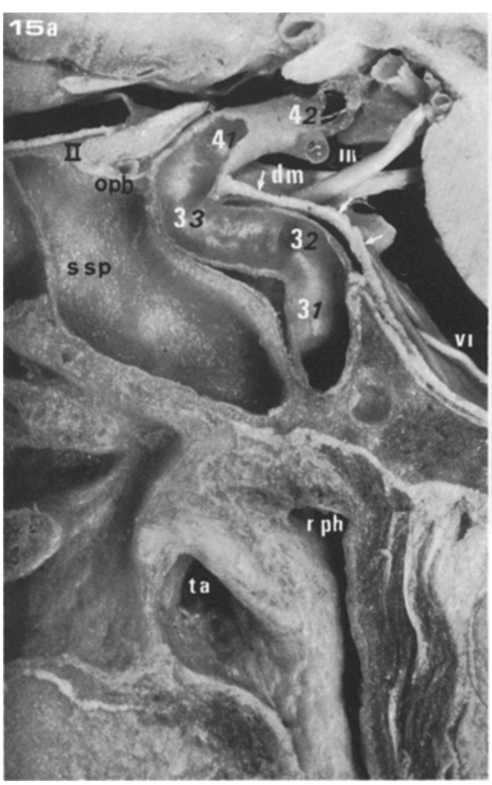


Fig. 14a and b
Relationship of the carotid siphon: **a** medial view of a paramedian sagittal cut; **b** emergence of the cavernous sinus, section taken in frontal plane

Rapports du siphon carotidien: **a** vue médiale d'une coupe sagittale paramédiane; **b** émergence du sinus caverneux en coupe frontale

ci a. carotis interna, *oph* a. ophthalmica, *CA* a. cerebri anterior, *tb* a. basilaris; *II* n. opticus, *VI* n. abducens, *Hy* hypophysis, *i* infundibulum, *cm* corpus mamillare, *nr* nucleus ruber; *cla* processus clinoideus anterior



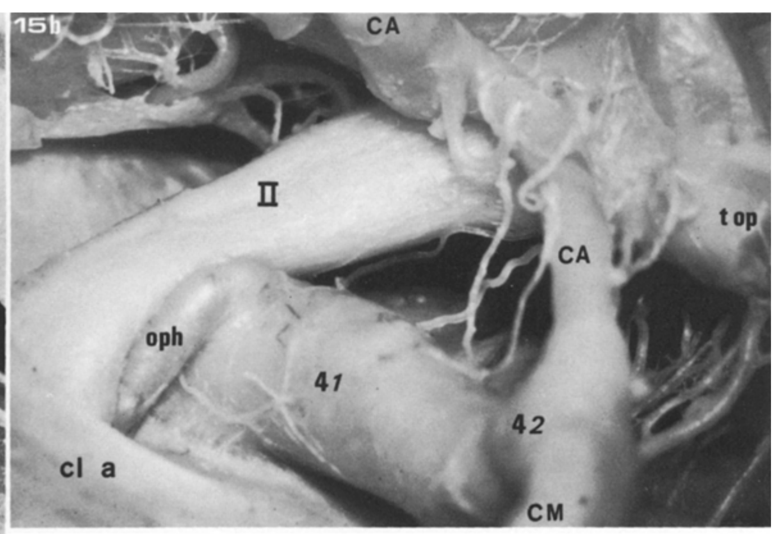


Fig. 15a and a
Sagittal section of the carotid syphon (**a**) and sub-arachnoidi portion of the internal carotid (**b**)

Coupe sagittale du siphon carotidien (**a**) et carotide interne sous-arachnoïdienne (**b**)

3*1* segment paraganglionnaire ou présellaire, 3*2* et 3*3* segments juxtasellaires, 4*1* segment supracaverneux, 4*2* segment terminal, *CA* a. cerebri anterior, *CM* a. cerebri media, *oph* a. ophthalmica; *II* n. opticus, *top* tractus opticus, *III* n. oculomotorius, *VI* n. abducens; *dm* dura mater; *cl a* processus clinoideus anterior; *ssp* sinus sphenoidalus; *rph* recessus pharyngeus; *ta* ostium pharyngeum tubae auditivae

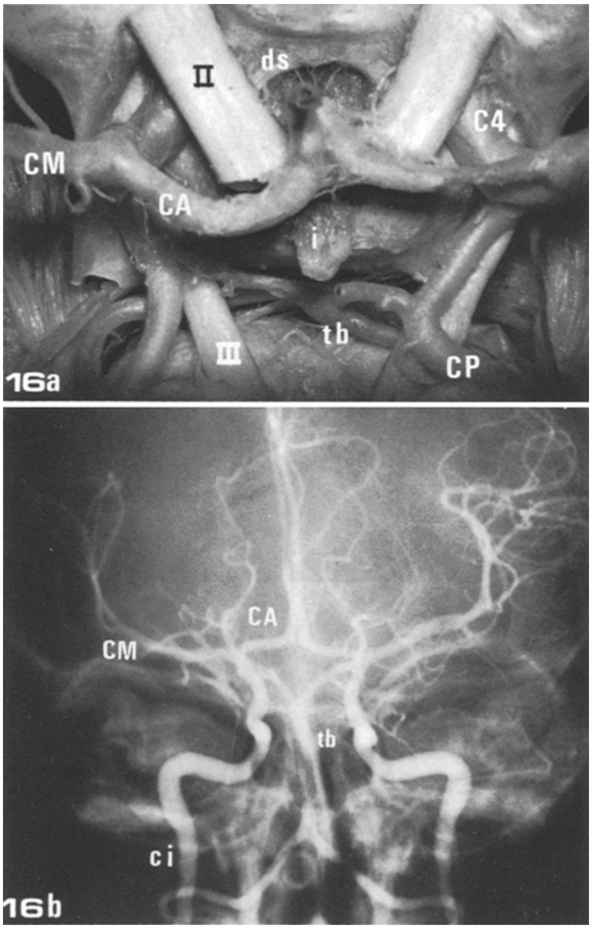


Fig. 16a and b
Circle of Willis

Circulus arteriosus cerebri

C4 pars subarachnoideale, *CA* a. cerebri anterior, *CM* a. cerebri media, *CP* a. cerebri posterior, *tb* a. basilaris; *II* n. opticus, *III* n. oculomotorius, *i* infundibulum; *ds* diaphragma sellae

of a ribbon like structure, the other nerves run in the outer wall and roof of the cavernous sinus. Thus as Taptas (1949) describes, the meningeal coverings are drawn into position with the developing nerves and become applied to the deep surface of the dural wall. However, according to Olivier and Papamiltiades (1951), a venous plexus is to be found between the two structures in 25% of cases. The arrangement of the nerves leaves a triangular space (Fig. 12b) limited superiorly by the 4th cranial nerve (n. trochlearis), inferiorly by the trigeminal ganglion and ophthalmic nerve, and posteriorly by the dorsum sellae. This triangle is anatomically constant, but of variable size, and provides an approach for exploration of the cavernous portion of the internal carotid artery, particularly in the case of certain carotico-cavernous fistulae (Parkinson 1965).

Relationship to the Pituitary Gland

The relationship between internal carotid and pituitary varies according to the sinuosity of the former. According to Harris and Rhoton (1976) the mean distance between the two structures in 50 dissections was 2.3 mm (maximum 7 mm) but in 14 cases they virtually touched, consistent with our own findings (Figs. 12d and 13d). The pituitary gland thus occupies the remaining space and moulds itself to the medial surface of the artery. This fact explains the difficulties sometimes encountered during transsphenoidal hypophysectomy.

Thus, as Dilenge and Heon (1974) have pointed out, the relationships of its cavernous portion allow the artery to be divided into a presellar or paraganglíar segment, a juxtasellar segment, and a terminal juxtaclinoid segment where the artery is situated beneath and medial to the anterior clinoid process (processus clinoideus anterior).

Subarachnoid Portion (C4)

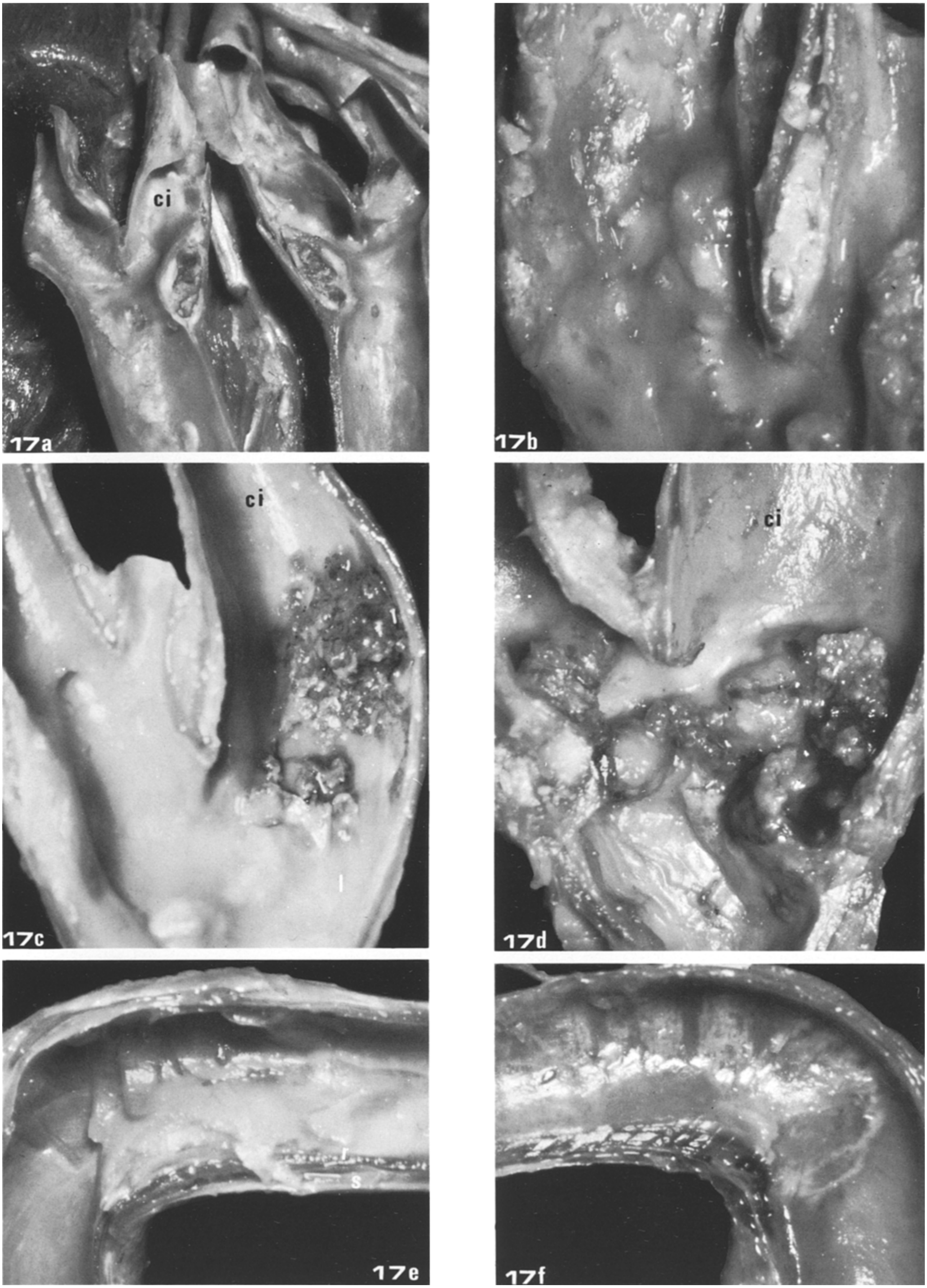
The internal carotid artery perforates the roof of the cavernous sinus immediately medial to the anterior clinoid process and emerges into the cisterns of the base of the brain. The artery slips beneath and then lateral to the optic nerve (n. opticus), curves backwards (so-called supracavernous segment), before assuming its original direction after the origin of the posterior communicating artery (a. communicans posterior). It then divides into anterior cerebral (a cerebri anterior) and middle cerebral (a cerebri media) arteries. The terminal segment belongs to the circle of Willis (Fig. 16). The exact arrangement of the terminal branches has been detailed recently by Lazorthes et al. (1979).

Conclusion

As a result of the age of the subjects being examined we found considerable pathology due to atheroma (Fig. 17). On the other hand, the multiple sinuosities observed in the course of the internal carotid artery appeared to develop much earlier in life, the subsequent relative lengthening of the vessel due to aging only serving to accentuate it. These sinuosities, however, determine passing of blood flow in the artery and encourage parietal damage, an important factor

Fig. 17a–f
Various pathological appearances of the carotid bifurcation (**a–d**) and pars petrosa (**e–f**)

Divers aspects pathologiques de la bifurcation carotidienne (**a–d**) et de la pars petrosa (**e–f**)


17a
ci
17b
17c
ci
l
l
17d
ci
17e
r
s
17f

in the complex pathogenesis of atherosclerosis. Finally, it is important to emphasize the fragility of the carotid syphon in the over 60 year old. The anatomical changes taking place with age which we observed increase the difficulties and risks of selective catheterization and the subsequent surgical intervention in this area.

References

Abraham J (1973) A study of the calibre of common and internal carotid arteries. Indian J Med Res 61:1694–1696

Adachi B (1928) Das Arteriensystem der Japaner, Bd. I. Kyoto: Verlag der Kaiserlichen Japanischen Universität

Anderson RD, Liebeskind A, Schechter MM (1972) Aneurysms of the internal carotid artery in the carotid canal of the petrous temporal bone. Radiology 102:639–642

Argenson C, Francke JP, Sylla S, Dintimille H, Papasian S, di Marino V (1979) Les artères vertébrales (segments VI et V2). Anatomica Clinica 2:29–41

Arnould G, Tridon P, Laxenaire M, Picard L, Thieriet M, Pourel J (1967) Angiomatose carotidienne réalisant un réseau admirable. Rev Neurol 117:358–366

Ask-Upmark E (1935) The carotid sinus an the cerebral circulation. An anatomical, experimental clinical investigation. Including some observations on rete mirable caroticum. Acta Psychiat Scand (Copenhagen) 10:1–374

Bedford MD (1966) The cavernous sinus. Br J Ophtalmol 50:41–46

Bellocq P (1925) Anatomie médico-chirurgicale. Fasc. 1. Masson, Paris

Bonnet P (1955) La loge caverneuse et les syndromes de la loge caverneuse. Clin Ophthalmol 1:2–17

Bugge J (1974) The cephalic arterial system in Insectivores, Primates, Rodents and Lagomorphs, with special reference to the systematic classification. Acta Anat 87:1–159

Clarisse J, Dobbelaere P, Francke JP, Julliot JP, Jomin M (1977) Superselective injection of the carotid and vertebrobasilar systems using a coaxial catheter. J Neuroradiol 4:5–11

Clarisse J, Macke A, Macke-Ribet C, Dobbelaere P, Francke JP (1979) Carotid atheroma and arterial senescence. J Neuroradiol 6:33–44

Congdon ED (1922) Transformation of the aortic-arch system during the development of the human embryo. Contrib Embryol Carneg Instit 14:47–110

Delvert JC, Théron J, Laffont J, Jan M, Santini JJ, Gouazé A (1979) Bases anatomiques de l'exploration radiologique des sinus intercaverneux à la recherche des expansions intra-sellaires. Anatomica Clinica 1:301–307

De Vriese B (1905) Sur la signification morphologique des artères cérébrales. Arch Biol 21:357–457

Dilenge D (1962) L'angiographie de l'artère carotide interne normale. Masson, Paris

Dilenge D, Héon M (1974) The internal carotid artery. In: Newton TH, Potts DG (eds) Radiology of the skull and brain, Vol II, Book 2. CV Mosby Company, Saint Louis

Du Boulay GH, El Gammal T, Trickey SE (1973) True and false carotid retia. Br J Radiol 46:205–212

Faivre J, Vallee B, Carsin M, Scarabin JM, Simon J (1978) Agénésie des portions cervicale et pétreuse de la carotide interne gauche. Revascularisation de sa portion caverneuse par une anastomose intercarotidienne transsphénoïdale. Neuroradiology 17:133–138

Francke JP (1974) Les artères des corps mamilaires. Etude anatomique chez quelques mammifères domestiques (Canis familiaris et Ovis aries). Mémoire DERBH, Amiens

Francke JP, Clarisse J, Dhellemmes P, Bousquet C, Francke-Mauroy B (1977) The arterial circle of the base of the brain and its feeding vessels in certain mammals. J Neuroradiol 4:271–289

Francke JP, Di Marino V, Pannier M, Argenson C, Libersa C (1980) Les artères vertébrales. Segments atlanto-axoïdien V3 et intracrânien V4-Collatérales. Anatomia Clinica 2:229–242

Glasgold AI, Horrigan WD (1972) The internal carotid artery presenting as middle ear tumor. Laryngoscope 82:2217–2221

Harris FS, Rhoton AL (1976) Anatomy of the cavernous sinus. A microsurgical study. J Neurosurg 45:169–180

Harwood-Nash DC, Fitz CR (1976) Neuroradiology in infants and children. CV Mosby Company, Saint Louis

Hasso A, Bentson J, Wilson G, Vignaud J (1975) Neuroradiology of the sphenoidal region. Radiology 114:619–627

House WF, Hitselberger WE (1976) The transcochlear approch to the skull base. Arch Otolaryngol 102:334–342

Jovanovic S (1971) Variations and development of the internal carotid artery in the cavernous sinus. Glas Srp Akad Nauka [Med] 23:163–173

Kier EL (1974) Fetal cerebral arteries: a phylogenetic and ontogenetic study. In: Newton TH, Potts DG (eds) Radiology of the skull and brain, Vol II, Book I. CV Mosby Company, Saint-Louis

Killien FC, Wyler AR, Cromwell LD (1980) Duplication of the internal carotid artery. Neuroradiology 19:101–102

Krayenbuhl HA, Yasargil MG (1965) Die zerebrale Angiographie. Georg Thieme, Stuttgart

Lancien G (1971) Une anomalie vasulaire rare: l'hypoplasie bilatérale des artères carotides internes. Thèse Méd, Rennes

Lapayowker MS, Liebman EP, Ronis ML (1971) Presentation of the internal carotid artery as a tumor of the middle ear. Radiology 98:293–297

Lazorthes G, Bastide G, Amaral-Gomes F (1961) Variations du trajet de la carotide interne d'après une étude artériographique. Arch Anat Pathol 9:129–133

Lazorthes G, Gouazé A (1968) Les voise anastomotiques de suppléance (ou système de sécurité) de la vascularisation artérielle de l'axe cérébro-médullaire. Bull Assoc Anat (Nancy) 53:1–230

Lazorthes G, Gouazé A, Santini JJ, Lazorthes Y, Laffont J (1971) Le modelage du polygone de Willis. Rôle des compressions des voies artérielles d'apport dans les mouvements de la colonne cervicale et de l'extrêmité céphalique. Neurochirurgie 17:361–378

Lazorthes G, Gouazé A, Salamon G (1976) Vascularisation et circulation de l'encéphale. Masson, Paris

Lazorthes G, Gouazé A, Santini JJ, Salamon G (1979) Le cercle artériel du cerveau. Anatomia Clinica 1:241–257

Legait E, Racadot I (1949) Modifications des voies afférentes de la circulation cérébrale au cours du développement chez quelques Mammifères. Bull Assoc Anat (Nancy) 36:444–450

Lie TA (1968) Congenital anomalies of the carotid arteries. Excerpta Medica Foundation Williams and Wilkins Co, Baltimore

Macke A, Macke-Ribet C (1978) L'artère carotide interne. Etude anatomique et microradiographique, exploration endoluminale. Thèse Méd, Lille

Michel D, Bourrat C, Schott B (1972) Le problème des peptites carotides. Journées internationales de circulation cérébrale, Toulouse

Moniz E (1927) L' encéphalographie artérielle. Son importance dans la localisation des des tumeurs cérébrales. Rev Neurol 2:72

Moniz E (1939) L'angiographie cérébrale, 2ed. Masson, Paris

Natali J, Thévenet A, Caron JP, Goutelle A (1973) Chirurgie des artères carotides et vertébrales dans leur segment extra-crânien. Masson, Paris

Olivier R, Papamiltiades M (1951) Le système caverneux veineux de la région latérosellaire. Bull Assoc Anat (Nancy) 36:769–773

Padget DH (1948) The development of the cranial arteries in the human embryo. Contrib Embryol Carneg Inst 32:205–261

Parkinson D (1965) A surgical approach to the cavernous portion of the carotid artery. Anatomical studies and case report. J Neurosurg 23:474–483

Patouillard P (1969) Etude anatomique de la loge latéro-sellaire et de son contenu. Thèse Méd, Clermont-Ferrand

Paullus WS, Pait TG, Rhoton AL (1977) Microsurgical exposure of the petrous portion of the carotid artery. J Neurosurg 47:713–726

Picard L, André JM, Renard M, Montaut J, Tridon P (1972) Réseau admirable carotidien humain. Acta Radiol (Diagn) 13:205–219

Rabischong P, Paleirac R, Vignaud J, Clay C, Comolet R, Bonis M, Rougier R (1974a) Contribution angiographique et expérimentale à l'hémodynamique du plexus caverneux. Ann Radiol 17:285–292

Rabischong P, Vignaud J, Paleirac R, Clay C (1974b) Anatomie sérielle de la loge caverneuse. Ann Radiol 17:215–224

Renn WH, Rhoton AL (1975) Microsurgical anatomy of the sellar region. J Neurosurg 43:288–298

Servo A (1977) Agenesis of the left internal carotid artery associated with an aneurysm on the right carotid syphon. J Neurosurg 46:677–680

Smith D, Larsen JL (1979) On the symmetry and asymmetry of the bifurcation of the common carotid artery. Neuroradiology 17:245–247

Streeter GL (1918) The developmental alterations in the vascular system of the brain of the human embryo. Contrib Embryol Carn Inst 8:5–38

Takahashi M (1977) Atlas of carotid angiography. Igaku Shoin LTD, Tokyo

Taptas JN (1949) La loge du sinus caverneux. Rev Otoneuro-ophtalmol 21:193–199

Théron J (1974) Aspect dynamique de la circulation au niveau des veines de la base du crâne. Ann Radiol 17:279–284

Thévenet A (1979) Chirurgie des carotides. Encyclopédie Médico-Chirurgicale, Paris, 43180 à 43205, 4-4-09

Tondüry G (1934) Einseitiges Fehlen der Arteria carotis interna. Gegenbaurs Morph Jb 74:625

Vitek JJ, Reaves P (1973) Thoracic bifurcation of the common carotid artery. Neuroradiology 5:133–139

Weibel J, Fields WS (1965) Tortuosy, coiling and kinking of the internal carotid artery. Neurology 15:7–18