Section 1 Central Nervous System

Chapter 1

The skull and brain

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Introduction and imaging methods

Computed tomography (CT) and magnetic resonance imaging (MRI) are the mainstays of cerebral imaging. Skull radiography now plays very little part in diagnosis, being largely replaced by multislice CT.

Non- or minimally invasive angiography performed using CT (CT angiography) or MRI (magnetic resonance angiography) has resulted in invasive catheter angiography being reserved for a few special diagnostic indications or as part of an interventional, (therapeutic), procedure.

Anatomical detail is far better displayed by MRI than by CT, although both are valuable in clinical practice.

With T1-weighted (T1W) MR images, grey matter is of lower signal intensity (darker) than white matter (Fig. 1.1). On T2-weighted (T2W) images, including T2-FLAIR sequences, the reverse is true (Fig. 1.2).

With CT, somewhat paradoxically, white matter is depicted as darker grey than grey matter (Fig. 1.3). The explanation is that CT is an X-ray investigation. White matter contains lipid as part of myelin, which is relatively radiolucent.

Fig. 1.1 T1W MRI. 'Mid-axial' section of the brain.

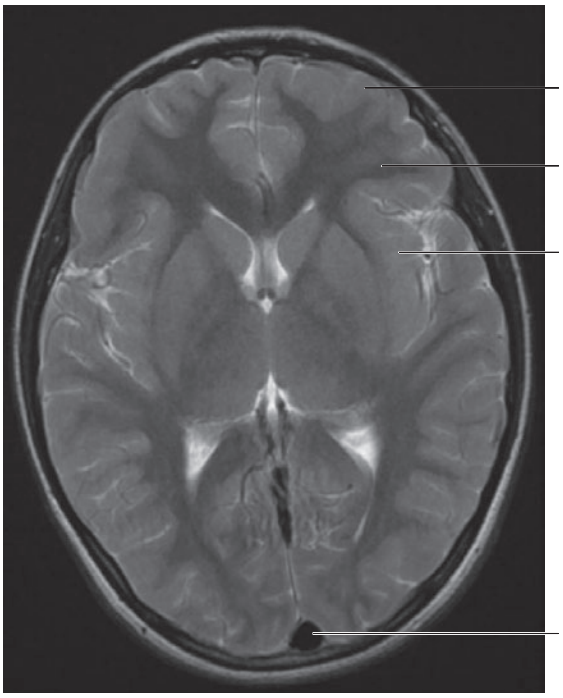


Fig. 1.2 T2W MRI. 'Mid-axial' section of the brain. Note the signal void due to blood flowing rapidly.

The appearance of myelinated tracts on MRI is rather more variable and will be influenced by the pulse sequence used. In perhaps its simplest form, the lipid in subcutaneous fat is typically high signal (white) on both T1 and T2 MR sequences.

Conversely, lipid is extremely radiolucent and appears black on CT.

Dense bone contains few free protons on which MRI is based and therefore appears as a signal void (black) on MR.

On CT, bone, which is radio-opaque, appears white.

Air in the paranasal sinuses appears black on both CT and MRI.

Besides compact bone and air, hypointensity on MRI occurs also with iron deposition in the globus pallidus and substantia nigra and as a feature of rapid blood or CSF flow (see below).

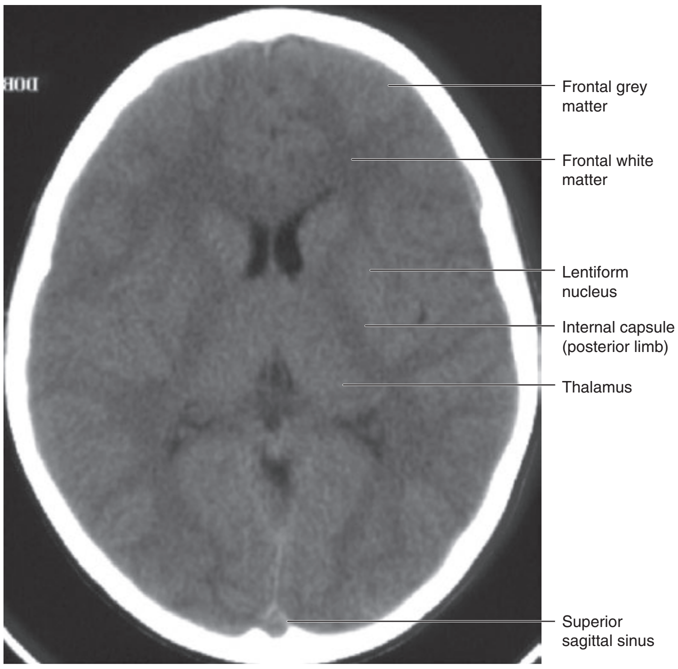


Fig. 1.3 Cranial CT. 'Mid-axial' section of the brain.

The intravenous contrast agents used in CT and MRI do not cause significant cerebral parenchymal enhancement, when the blood–brain barrier is intact.

Iodinated contrast agents administered intravenously for CT enhance blood within the cranial arteries and veins and dural venous sinuses (Fig. 1.4).

Enhancement is seen also in the highly vascular choroid plexuses and in those structures outside the blood–brain barrier such as the pituitary gland and infundibulum.

With MRI the mechanism of contrast enhancement with intravenous gadolinium DTPA is quite different from CT, but nevertheless, on T1W images, those structures which enhance become hyperintense (whiter) in much the same way as with CT.

One notable difference, however, is in the depiction of rapidly flowing blood with MRI, which appears as a 'signal void' (black) and does not enhance (Fig. 1.2). This principle applies also to CSF, which can flow rapidly through the cerebral aqueduct, causing a signal void seen particularly on T2W axial images.

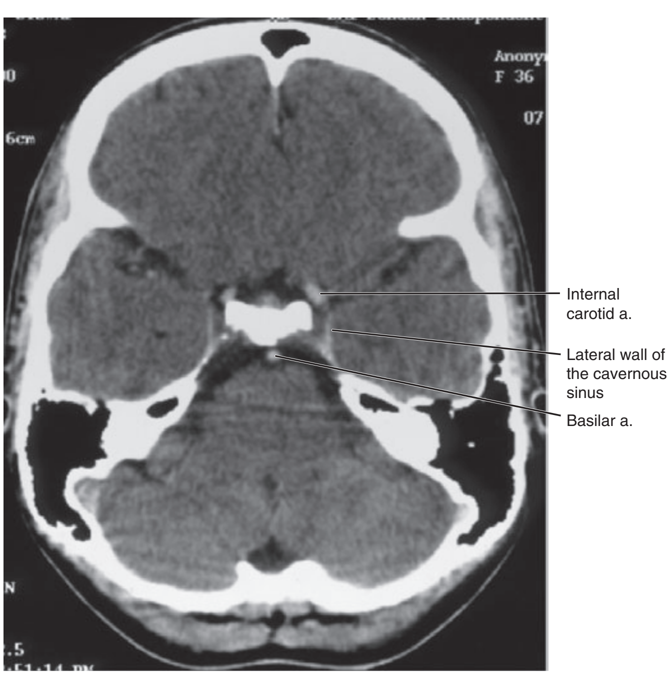


Fig. 1.4 Contrast-enhanced cranial CT.

Osteology of the skull

The brain is supported by the skull base and enclosed in the vault or calvarium. The skull base develops in cartilage, the vault in membrane. The central skull base consists of the occipital, sphenoid and temporal bones. The frontal and ethmoidal bones complete the five bones of the skull base. Skull sutures are located between bones formed by membranous ossification and consist of dense connective tissue. In the neonate they are smooth, but through childhood interdigitations develop, followed by perisutural sclerosis, prior to fusion in the third or fourth decades or even later (Fig. 1.5). The anterior fontanelle or bregma is located between frontal and parietal bones at the junction of sagittal and coronal sutures. It closes in the second year.

The posterior fontanelle or lambda is closed by the second month after birth.

The skull vault consists of inner and outer tables or diploe separated by a diploic space. This space contains marrow and large valveless, thin-walled diploic veins, which contribute to a rich cranial-cerebral anastomosis to provide both a route for the spread of infection across the vault and collateral pathways in the event of venous sinus occlusion.

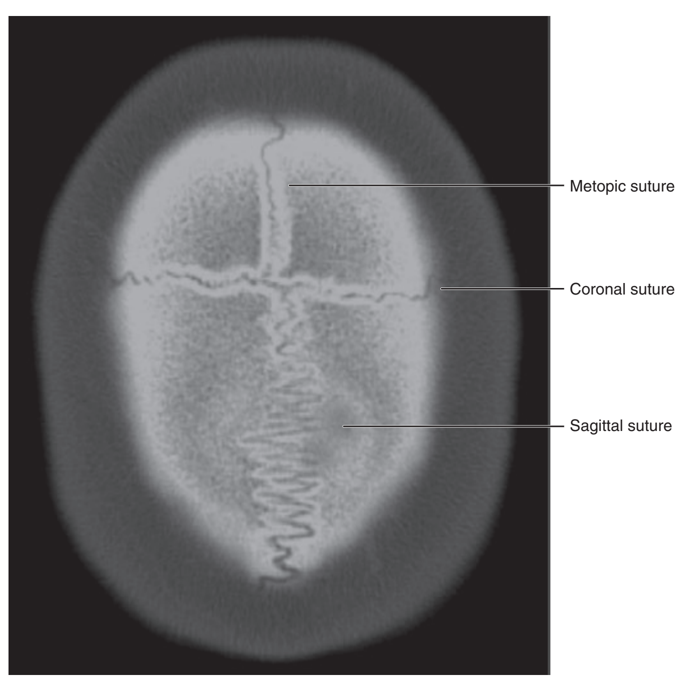


Fig. 1.5 Cranial CT, bone algorithm. The cranial sutures at the vertex of the skull. There is a persistent metopic suture. Note the interdigitation and perisutural sclerosis of the sagittal suture.

Fig. 1.6 Cranial CT, bone algorithm. Pseudo-erosive changes due to the arachnoid granulations.

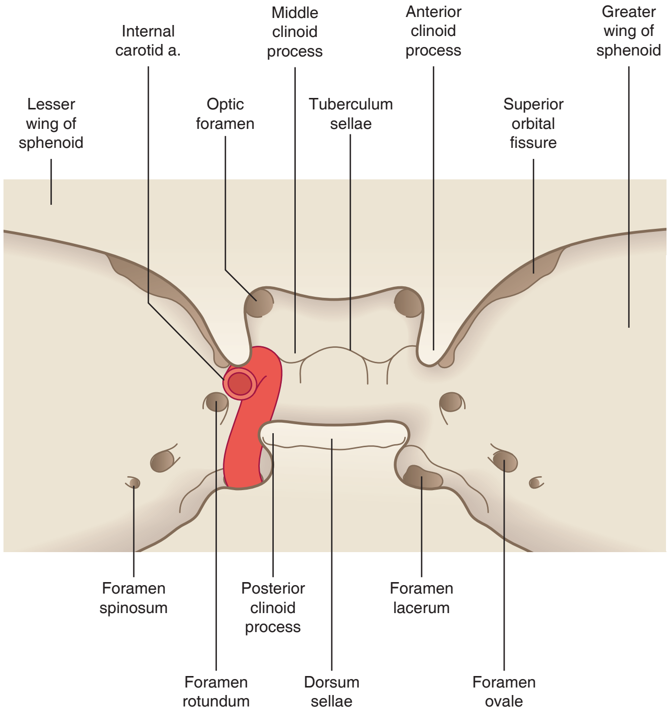


Fig. 1.7 The bony anatomy of the sellar region.

Venous lacunae are found mainly in the parietal bone, near to the midline adjacent to the superior sagittal sinus. They receive some of the cerebral venous return and are invaginated by arachnoid granulations, which are the sites of reabsorption of cerebral spinal fluid into the venous system. Lacunae cause localized thinning of the inner table (Fig. 1.6).

The frontal bone forms in two halves, which normally fuse at five years. The intervening suture is known as the metopic suture.

Occasionally, the halves remain separate and the suture may persist wholly or in part into adult life in 5–10% of individuals (Fig. 1.5).

The orbital plates of the frontal bone contribute most of the anterior fossa floor with a cribriform plate of the ethmoid bone interposed between them in the midline. The crista galli, to which the falx is attached, ascends vertically from the cribriform plate and may appear hyperintense on T1W images due to contained fatty marrow.

The two parietal bones are separated from each other by the sagittal suture and from the frontal bone by the coronal suture (Fig. 1.5). Posteriorly, each parietal bone articulates with the occipital bone. Anteriorly, it articulates with the frontal bone and the greater wing of the sphenoid bone and inferiorly with the temporal bone. The frontal, sphenoid parietal and temporal bones meet at the pterion, which normally closes at 3–4 months.

The sphenoid bone consists of a body, greater and lesser wings and the pterygoid plates. The body encloses the sphenoid air sinuses, which are paired and usually asymmetrical. The pituitary fossa and posterior clinoid processes are borne on the superior surface. The planum sphenoidale articulates with the cribriform plate. The anterior clinoid processes are part of the lesser wing and the tuberculum sellae dips anteriorly between them into the optic groove.

The lesser wing forms the posterior part of the floor of the anterior cranial fossa and its posterior border constitutes the sphenoid ridge.

Meningiomas of the skull base may arise from any of these sphenoid locations, hence the detail given (Fig. 1.7).

The greater wing of the sphenoid bone forms the floor of the middle cranial fossa, which extends posteriorly to the petrous ridge and dorsum sellae. The dorsum sella is the posterior boundary of the pituitary fossa and merges laterally with posterior clinoid processes. The greater wing also separates the temporal lobe of the brain from the infratemporal fossa below. The medial and lateral pterygoid plates of the sphenoid bone pass inferiorly behind the maxilla.

The foramina ovale rotundum and spinosa are within the greater wing of the sphenoid bone (Fig. 1.8). The foramina ovale and spinosum are often asymmetrical, the foramen rotundum rarely so.

The foramen rotundum travels from Meckel's cave to the pterygopalatine fossa and transmits the maxillary division of the trigeminal nerve. On coronal CT the foramina are demonstrated inferior to the anterior clinoid processes.

The foramen ovale transmits the mandibular division of the trigeminal nerve and the accessory meningeal arteries. It runs anterolaterally from Meckel's cave to emerge near to the lateral pterygoid plate. The foramina may be identified on coronal CT scan inferolateral to the posterior clinoid processes.

The foramen spinosum is situated posterolateral to the larger foramen ovale and transmits the middle meningeal artery and vein between the infratemporal and middle cranial fossae.

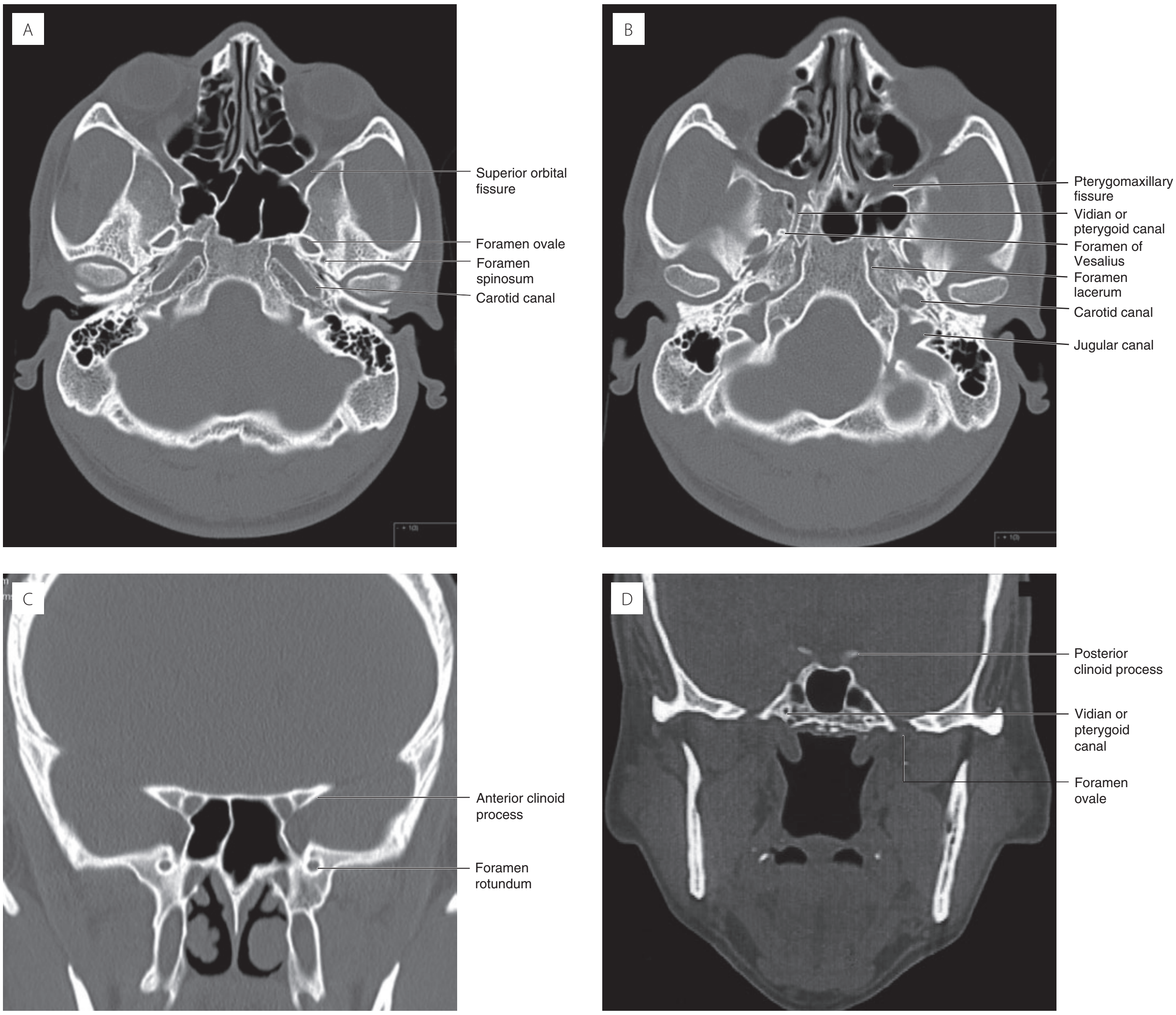


Fig. 1.8 Cranial CT, bone algorithm. The skull base. Axial, (A) superior to (B). Coronal, (C) anterior to (D).

The foramen lacerum contains cartilage and is traversed only by small veins and nerves. It separates the petrous apex, the body of the sphenoid and the basiocciput and is crossed by the internal carotid artery. Smaller, inconstant foramina are sometimes encountered. The Vidian or pterygoid canal is found medial to the foramen rotundum. The foramen of Vesalius transmits an emissary vein and is medial to the foramen ovale.

The temporal bone has four parts. The squamous part forms the lateral wall of the middle cranial fossa and is separated from the parietal bone by the squamosal suture. Its zygomatic process contributes to the zygomatic arch and the squamosal portion also bears the mandibular condylar fossa.

The petromastoid portion forms part of the middle and posterior fossa floors. The styloid process passes inferiorly from the base of the petrous bone and the stylomastoid

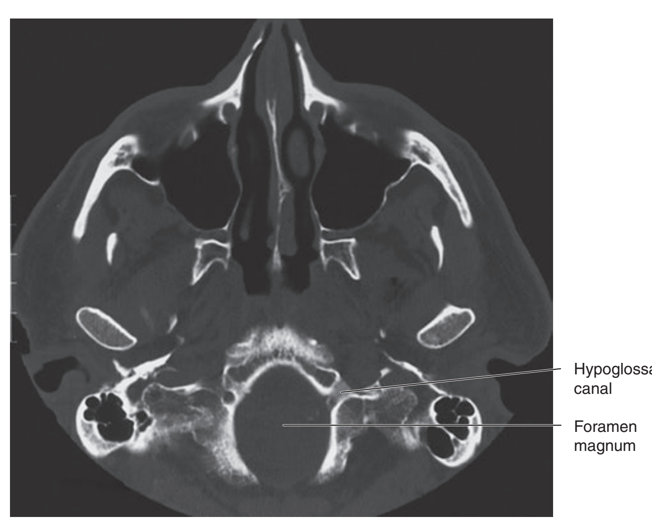
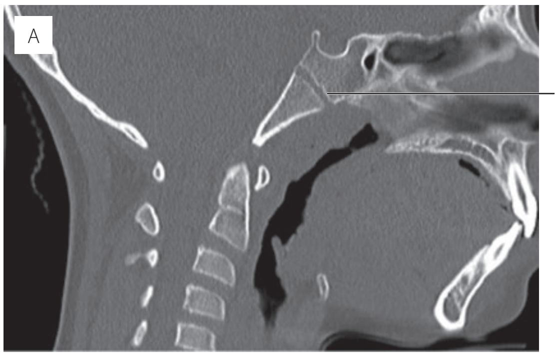


Fig. 1.9 Cranial CT, bone algorithm. The hypoglossal canal.



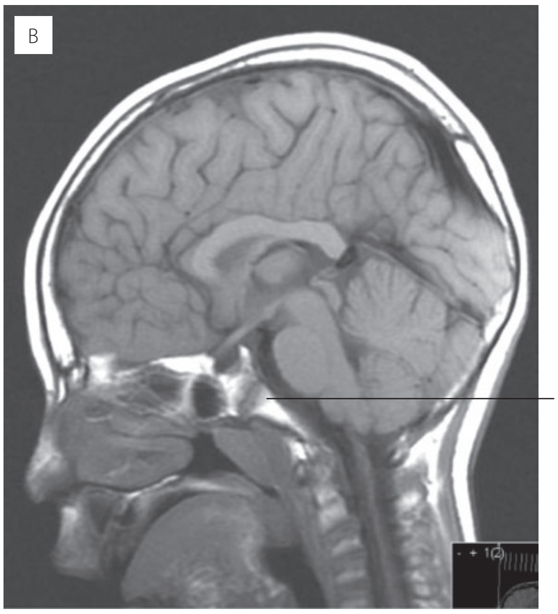


Fig. 1.10 (A) Cranial CT. Sagittal reformat bone algorithm. (B) Cranial MR. Midline sagittal section of the brain. Spheno-occipital synchondrosis.

foramen lies behind the styloid process transmitting the facial (VIIth) cranial nerve.

The occipital bone forms most of the posterior cranial fossa walls. This is the largest of the three cranial fossae. It also gives rise to the occipital condyles which articulate with the atlas and the anterior condylar canals which transmit the hypoglossal (XIIth) cranial nerve (Fig. 1.9). Also inferiorly but more anteriorly, the occipital bone articulates with the sphenoid to form the clivus. The articulation is visible in children as the basisphenoid synchondrosis (Fig. 1.10).

In the adult the clivus is hyperintense on T1W MR images due to replacement of red marrow with fat. The transition from hypointensity occurs at around 7 years. Immature red marrow in children can enhance with intravenous gadolinium.

The occipital bone is often devoid of a diploic space inferiorly. This accounts for the sparing of the occipital bone in thalassaemia major, where the response to chronic haemolysis causes reactive change ('hair on end' appearance) elsewhere in the skull vault.

The skull radiograph (Fig. 1.11)

Skull radiography is performed much less frequently now because of the versatility and reliability of cranial CT. The plain film images are complex with multiple overlapping lines and interfaces and of course give very limited and indirect evidence of cerebral pathology.

When interpreting a skull radiograph perhaps the most important requirement is to distinguish a normal lucency from a fracture. Convolutional markings are absent at birth, most prominent at between 2 and 5 years and absent after about 12 years.

Vascular markings similarly do not develop until the postnatal period but then persist throughout life. They are less radiolucent than fractures, with indistinct margins and often branch. Diploic veins are responsible for the majority of impressions, although the dural venous sinuses (superior sagittal, lateral and sigmoid) cause depressions on the inner table, visible on plain radiographs.

There is a vein running along the coronal suture large enough to be labelled the sphenobregmatic sinus, which gives rise to a prominent vascular impression.

Venous impressions are larger than those due to arteries and vary in calibre. Arterial impressions have parallel walls and reduce in calibre only after branching.

Normal vault lucencies and calcifications are listed in Table 1.1

Table 1.1 Lucencies and calcifications seen on normal skull radiography

Lucencies
Sutures
Vascular impressions
Normal vault thinning, e.g. temporal bone
Arachnoid granulations
Pneumatization
Calcifications (Fig. 1.12)
Pineal gland
Habenular commissure
Choroid plexus
Dural calcification including petroclinoid and interclinoid 'ligaments'

The cerebral envelope

See Fig. 1.13

The meninges invest the brain and spinal cord. The three constituent parts are the outer, fibrous dura mater, the avascular, lattice-like arachnoid mater and the inner, vascular layer, the pia mater.

Although the dura and arachnoid are applied closely, there is a potential space, known as the subdural space, between them into which haemorrhage may occur or pus form. Its existence in the normal individual is controversial. The subarachnoid space contains cerebral spinal fluid, which surrounds the cerebral arteries and veins. It is situated between the arachnoid and the pia, which is closely applied to the cerebral surface. The cranial dura has two layers, which separate to enclose the dural venous sinuses.

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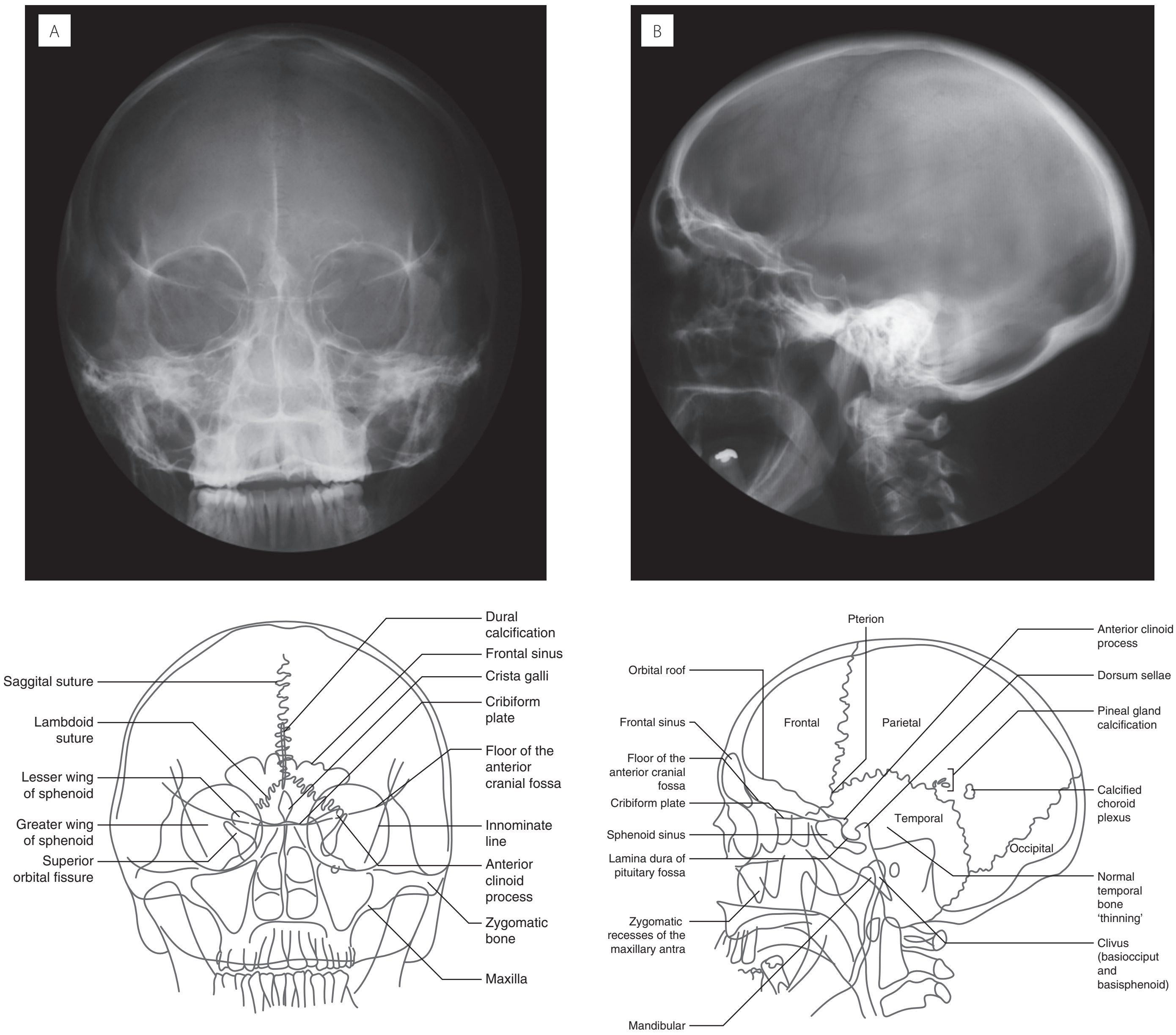

Fig. 1.11 Frontal (A) and lateral (B) skull radiographs.

The outer layer is the periosteum of the inner table of the skull (the endosteum). The inner layer covers the brain and gives rise to the falx and tentorium. Dura is hyperdense on CT images and relatively hypointense on MRI. It shows contrast enhancement on both modalities and since the falx may calcify or ossify, MRI may demonstrate focal regions of signal void due to calcification or of hyperintensity due to fat within marrow.

The falx is a sickle-shaped fold of dura, comprising two layers, which forms an incomplete partition between the cerebral hemispheres. It extends from the crista galli to the internal occipital protuberance, where it joins the tentorium and is thinner anteriorly. The falx is demonstrated as a midline linear density on axial CT scan near to the vertex, but inferiorly and posteriorly assumes a triangular shape conforming to the superior sagittal sinus in cross-section. The tentorium cerebelli, another double dural fold, is attached from the posterior clinoid processes along the petrous ridges to the internal occipital protuberance. Its upper, free, medial border surrounds the midbrain. This passes anteriorly through the opening, known as the tentorial hiatus or incisura.

The uncus of the hippocampus and the posterior cerebral arteries lie above the free edge of the tentorium and both are at risk of compression against the tentorial edge when there is raised intracranial pressure in the supratentorial compartment ('coning'). The free border anteriorly encloses the cavernous sinus on each side of the pituitary fossa before attaching to the anterior clinoid processes.

For diagnostic purposes it is important to identify in which intracranial compartment a lesion is situated. On axial CT, structures medial to the line of the tentorial edge are in the infratentorial compartment; those lateral to that line are in the supratentorial compartment (Fig. 1.14).

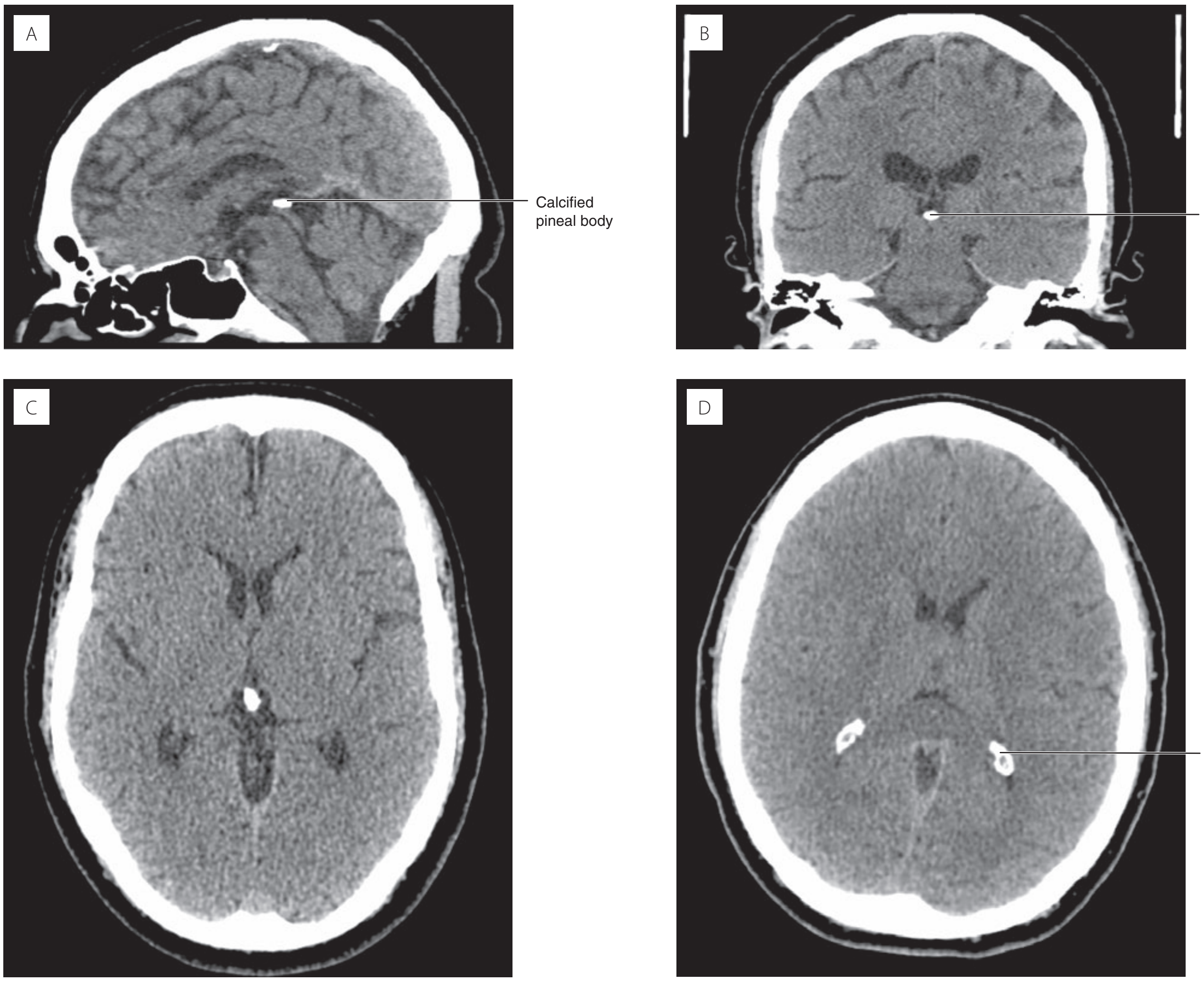

Fig. 1.12 CT scans showing calcified pineal body in sagittal section (A), coronal section (B) and axial section (C), and choroid calcification in axial section (D).

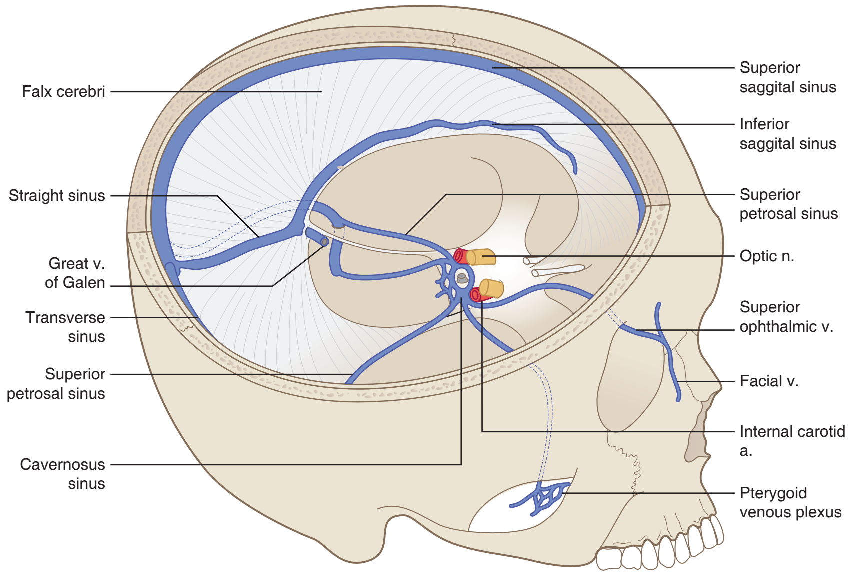

Fig. 1.13 The cranial dura.

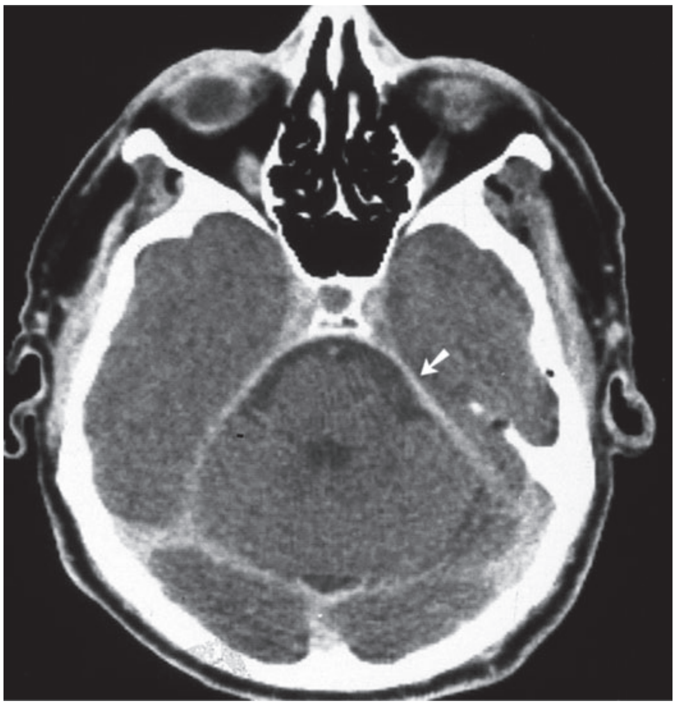

Fig. 1.14 Axial CT with intravenous contrast showing the tentorial margins (arrow). Note that the dura continues anteriorly to form the lateral wall of the cavernous sinus.

The falx cerebelli is a small fold of dura attached superiorly to the posterior part of the tentorium in the midsagittal plane, which encloses the occipital sinus posteriorly. It terminates just above the foramen magnum and its free anterior border projects into the cerebellar notch. The diaphragma sellae is an incomplete roof over the pituitary gland and is pierced by the pituitary stalk. There is no subarachnoid space in the sella since the meningeal layers fuse. On both CT and MRI meningeal enhancement following intravenous contrast is a normal feature.

Meningeal blood supply and innervation

The middle meningeal artery is the main arterial supply to the meninges (Fig. 1.15), but there are contributions from the cavernous carotid, the ophthalmic and vertebral arteries. There is also an accessory meningeal artery, which arises either from the maxillary or middle meningeal arteries and enters the skull through the foramen ovale. The middle meningeal artery is extradural and both it and the middle meningeal veins groove the inner table of the skull. Branches of the external carotid artery may often supply the lower cranial nerves. The middle meningeal arteries supply branches to both the trigeminal and the facial ganglia. The occipital artery gives branches which pass via the jugular foramen and condylar canal to supply the glossopharyngeal (IXth), vagal (Xth), accessory (XIth) and hypoglossal (XIIth) cranial nerves. Innervation of the dura is primarily from the trigeminal nerve, but also from the lower cranial nerves and the first three cervical segments. This may account for cervical pain in cranial subarachnoid haemorrhage.

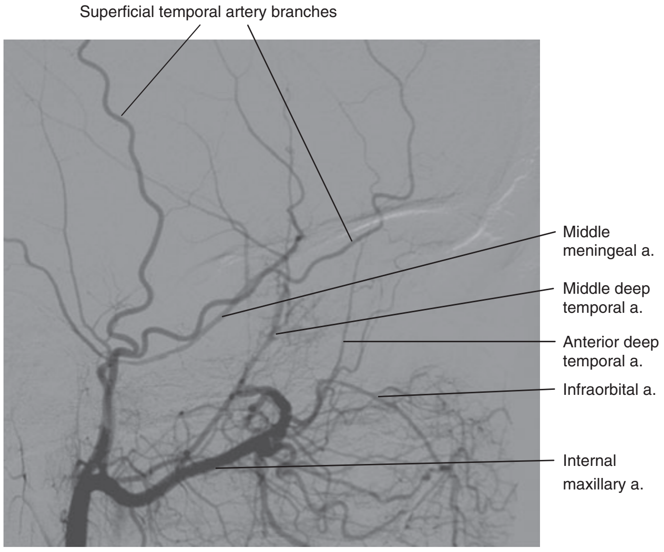

Fig. 1.15 External carotid angiogram, lateral projection.

The subarachnoid cisterns (Fig. 1.16)

Where the brain and skull are not closely applied, a number of subarachnoid cisterns are defined. They are situated at the base of the brain and around the brainstem, the free edge of the tentorium and the major arteries. The subarachnoid cisterns connect relatively freely with one another and their patency is essential for the normal circulation of cerebral spinal fluid. Although there are arachnoid membranes within the cisterns causing partial compartmentalization, the definition of a particular cistern is a result of the arbitrary division of what is effectively a single space.

The cisterna magna lies between the medulla and the posteroinferior surface of the cerebellum and is triangular in sagittal section. It continues below the spinal subarachnoid space and receives cerebral spinal fluid from the fourth ventricle. It is sometimes punctured percutaneously in the midline to obtain cerebral spinal fluid for examination.

The vertebral and posterior inferior cerebellar arteries travel through the lateral parts of the cisterna magna, which also contains the glossopharyngeal, vagus and spinal accessory nerves. In some, otherwise normal, individuals the system is very large and described as a mega-cisterna magna.

The pontine cistern is anterior to both the pons and medulla and contains the basilar artery and cranial nerves V to XII. It is continuous around the brainstem, with the quadrigeminal plate cistern posteriorly and the interpeduncular cistern superiorly.

The chiasmatic or suprasellar cistern extends from the infundibulum to the posterior surface of the frontal lobes and lies between the uncus on either side. It includes the proximal parts of the Sylvian fissures and contains the circle of Willis. Since the majority of berry aneurysms are borne on the circle of Willis, it can be appreciated that their rupture results in subarachnoid haemorrhage in the first instance.

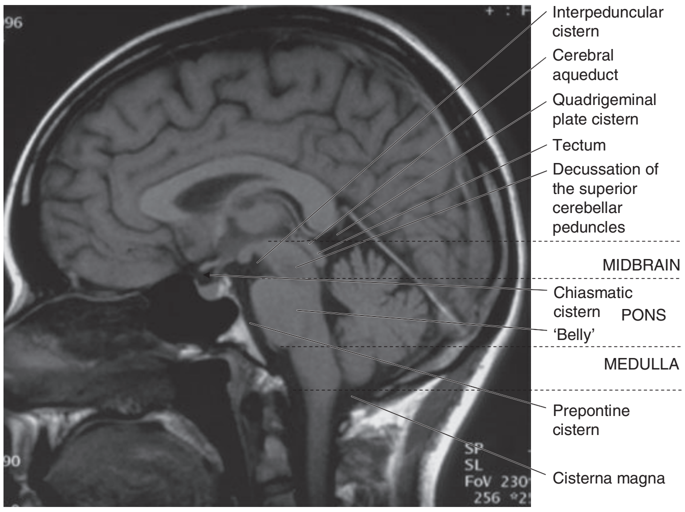

Fig. 1.16 Cranial MR. Midline sagittal section of the brain. The subarachnoid cisterns.

The chiasmatic cistern leads posteriorly to the interpeduncular or intercrural cistern, which contains the terminal basilar artery and its branches and the oculomotor (IIIrd cranial) nerves. Blood within this cistern may be the only evidence of subarachnoid haemorrhage.

The ambient cistern surrounds the midbrain and transmits the posterior cerebral and superior cerebellar arteries, the basal veins of Rosenthal and the trochlear nerves. The 'wings' of the ambient cistern are its lateral extensions posterior to the thalami.

The quadrigeminal cistern (cistern of the great cerebral vein of Galen) lies adjacent to the superior service of the cerebellum and extends superiorly around the splenium of the corpus callosum. It contains the posterior cerebral, posterior choroidal and superior cerebellar arteries, and the trochlear (IVth cranial) nerves. It is also the location of the venous confluence where the vein of Galen joins the inferior sagittal and straight dural venous sinuses.

The cistern of the lamina terminalis is superior to the chiasmatic cistern. It contains the anterior communicating artery and leads into the callosal cistern, through which the pericallosal artery travels.

The brainstem and cranial nerves

See Fig. 1.17

The brainstem consists of the midbrain, pons and medulla (Fig. 1.16). Even high field strength MRI shows little internal detail under normal scanning conditions. To demonstrate the exiting cranial nerves, high-resolution, heavily T2-weighted

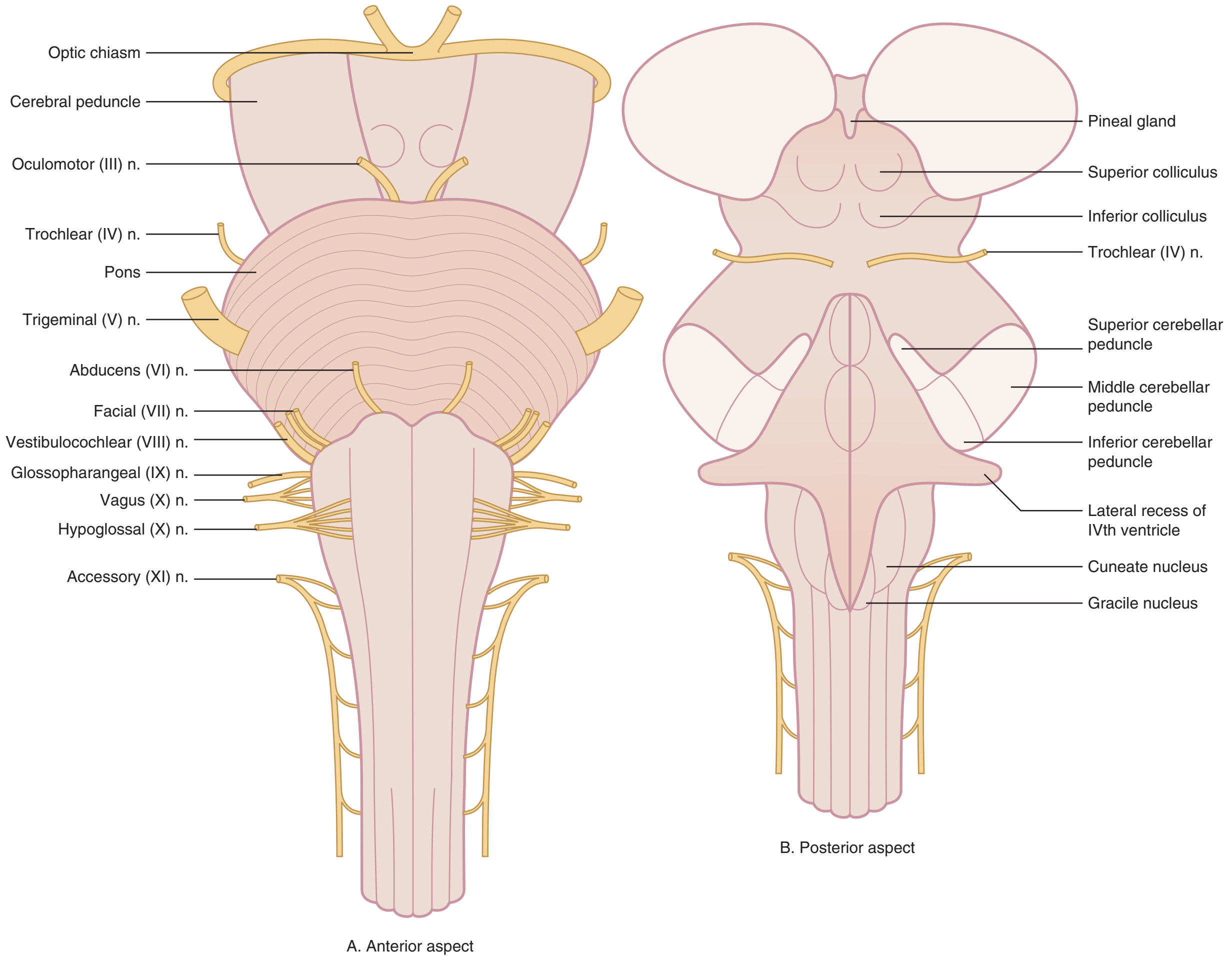

Fig. 1.17 The brainstem. A. Anterior aspect B. Posterior

thin-section axial and coronal scans are required. These provide contour images of the nerves and brainstem against hyperintense (white) CSF. Even then the demonstration of the smaller nerves is inconstant.

The midbrain

The midbrain has two prominent cerebral peduncles anteriorly and a dorsal tectum. Within the substance of the midbrain the red nuclei and the substantia nigra can be identified (Fig. 1.18).

The red nuclei are hypointense on T2W images due to their vascularity and the substantia nigra due to their iron content.

As with the pons the appearance of the midbrain is very different from its axial appearance. In a midline section only the central tegmentum and dorsal tectum are seen, separated by the cerebral aqueduct.

The tectum consists of four colliculi ('hillocks') or quadrigeminal bodies, which are involved in visual and auditory reflexes (Figs. 1.16, 1.28).

Cranial nerves arising in the midbrain are the oculomotor (IIIrd) and the trochlear (IVth). Both have their nuclei in the periaqueductal grey matter.

The oculomotor (IIIrd) arises from the anterior midbrain, on the medial side of the cerebral peduncle (Fig. 1.19), and passes between the superior cerebellar and posterior communicating arteries. Aneurysms arising at the origins of either of these two arteries can cause a IIIrd nerve palsy, although posterior communicating artery aneurysms are much more common.

The nerve then passes inferior to the posterior communicating artery, close to the free edge of the tentorium, into the cavernous sinus. Its cisternal portion is particularly well shown on axial FLAIR MR images.

The trochlear (IVth) nerve is the smallest in calibre, has the longest intracranial course and is the only cranial nerve arising from the dorsal aspect of the brainstem (Fig. 1.20).

The pons

The pons has a bulbous anterior portion (the 'belly'), seen prominently on sagittal images, and a dorsal tegmentum (Fig.1.16).

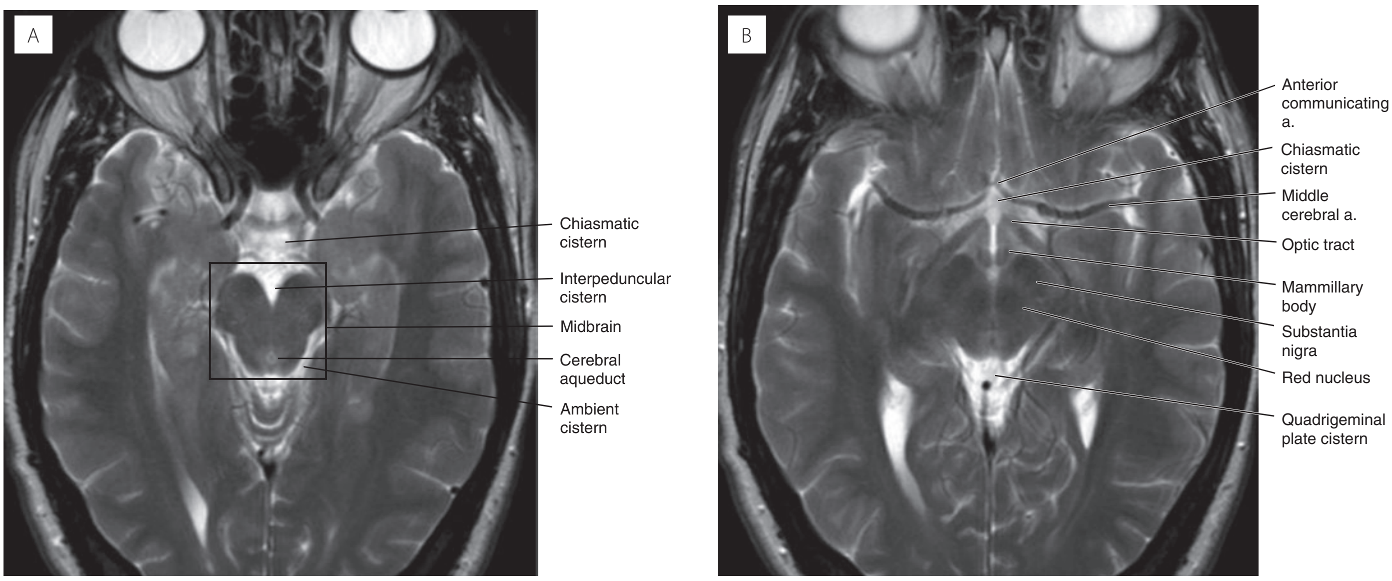

Fig. 1.18 T2W axial MRI. The midbrain: (B) is cranial to (A).

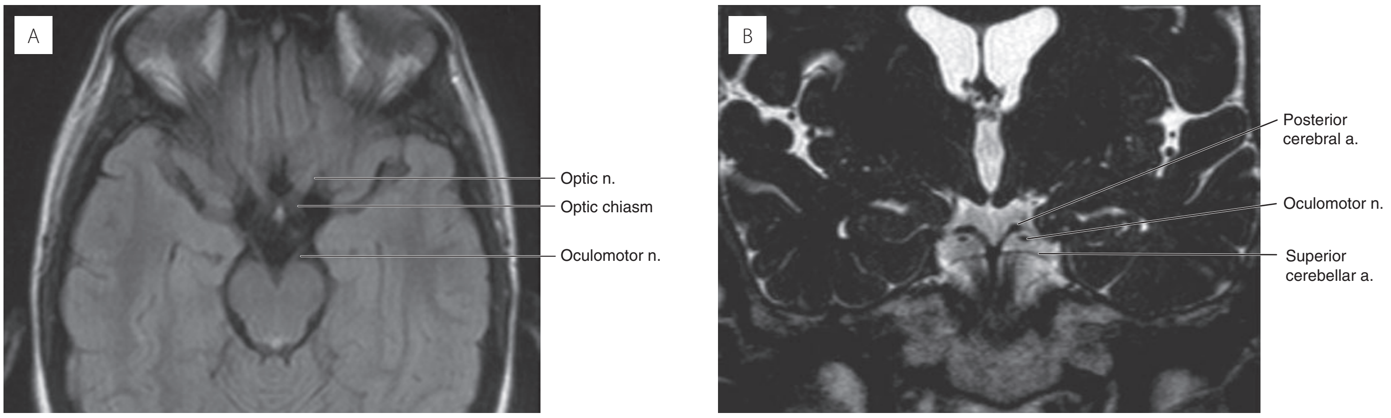

Fig. 1.19 FLAIR axial MRI (A); T2W coronal MRI (B). The oculomotor (IIIrd cranial) nerve.