2 Cephalic Reference Lines Suitable for Neuroimaging

Both morphometric and topographic approaches to analyze brain structures require a careful choice of reliable anatomic landmarks in order to achieve appropriate imaging and clinical correlations. Therefore, a precise topographic analysis of brain structures ought to be performed using definite brain reference lines, which are based most efficiently on commissural landmarks. Whenever possible, correlations with cutaneous and cranial anthropologic points are necessary for multimodal imaging purposes (Broca 1873; Ariens Kappers 1947; Talairach et al. 1952; Guiot and Brion 1958; Delmas and Pertuiset 1959; Cabanis et al. 1978; Olivier et al. 1985, 1987; Baulac et al. 1990; Tamraz et al. 1990).

The ability of MRI to visualize tissues in any direction, due to its multiplanar and computerized capabilities, permits the evaluation of specific anatomic structures from the most suitable orientation by direct scanning either parallel or orthogonal to the long axis of the anatomic structure studied.

In this chapter, the various cranial reference lines will first be reviewed. Subsequently, the anatomic and physiologic cephalic orientations widely used in anatomic imaging will be covered.

Particular attention will be devoted to a new sylvian approach to brain anatomy based on recent ontogenetic, phylogenetic and anatomic data obtained using the reference system based on two specific reference lines, namely the "chiasmatico-commissural line" (CH-PC line), which is oriented parallel to the "sylvian fissure" and defines the "chiasmato-mamillo postcommissural plane"; and the "commissural-obex line" (PC-OB line), which is perpendicular to the latter and corresponds to the vertical long axis of the brainstem (Tamraz et al. 1989, 1990, 1991).

These orthogonal reference planes, suitable for multimodal imaging, can be used routinely in brain imaging with highly reproducible results. The anatomic landmarks defining these reference lines are easily seen on a midsagittal MR view, and are present in all vertebrates. From an anatomic point of view, both ontogenetically and phylogenetically, the accuracy of these midline structures located at the mid-brain-diencephalic junction need not be demonstrated.. Constant and statistically proven angular variations demonstrate the validity of these cephalic orientations both in vivo and in the cadaver: (1) the angular relationship between the CH-PC line and the bicommissural line (AC-PC), called the commissural angle (CH-PC-AC) is 24 ± 2.3; (2) the angular relationship between the CH-PC line and the PC-OB brainstem vertical axis joining the posterior commissure to the obex, named the CH-PC-OB truncal angle, is 93 ± 3.4.

It is worth noting that the bicommissural line (Talairach et al. 1952), which is very close to the orbitomeatal or canthomeatal lines used in conventional radiology, has great validity and continues to be used in brain imaging fields, despite its great deviations, due to its neurosurgical stereotactic validation (Talairach et al. 1957, 1967; Schaltenbrand and Bailey 1959; Schaltenbrand and Wahren 1977) and its neuroradiological evaluation (Salamon and Huang 1976; Szikla et al. 1977; Salamon and Lecaque 1978; Vanier et al. 1985; Talairach and Tournoux 1988; Bergvall et al. 1988). Its usefulness is obvious when interest is in the study of the central region of the brain. This is also true for the more recently described callosal reference plane demonstrated and validated for routine use by Olivier et al. (1985, 1987) and Lehman et al. (1992).

I Cranial Reference Lines and Planes

A Historical Background and Overview

More than 80 cephalic reference lines based on cranial and anthropological landmarks have been defined and reported. These reference systems were developed mainly by anatomists and anthropologists at the end of the eighteenth century.

Within the field of comparative craniology, a search for a horizontal plane for the skull was performed by Daubenton (Daubenton and Daele 1764), by Cuvier (1835) and later by Lucae (1872), along with many others. In his communication to the French Academy of Science in 1764, Daubenton described the importance of the plane of the foramen magnum as the horizontal plane tangent at the middle of its posterior border to the condylar processes of the skull. He pointed out that this plane is differently oriented in humans as compared with animals, passing through the inferior aspect of the orbits in man and considered by him as horizontal and perpendicular to the vertical axis of the body and neck when an erect position is assumed. This differs in monkeys, in which the plane passes beneath the mandible, becoming even more obliquely tilted downward in lower species such as the dog. Daubenton was convinced that horizontality is closely related to the orientation and position of the foramen magnum located in a central position at the base of the skull, stating "plus le grand trou occipital est éloigné du fond de l'occiput plus le plan de cette ouverture approche de la direction horizontale" (Daubenton and Daele 1950, p 570). His contribution to craniology and anatomy differs from previous contributions in this field, which lacked precision in the choice of anatomic landmarks.

These attempts were used a few decades later for works on racial morphologic differences which were extensively pursued at the end of the eighteenth century, and are well represented by the important contributions of Camper (1791), Blumenbach (1795), Doornik (1808) and many others. In 1791, Camper defined an interesting cephalic plane of orientation joining the spina nasalis inferior to both external auditory meati. About 20 years earlier, he had reported many lines and angles in order to show the differences which may be depicted on a face, reporting his results at the Academy of Painting in Amsterdam (1770). Camper's horizontal plane was slightly modified by Cuvier (1795)for use in his works on comparative anatomy. At the same time, Blumenbach defined the norma verticalis of the cranium when lying horizontally, as observed from above.

Cranial reference systems underwent a major additional development in the nineteenth century with the development of phrenologic craniometry as defined in Edinburgh by the Scotsman Combe (1839). From his research on brain proportions, Combe proposed a frontoparietal line, which was to be defined later by one of his pupils, Morton (1839), in the United States, as the line joining the frontal to the parietal ossification centers of the skull.

B The Need for a Consensus

Given the presence of several reference lines, an attempt to find a consensus became obvious and necessary. Following a meeting in Göttingen, German anthropologists adopted the line advocated by Von Baer, which corresponds to the superior border of the zygomatic arch, and named it the horizontal line of Göttingen (1860). This line modifies to some extent the line of Lucae (1872) who defined as the horizontal, the line passing through the axis of the zygomatic arches.

At the same time in France, Broca (1862), in one of his major contributions on the natural position of the head, observed that the horizontal plane corresponds to the alveolar-condylar plane, defined as the reference plane passing through the inferior aspect of the occipital condyles and joining the middle of the alveolar ridge. Broca considered and defended this plane as the horizontal plane of the cranium (1873). An alternative was proposed by Hamy, namely, the glabella-lambda plane, which was roughly parallel to the latter. From 1862 to 1877, Broca evaluated this plane with respect to many others, such as the masticatory plane, the glabellar-occipital, the nasion-opisthion, and the nasion-inion, pointing to their variability as compared to the alveolar-condylar plane (1862), which he considered as the skull reference baseline (1873), or the plane of the "vision horizontale" (1862), also called the "visual plane" (1873) and later the "bi-orbital" plane (1877) (Fig. 2.1). A century later, this plane was described, using computerized assisted tomography (CT), as the neuro-ocular plane (Cabanis et al. 1978).

According to Topinard (1882), the English anthropologists accepted Broca's choice of the visual plane as the reference plane, while the Germans remained attached to Merckel's "orbito-auditory" plane (1882), also named "auriculo-suborbital" plane by Ihering (1872), and modified by Virchow and Hoelder to become the "supra-auricular-infra-orbital" plane. The latter plane was retained during the Munich Con-

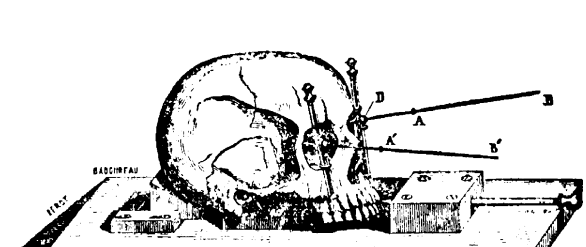


Fig. 2.1. The "bi-orbital" plane of Broca (1877)

gress (1877) and adopted in Frankfurt as the "infra-orbital-meatal" plane, widely known as the Frankfurt-Virchow plane, which received the general acceptance of most of the anthropologists of the time.

C Classification of the Cephalic Reference Planes

A great number of cranial and cephalic reference planes and lines have been described, which are of variable importance based on an anatomic, phylogenetic or anthropologic point of view. Saban (1980), in an attempt to codify the available data in this field, proposed a classification of these reference lines and planes based on anatomic grounds. The craniofacial references reported in his exhaustive review of the literature are grouped as follows: craniofacial planes based on external landmarks, including superior horizontal planes (Table 2.1), inferior horizontal planes (Table 2.2), base of the skull planes (Table 2.3) and vertical planes (Table 2.4); and craniofacial planes based on endocranial landmarks (Table 2.5).

Some of these are of great interest as they are used in anthropology as well as in radiology and are widely applied. This includes the Frankfurt-Virchow plane, the nasion-opisthion, the nasion-basion, and others. Olivier (1978) pointed out, in view of comparative studies on craniofacial planes, that the nasion-opisthion and the Frankfurt-Virchow planes are remarkably constant. Other reference planes have been rediscovered and reevaluated with respect to their potential accuracy in regional anatomy and imaging studies.

D The Choice of a Nomenclature

The development and diversification of increasingly complex radiology procedures made a unified and pragmatic approach to cephalic orientation a necessity. The need for a universal consensus was obvious. In a study meeting of the World Federation of Neurology, held in Milan in 1961 and oriented toward problems of projections and nomenclature, the commission of nomenclature retained as basal reference lines two so-called horizontal baselines of radiological importance: (1) the anthropological basal line, and (2) the orbitomeatal (or canthomeatal) basal line (WFN 1962). These lines meet at an angle of 10° (Fig. 2.2).

II Brain Horizontal Reference Lines and Planes

A total of six cephalic reference lines and planes are currently used in neuroimaging fields, which are suitable for diagnostic, functional or interventional purposes (Fig. 2.3, Table 2.6). These are: the bicommissural plane (Talairach et al. 1952), and the intercommissural plane (Schaltenbrand and Bailey 1959), the cephalic reference plane of Delmas and Pertuiset (1959), the neuro-ocular plane (Cabanis et al. 1978), the callosal plane (Olivier et al. 1985), and the chiasmatico-commissural plane (Tamraz et al. 1989, 1990).

Table 2.1. Superior horizontal cranial reference lines (modified from Saban 1980)

Literature reference	Reference line	Description
Hamy 1873	Glabella-lambda line	Roughly parallel to the alveolar-condylar plane of Broca
Krogmann 1931	Horizontal line	Parallel to Frankfurt plane, proceeding from the nasion
Lucae 1872		Axis of the zygomatic arches
Merkel 1882	Horizontal orbital-auditory line	Center of the external auditory meatus; inferior rim of the orbit
Morton 1839; Combe 1839	Horizontal plane	Plane passing through the four prominent points of the frontal and parietal bones
Perez 1922	Vestibian axis	
Virchow-Hoelder 1875 (Topinard 1882)	Supra-auricular-suborbital plane Horizontal line of Munich (1877)	Superior border of the external auditory meatus; inferior border of the orbit
Von Baer 1860	Horizontal line of Göttingen	Superior border of the zygomatic arch

Table 2.2. Inferior horizontal cranial reference lines (modified from Saban 1980)

Literature reference	Reference line	Description
Barclay 1803	Inferior facial plane	Tangent to inferior border of the mandible
Blumenbach 1795	Cranium in norma verticalis	Lying on its base over a horizontal plane
Broca 1862	Plane of mastication	Inferior border of the teeth of the maxilla
Broca 1862	Horizontal plane of the head Alveolar-condylar plane Cardinal plane of the cranium (1873)	Alveolar point at the inferior border of the alveolar ridge – inferior aspect of both occipital condyles
Broca 1862	Plane of horizontal vision, or visual plane (1873) or bi-orbital plane (1877)	The natural attitude of the head is that which permits the eyes to reach the horizon without muscular contraction
Daubenton and Daele 1764	Plane of the foramen magnum	Center of the posterior edge of the occiput – condylar facet
Camper 1791	Horizontal plane	Spina nasalis anterior – center of the external auditory meati
Doornik 1808	Horizontal line	Incisors – most prominent point of the occiput
His 1860, 1876	Horizontal line	Spina nasalis anterior – opisthion (plane perpendicular to midsagittal)
Lucae 1872	Horizontal line	Spina nasalis anterior – basion
Martin 1928	Line of the alveolar ridge or horizontal alveolar line	Alveolar border between median incisors and the molars (study of the mandible)
Martin 1928	Line of the base of the skull	Nasion-basion (perpendicular to midsagittal plane)
Spix 1815	Alveolar-condylar plane	Tangent to the inferior aspect of the occipital condyles – median-most declivitous point of the superior alveolar ridge

Table 2.3. Reference lines from the base of the skull (modified from Saban 1980)

	Literature reference	Reference line Description
Aeby 1862	Nasion-basilar plane	Base of the nose – basion
Barclay 1803	Inion-glabellar line	Horizontal of Schwalbe (glabella-inion line)
Broca 1872	Nasion-opisthion line	Base of the nose (nasion) – opisthion
Broca 1872	Nasion-inion line	Base of the nose (nasion) – inion
Bell 1805	Basion-supraorbital line	Basion – superior orbital rim
Keith 1910	Subcerebral plane	Median frontomalar symphysis – median parietomastoid symphysis
Martin 1928	Glabella-opisthion line	Glabella – opisthion

A The Bicommissural Reference Plane

The bicommissural plane (AC-PC) of Talairach et al. (1952), is defined as the plane through the line joining the upper border of the anterior commissure (AC) to the lower border of the posterior commissure (PC) (Figs. 2.3, 2.4). It is widely accepted and used by numerous neurosurgeons and a large community of neuroradiologists, mainly since the advent of CT. The intercommissural plane joins the center of both the anterior and posterior commissures (Schaltenbrand and Bailey 1954, 1959).

Table 2.4. Vertical reference lines of the skull (modified from Saban 1980)

Literature reference	Reference line	Description
Busk 1861	Vertical plane	Auriculo-bregmatic line
Bell 1806	Vertical axis of the cranium	Cranium maintained in equilibrium over a stick held through the center of the foramen magnum
Clavelin 1932	Vertical plane of the mandible	Glenion – posterior border of the mandible
Klaatsch 1909	Vertical line	Bregma – basion
Maly 1924	Vertical plane of the orbital aperture	Superior border – inferior border of the orbital aperture

Table 2.5. Cranial reference lines based on endocranial landmarks (modified from Saban 1980)

Literature reference	Reference line	Description
Barclay 1803	Palatine plane	Passing through the palatine vault
Beauvieux 1934	Plane of the ampullas	Passing through the three ampullas of the semicircular canals
Bjork 1947	Horizontal plane	Nasion – center of the sella turcica
Girard 1911	Plane of the horizontal semicircular canal	
Huxley 1863	Basi-cranial axis or basi-occipital line	Middle of the anterior border of the foramen magnum – anterior extremity of the sphenoid
Villemin and Beauvieux 1937	Nasion-opisthion line	
Walther 1802	Horizontal line	Crista galli-inioning)

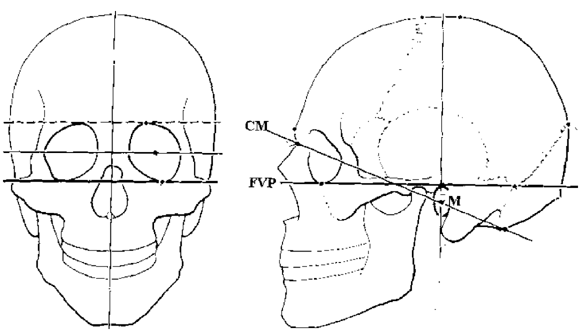


Fig. 2.2. Radiologic reference baselines, modified according to the WFN (1962). *CM*, canthomeatal baseline; *FVP*, anthropological baseline

Table 2.6. Major brain reference lines (suitable for neuroimag

Brain horizontal planes / lines:
1. Bicommissural plane (Talairach et al. 1952, 1957) and intercommissural plane (Schaltenbrand and Bailey 1954, 1959) 2. Cephalic plane (Delmas and Pertuiset 1959) 3. Neuro-ocular plane (Cabanis et al. 1978) 4. Callosal plane (Olivier et al. 1985) 5. Chiasmato-commissural plane (Tamraz et al. 1989, 1990)
Brain vertical planes / lines:
1. Commissuro-mamillary plane (Guiot and Brion 1958) 2. Commissural-obex plane (Tamraz et al. 1989, 1991) 3. Commissuro-mamillary plane (Baulac et al. 1990)

1 Biometric Data

The interest of a great number of anatomists, anthropologists and neurosurgeons in this reference line explains the importance of the data available in the scientific literature based on these bicommissural landmarks (Talairach et al. 1952, 1957, 1967; Schaltenbrand and Bailey 1959; Salamon and Huang 1976; Szikla et al. 1977; Talairach and Tournoux 1988).

Neuroradiology has provided stereotactic validation of this reference plane at least for the deep nuclear structures of the brain, explaining its frequent

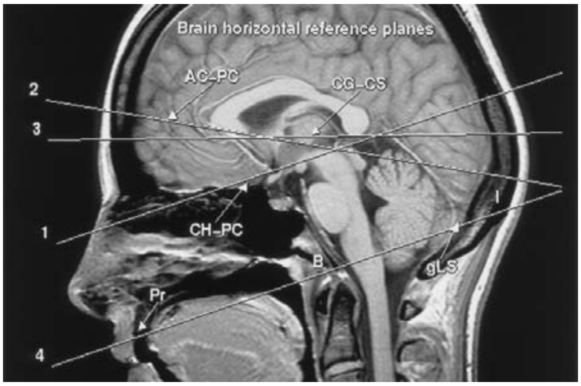


Fig. 2.3. Horizontal brain reference lines and planes. *AC-PC*, bicommissural plane; *CG-CS*, callosal plane; *CH-PC*, chiasmatico-commissural plane

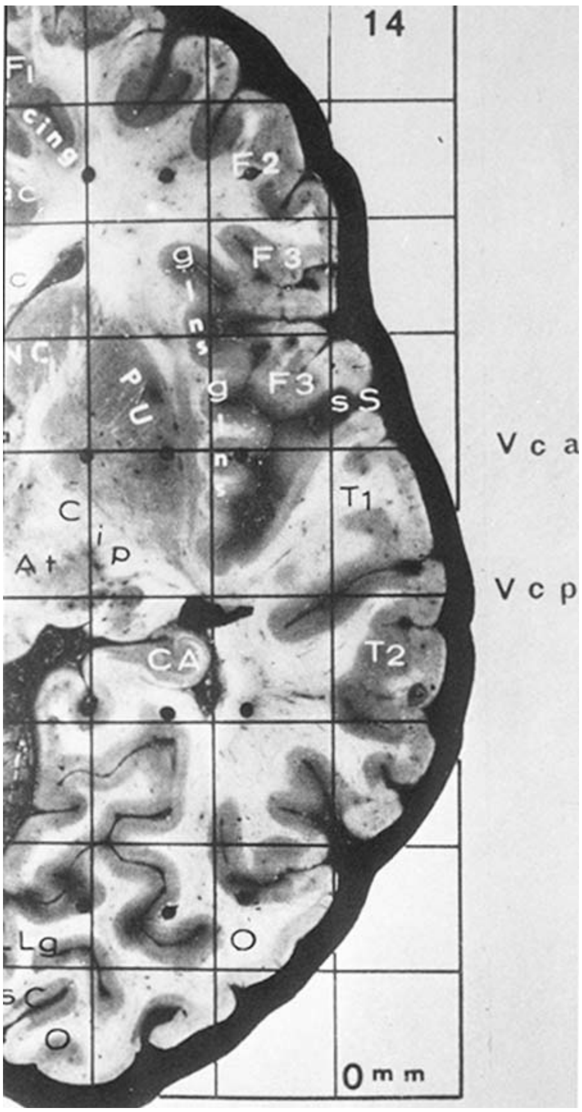


Fig. 2.4. The bicommissural plane of Talairach et al. (1952). (From Talairach et al. 1967)

use in brain imaging mainly since the advent of CT (Michotey et al. 1974; Salamon and Huang 1976; Szikla et al. 1977; Habib et al. 1984; Vanier et al. 1985; Gelbert et al. 1986; Bergvall et al. 1988; Rumeau et al. 1988).

According to Cabanis and Iba-Zizen the canthomeatal line (OM), retained as the radiological reference line (WFN 1962) which joins the outer canthus of the eye to the center of the auditory meatus, the latter corresponding cutaneously to the tragion, has been shown to be very close (1.4±2.7°) to the bicommissural line (Szikla et al. 1977) (Fig. 2.5). This observation has revived interest in external references. Other similar observations have been reported by Tokunaga et al. (1977) and Takase et al. (1977), who tried to demonstrate the approximate parallelism of the glabella-inion line (GIL), which joins the glabella to the inion, i.e., the external occipital protuberance and the fronto-occipital line (FOL) defined as the longest endocranial fronto-occipital diameter, with the bicommissural line (Fig. 2.6). Nevertheless, we agree with Bergvall et al. (1988) that these external landmarks, although suitable for different imaging modalities and helping patient positioning in the routine practice, are much too approximate and unreliable for precise anatomical and topometric studies. The opinion that the reference and the related target structure ought to pertain to the same ontogenetic system is still accepted.

Concerning the landmarks of the AC-PC line, i.e., the AC and the PC, significant variations responsible for potential errors may be observed with variations in AC diameter ranging from 2 to 5 mm, considering PC at a fixed position. Such variations may correspond to a difference of up to 7° in angle. To avoid such variations dependent on the diameter of the AC, Tokunaga et al. adopted a center-to-center positioning of the reference plane. On the other hand, a center-to-center orientation of the AC-PC line, called the intercommissural line (Amador et al. 1959), is used (Tokunaga et al. 1977) in order to minimize variation in the determination of the end points at the landmark levels since the center of AC is easier to define than its limiting border, which varies with the resolution of the MR system and slice thickness. From an imaging point of view such observations are obvious. Considering AC, we agree with Delmas and Pertuiset (1959) that the inferior border of AC is easier to delimit than its superior border, minimizing errors that could be introduced by the proximity of the anterior columns of the fornix (Tamraz et al. 1990). For accuracy and preciseness based on anatomic grounds, as presently obtained using midline

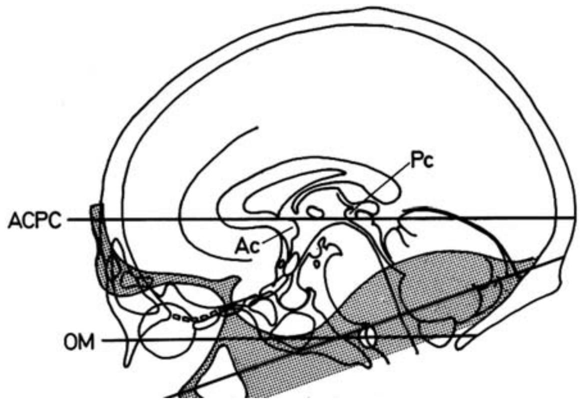


Fig. 2.5. Close parallelism between the canthomeatal line (*OM*) and the bicommissural line (*ACPC*). *AC*, anterior commissure; *PC*, posterior commissure. (According to Cabanis and Iba-Zizen; from Szikla et al. 1977)

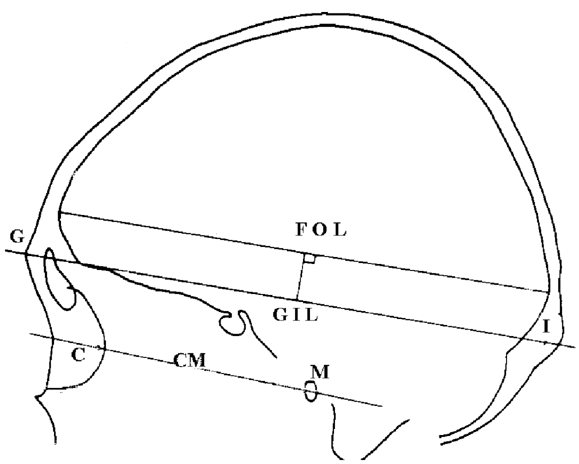


Fig. 2.6. Approximate parallelism of glabella-inion line (*GIL*) and fronto-occipital line (*FOL*), with the canthomeatal line (*CM*). (From Tokunaga et al. 1977, and Takase et al. 1977)

brain commissures, the choice of landmarks ought to be adapted to the imaging system being used.

Reference to stereotactic and topometric atlases is necessary in order to best achieve reliable clinical and anatomical correlations using MR imaging and accurate coordinates and landmarks (Talairach et al. 1957, 1967; Schaltenbrand and Bailey 1959; Delmas and Pertuiset 1959).

2 Anatomic and Imaging Correlations

This reference system provides a definite and accurate relationship to the central gray nuclei (Talairach et al. 1957; Schaltenbrand and Bailey 1959). Anatomically, this reference line roughly follows the direction of the hypothalamic sulcus, separating the thalamus and the hypothalamic region. Thus, it totally differs from the chiasmatico-commissural line on anatomic, ontogenetic and phylogenetic grounds, the latter being situated more caudally at the level of the diencephalon-mesencephalic junction.

The bicommissural line also maintains to some extent reliable relationships to telencephalic structures and helps in the localization of individual gyri on the brain cortex as demonstrated by numerous works carried out by Salamon and Talairach. The major brain sulci seem to maintain relatively constant relationships with respect to the bicommissural line (Szikla and Talairach 1965; Szikla 1967; Talairach et al. 1967). As pointed out by Rumeau et al. (1988), Talairach noted the increasing variations observed with respect to cortical topography. These may show differences in location up to 20 mm from central to peripheral regions. Moreover, in their neuroimaging and anatomic study of 30 brains oriented according to the bicommissural line, these authors reported difficulties in the identification of three major regions: the temporal parieto-occipital, the pars triangularis of the inferior frontal gyrus, and the paracentral lobule, due to important individual variations.

Localization of the central sulcus is one of the most important applications of the bicommissural line of Talairach, which is found between the anterior (VCA) and posterior (VCP) vertical lines perpendicular to the AC-PC. These are tangent to the posterior border of the AC and the anterior border of the PC, respectively. (Fig. 2.7). In axial cuts, as reported by Talairach et al. (1967), the central sulcus is found

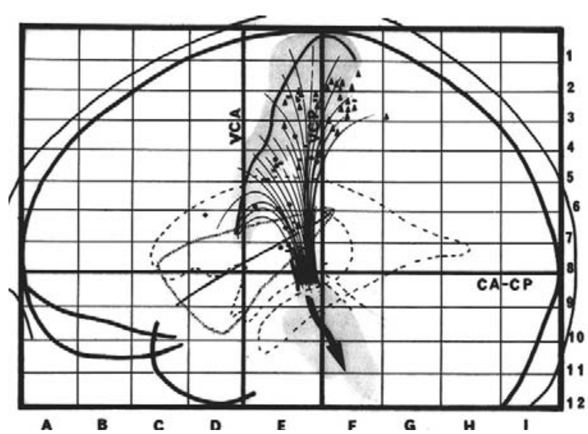


Fig. 2.7. The central sulcus: anatomic correlations using the bicommissural coordinates. (From Talairach et al. 1967)

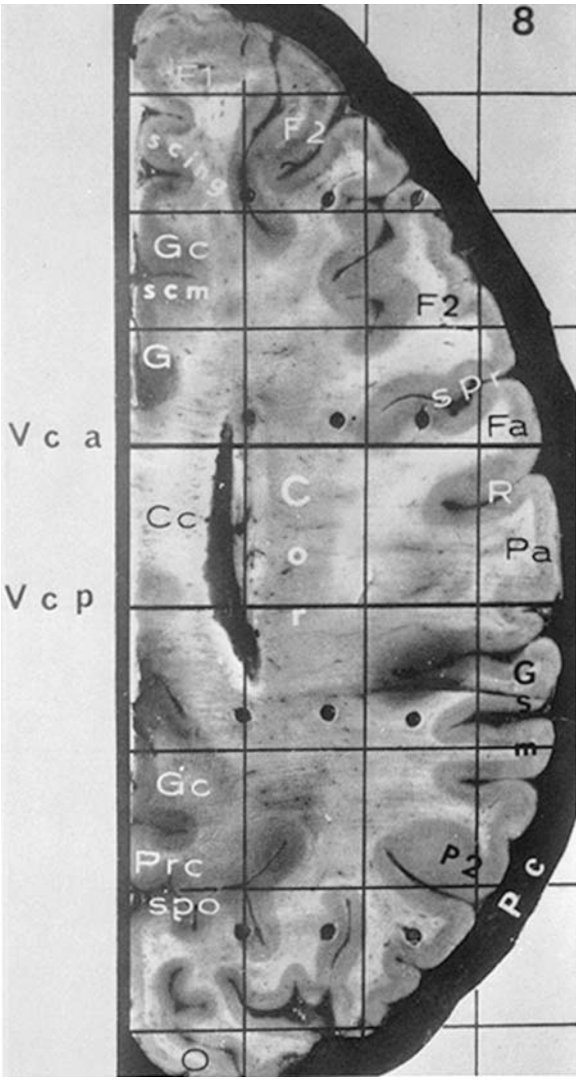


Fig. 2.8. The central sulcus: anatomic correlations using the bicommissural coordinates. (From Talairach et al. 1967)

about midway between the anterior to posterior extension of the supraventricular cuts (Fig. 2.8). It originates caudally, 0.5 cm behind or in front of the VCA (Fig. 2.9) and ends cranially at about 1 cm posterior to the VCP. Its sinuous course is roughly contained between the VCA and VCP.

Recently, Devaud et al. (1996), proposed a new method to localize the central sulcus using the "rolandic line". This approach, as proposed, is based on the callosal line as defined by Olivier et al. (1985), joining the most inferior points of the genu and the splenium of the corpus callosum. The long axis of the central sulcus follows the direction of the rolandic line which seems to be a reliable way to identify the axis on a lateral image of the brain. In the view of the authors this is even more accurate for central sulcus identification than the vertical planes defined using the bicommissural system of Talairach (Szikla and Talairach 1965; Talairach et al. 1967).

The methodology adopted based on the callosal system (Oliver et al. 1985, 1987) comprises the callosal plane and the anterior and posterior vertical callosal planes, to which are added a superior tangential plane, rising to the highest point of the hemisphere, and a parallel inferior plane, passing through the lowest point of the temporal fossa. The rolandic line is generated by joining the two intersection points between the callosal planes and the tangential hemispheric extending from the posterior superior to the anterior inferior points, parallel to the direction of the central sulcus (Fig. 2.10). According to the authors, the central sulcus can be identified on any sagittal cut using the rolandic line, which may also be displayed on the lateral angiograms. The inferior tangential line is traced from the lateral sagittal image at a distance of 30 mm from the midsagittal cut. The major anatomic correlations observed by the authors show that the rolandic line seems to follow the direction of the central sulcus, beginning at the sulcal fundus or at the depth of its midextension in nearly 90% of cases.

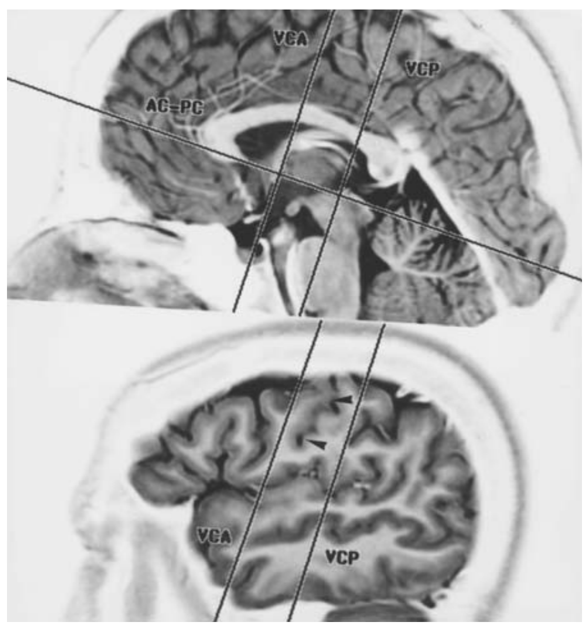
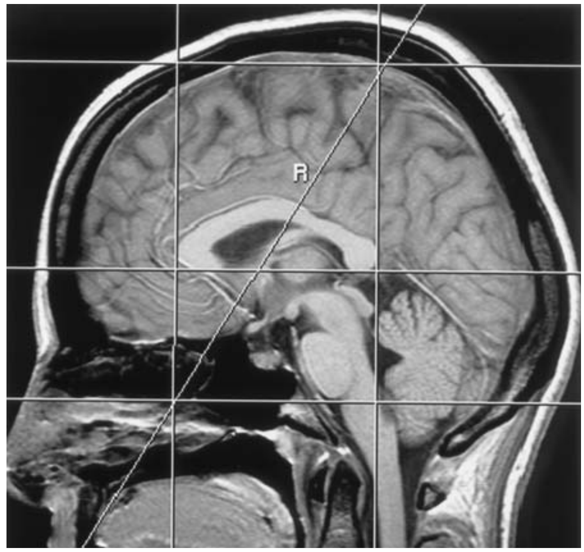
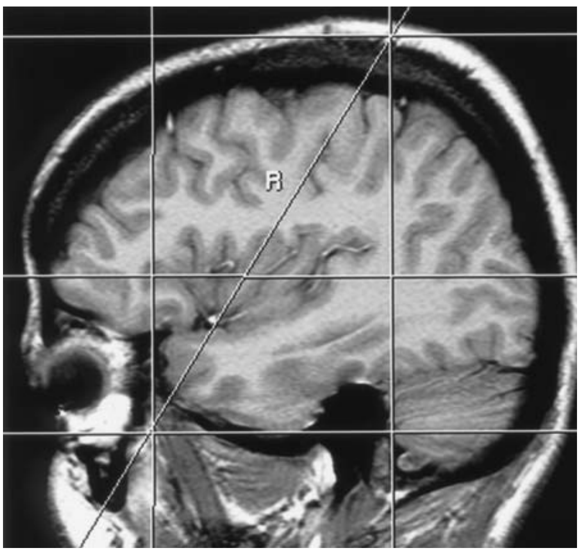


Fig. 2.9. MR correlations: lateral projections of VCA and VCP that could help to localize the central sulcus (*arrowheads*)

Fig. 2.10A–C. The rolandic line (*R*) based on the callosal orientation plane (Olivier et al. 1985). (According to Devaux et al. 1996)



A



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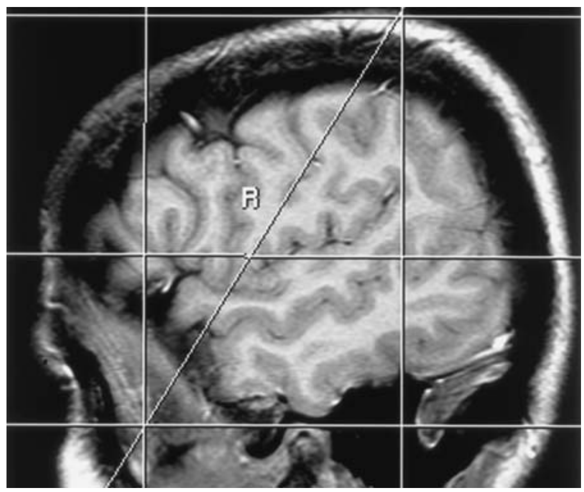


C

To conclude, despite its deviations, the bicommissural brain reference line is most useful in the localization of the central gray nuclei and the identification of the central sulcus. The advent of MRI, with its direct multiplanar and three-dimensional capabilities, has modified our approach to brain anatomy and sectional imaging (Figs. 2.11–2.13).

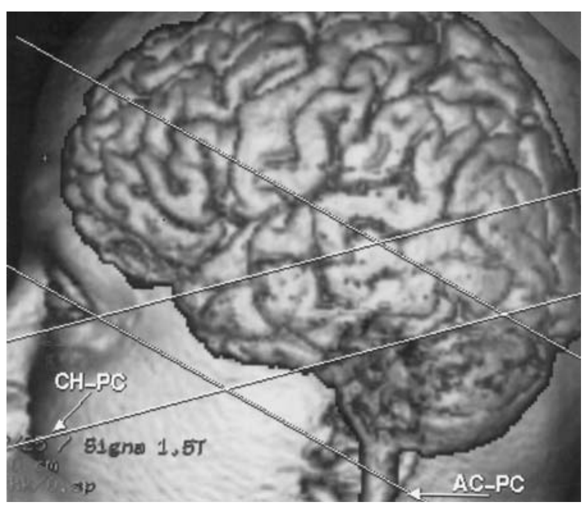


Fig. 2.11. The bicommissural plane (*AC-PC*) most suitable for the study of the central region

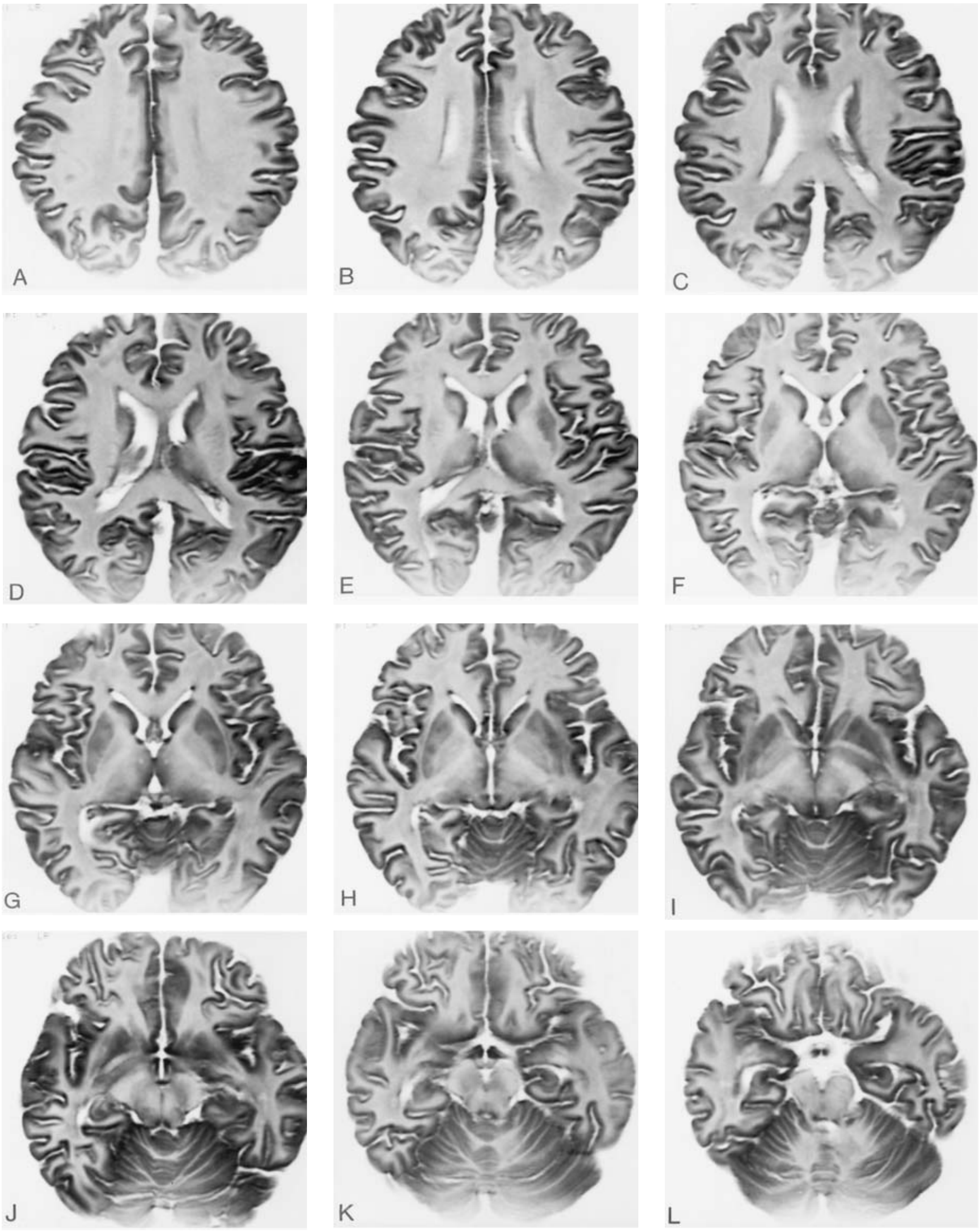


Fig. 2.12A–L. Successive 3 mm axial cuts of a formalin-fixed brain parallel to the AC-PC reference, as compared to the chiasmatico-commissural plane (*CH-PC*) most suitable for the study of the perisylvian region and the temporal lobes

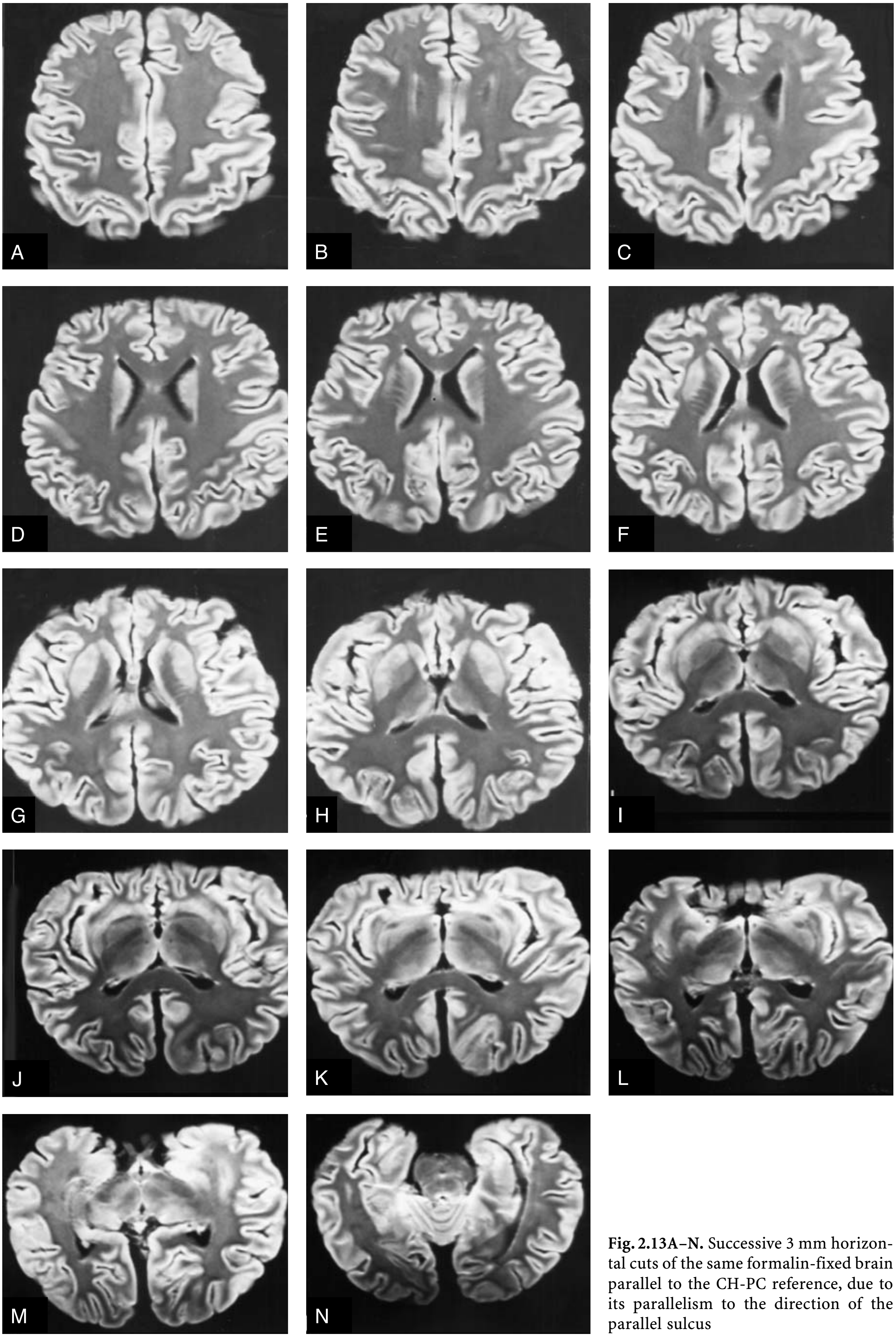


Fig. 2.13A–N. Successive 3 mm horizontal cuts of the same formalin-fixed brain parallel to the CH-PC reference, due to its parallelism to the direction of the parallel sulcus

B The Delmas and Pertuiset Reference Plane

1 Anatomic and Imaging Correlations

In their atlas "Topométrie crânio-encéphalique chez l'homme", Delmas and Pertuiset (1959) defined a horizontal brain reference plane passing rostrally through the lower part of the AC and caudally tangent to the highest part of the floor of the third ventricle (Figs. 2.14, 2.15). Instead of those based on the AC-PC plane, landmarks used by these authors better delineated the inferior border of the AC, freeing it from the close relation to the anterior columns of the fornix. This is, in our opinion, even more pertinent when a midsagittal MR cut is used to orient the slab. Partial volume effects, particularly in the case of thick slices, may introduce a significant positioning error, as previously reported for the AC-PC. The other posterior landmark shows a great advantage over PC, because this latter area, situated caudally to the posterior perforated substance, appears to be much less topometrically variable. The position of the PC varies with the degree of dilatation of the third ventricle and the cerebral aqueduct.

The frontal plane, perpendicular to the reference and tangent to the anterior border of PC, is called the posterior commissural plane. The other one, anteriorly located and parallel to the previous, as well as tangent to the posterior border of the AC, is named the anterior commissural plane. It is a more accurate reference for the study of adjacent structures, such as the pallidum, caudate, and amygdaloid nuclei. The two vertical planes are separated by about 20 mm according to the authors.

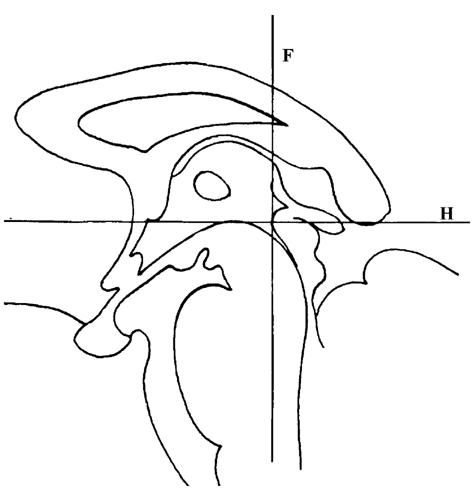


Fig. 2.14. The brain reference plane of Delmas and Pertuiset (1959)

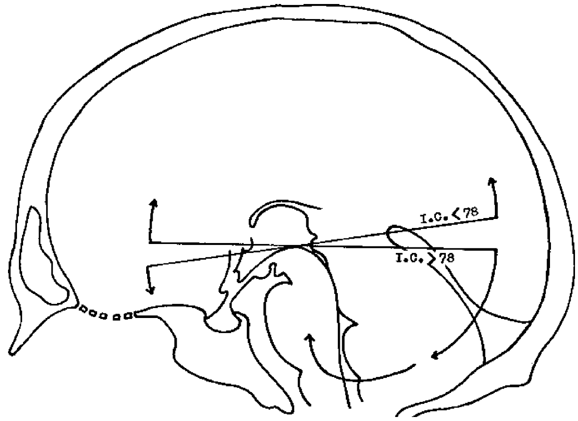


Fig. 2.15. Topometric variations of brain structures with respect to the cephalic index (*IC*) according to Delmas and Pertuiset (1959)

It is interesting to note, as reported by the authors, that the horizontal cuts included in the atlas of cross-sectional anatomy correspond to an anatomic position in which the brain reference plane is parallel to the cranial plane on which the head was oriented, the Frankfurt anthropological baseline. This atlas may be obviously used as a reference for anatomic imaging correlations when based on the infraorbital meatal baseline, i.e., the anthropologic baseline (WFN 1962), where the head is sectioned horizontally, as shown in the atlas, with a parallelism between the line of Frankfurt and the brain reference line.

2 Topometric Findings

This work, presented as a three-dimensional atlas, provides important topometric data for 21 anatomic structures studied by the authors which are: the anterior, centromedian, dorsomedian, ventral anterior, ventral posterior, lateral and medial pulvinar thalamic nuclei, the lateral and medial geniculate bodies, the mamillary body, the red nucleus, the subthalamic nucleus, the substantia nigra, the zona incerta, the amygdala, the pallidum, the caudate nucleus, the putamen, the superior and inferior colliculi, and the dentate nucleus of the cerebellum. Interesting data concerning variations in volume and position of such deep brain structures with respect to the cephalic index are shown.

The authors classified the 21 structures into three groups based on their volumes. The first group comprises the mamillary body, the lateral and medial geniculate bodies, and the superior and inferior colliculi. This group did not show any variations in volume or shape. The second group, represented by the nucleus subthalamicus, the putamen, the amygdala, and the dentate nucleus, showed symmetrical variations in volume. Of the remaining structures, some presented an asymmetric increase in volume, including the dorsomedian, centromedian, ventral posterior and the medial pulvinar thalamic nuclei, and the zona incerta, but most of the others failed to show statistically significant correlations.

Considering variations in position, the authors emphasized the close relation observed based on the cephalic index (Fig. 2.15) and separated the variations observed in individuals in which the cephalic indices were between 78 and 89 (Figs. 2.16, 2.17) from those in the 70 to 78 interval (Figs. 2.18, 2.19). The greatest statistical significance has been observed in the former category, i.e., in cases of mesocephaly rather than brachycephaly. On the other hand, these variations differ also with respect to the position of the anatomic structure as compared to the midsagittal plane. The medially located structures, including the red nucleus, substantia nigra, subthalamic nucleus, mamillary body, dentate nucleus, and the dorsomedian, centromedian and medial pulvinar thalamic nuclei, are displaced posteriorly and upward. The paramedial structures are displaced anteriorly in an upward or downward direction. This includes the thalamic anterior and ventral anterior nuclei, the medial geniculate body, and the amygdala. These two groups behave differently from the more laterally located structures, such as the lentiform and the caudate nuclei, which seem to vary in relation to the cortex.

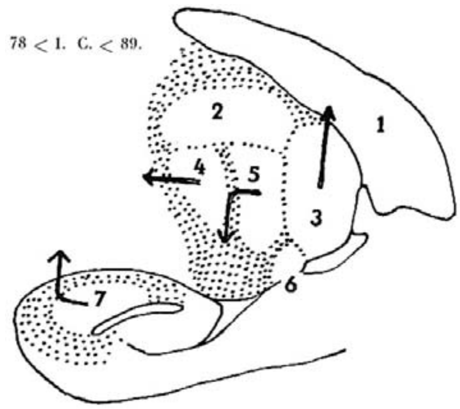


Fig. 2.17. Topometric variations observed in cephalic indices comprised between 78 and 89. *1*, lateral ventricle; *2*, ventral lateral thalamic nucleus; *3*, lateral pulvinar nucleus; *4*, ventral anterior thalamic nucleus; *5*, ventral posterior thalamic nucleus; *6*, lateral geniculate body; *7*, amygdala. (From Delmas and Pertuiset 1959)

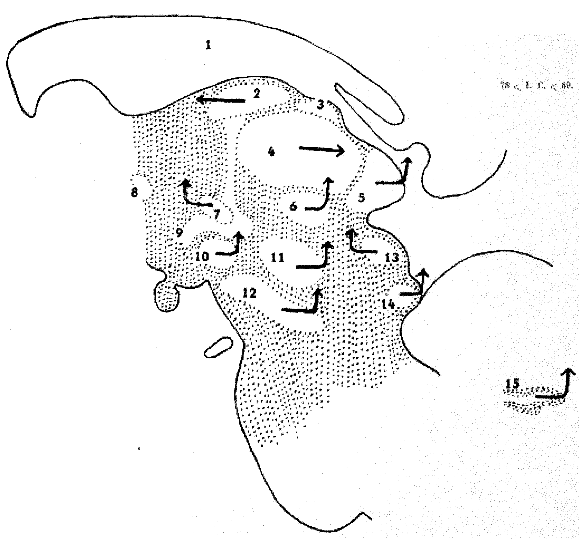


Fig. 2.16. Topometric variations observed in cephalic indices comprised between 78 and 89. *1*, lateral ventricle; *2*, anterior thalamic nucleus; *3*, lateral dorsal nucleus of thalamus; *4*, dorsomedial nucleus of thalamus; *5*, medial pulvinar nucleus; *6*, centromedian thalamic nucleus; *7*, zona incerta; *8*, anterior commissure; *9*, tegmental area; *10*, subthalamic nucleus; *11*, red nucleus; *12*, locus niger; *13*, superior colliculus; *14*, inferior colliculus; 15, dentate nucleus of cerebellum. (From Delmas and Pertuiset 1959)

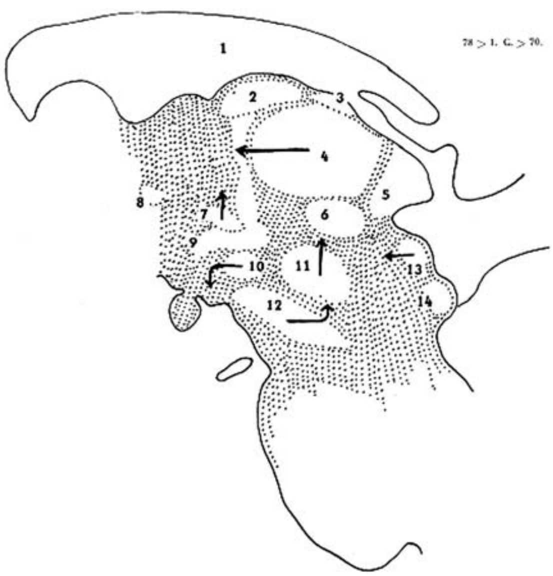


Fig. 2.18. Topometric variations observed in cephalic indices comprised between 70 and 78. *1*, lateral ventricle; *2*, anterior thalamic nucleus; *3*, lateral dorsal nucleus of thalamus; *4*, dorsomedial nucleus of thalamus; *5*, medial pulvinar nucleus; *6*, centromedian thalamic nucleus; *7*, zona incerta; *8*, anterior commissure; *9*, tegmental area; *10*, subthalamic nucleus; *11*, red nucleus; *12*, locus niger; *13*, superior colliculus; *14*, inferior colliculus; *15*, dentate nucleus of cerebellum. (From Delmas and Pertuiset 1959)

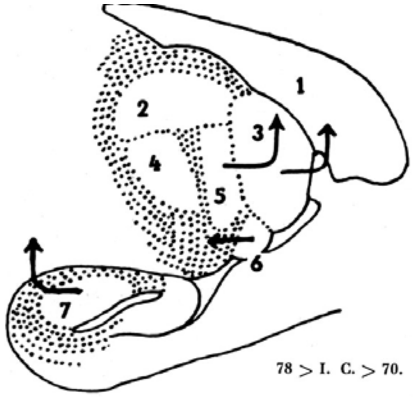


Fig. 2.19. Topometric variations observed in cephalic indices comprised between 70 and 78. *1*, lateral ventricle; *2*, ventral lateral thalamic nucleus; *3*, lateral pulvinar nucleus; *4*, ventral anterior thalamic nucleus; *5*, ventral posterior thalamic nucleus; *6*, lateral geniculate body; *7*, amygdala. (From Delmas and Pertuiset 1959)

C The Neuro-ocular Plane

The neuro-ocular plane (NOP), originally described in the CT study of the optic nerve in papilledema (Cabanis et al. 1978; Salvolini et al. 1978), best defines the cephalic orientation for scanning of patients with visual complaints. It is defined as the "plane passing through the lenses, the optic nerve heads and the optic canals, with the patient maintaining primary gaze" as shown on CT, and confirmed anatomically (Cabanis et al. 1978). It is now routinely used in CT and MR (Fig. 2.20), particularly in the exploration of patients presenting neuro-ophthalmological problems. The anatomic correlation obtained by Cabanis brought a definite confirmation to the clinical relevance of this cephalic orientation, which is most suitable for the exploration of the visual pathways (Fig. 2.21).

1 Anatomic and Imaging Correlations

NOP orientation provides the optimal conditions for CT or MR exploration of the intraorbital structures. The partial volume effect on the optic nerves is particularly reduced to a minimum (Cabanis et al. 1978; Brégeat et al. 1986). Anatomic, neuroradiologic, and clinical validations have been obtained (Tamraz 1983; Tamraz et al. 1984, 1985, 1988; Cabanis et al. 1981, 1982, 1988).

External cutaneous landmarks, experimentally determined and defined by the acanthion-tragion line (Fig. 2.22 A), are helpful to orient the patient's head in routine practice. Bony landmarks, defined by

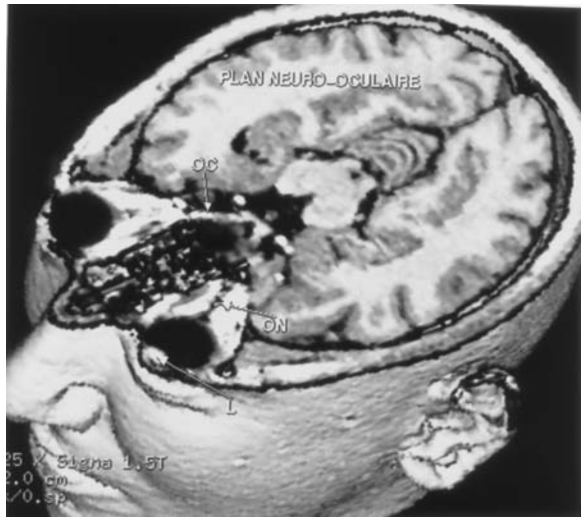


Fig. 2.20. The neuro-ocular plane (*NOP*) in a three-dimensional MR correlation, showing the cephalic landmarks in the axial plane: the lenses (*L*), the optic nerve heads (*ON*) and the optic canals (*OC*), as described by Cabanis et al. (1978)

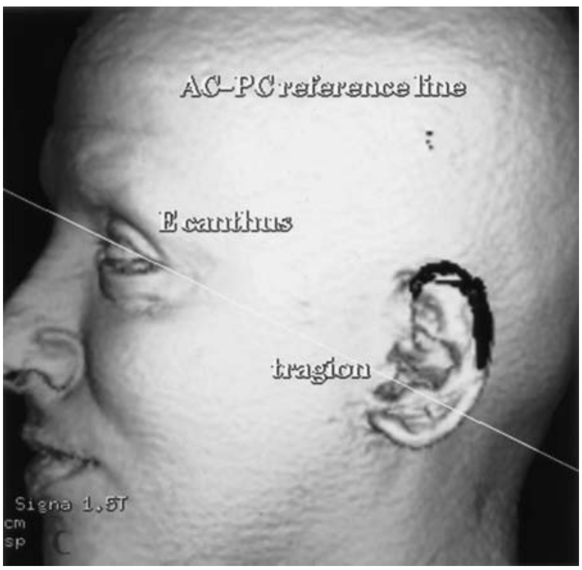
Fig. 2.21. The neuro-ocular plane (*NOP*), anatomic correlation. (Reprinted from Cabanis 1978)

the prosthion-opisthion line, are also available and may be used on a sagittal localizer (Cabanis et al. 1982).

The NOP is the most appropriate cephalic orientation for investigations in the axial and coronal

A

B

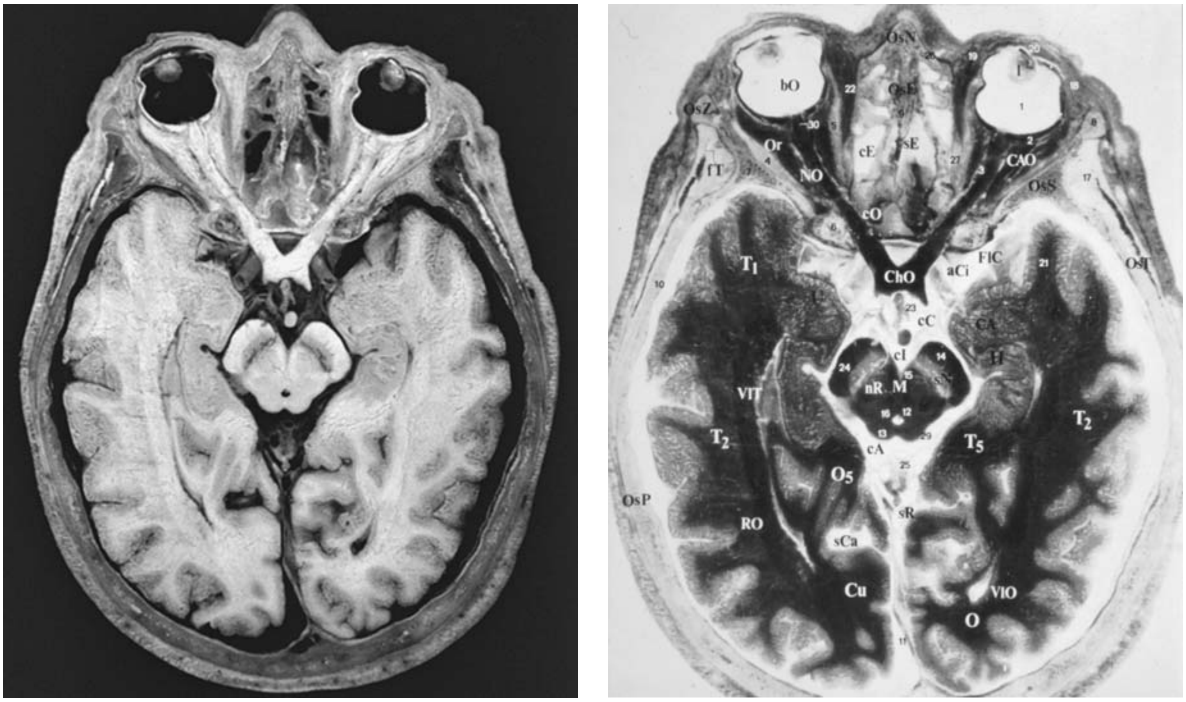


C

Fig. 2.22A–C. Cutaneous landmarks of the neuro-ocular plane (*NOP*) defined by the canthomeatal line (**A**) as compared to the CH-PC reference line (**B**) and the AC-PC reference line (**C**)

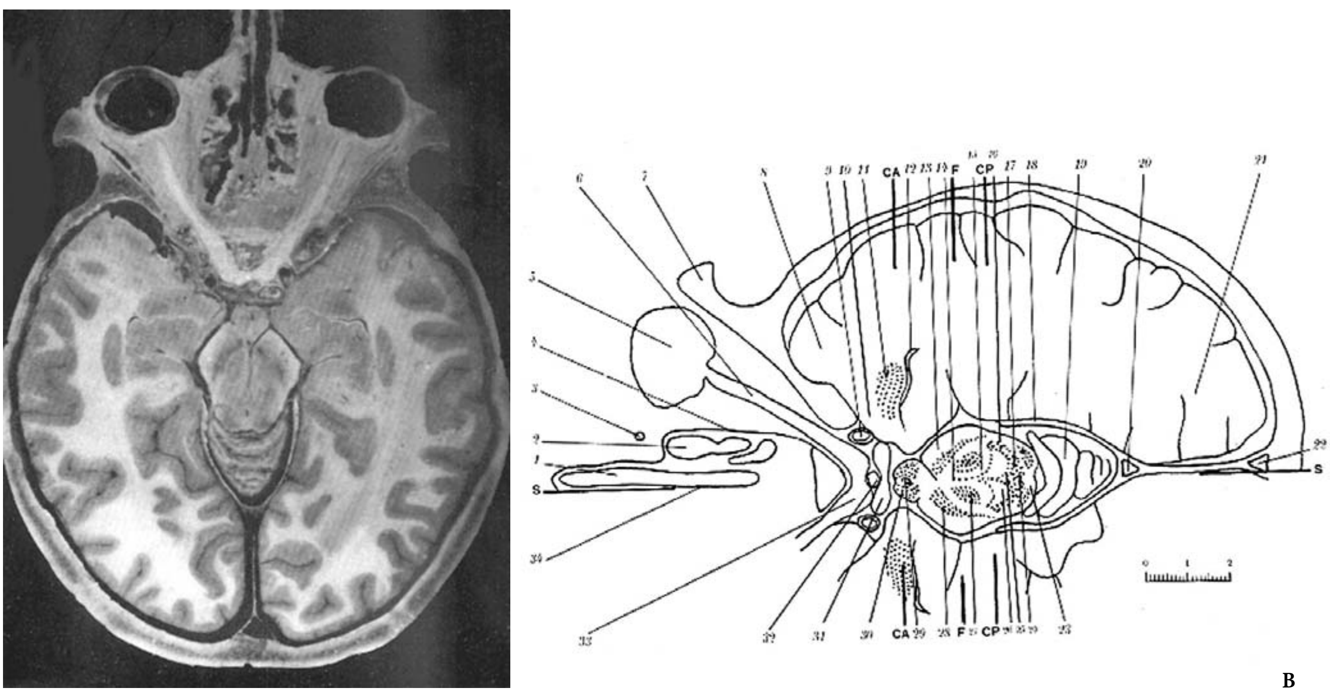
planes, for biometric studies, and for follow-up of eye diseases and examination of the intraorbital optic nerves. In fact, along its orbitocranial route, the visual pathway maintains a roughly horizontal orientation from the eyes to the calcarine fissure. For this reason, using the NOP as the cephalic reference plane appears to be the most accurate choice for the study of the brain and visual pathways, and the orbital optic nerves. This also applies to the screening and study of diseases involving the face and the skull base, due to a close parallelism with the Frankfurt-Virchow anthropologic reference baseline.

Such a reference atlas of cross-sectional anatomy of the head oriented in the NOP (Fig. 2.23), which includes the main anatomic correlations observed, may be used in routine practice for image interpretation (Tamraz 1983; Tamraz et al. 1984, 1985; Cabanis et al. 1988). The anatomic cuts in this work are detailed views based on these references. The coronal cuts used closely apply to the definition of the PC-OB line in the specimens reported. The perpendicular to the NOP is, in this case, presumably fortuitously parallel to PC-OB plane. It is not surprising that the respective MR correlations generally differ to some extent, as may also be observed in the published atlas (Fig. 2.37 p. 87). Actually, considering the axial landmarks, the perpendicular to the NOP is difficult to determine precisely and is angled about 10° as compared to the PC-OB plane. Similarly, the horizontal cuts reproduced in the atlas of Delmas and



A B

Fig. 2.23A,B. The neuro-ocular plane (*NOP*). Topometric findings. (From Tamraz 1983; Cabanis et al. 1988)



A B

Fig. 2.24A,B. Axial anatomic cut (C27–HS, 19 mm) passing through the orbital and canalicular optic nerves, with the specimen oriented according to the Frankfurt-Virchow plane (anthropological baseline), and reported as fortuitously parallel, in the published case, to the defined brain reference. (From Delmas and Pertuiset 1959)

Pertuiset (1959) and oriented according to the Frankfurt-Virchow plane, as previously mentioned, show a close anatomic similarity as compared to the NOP (horizontal cut C27–HS 19 mm, Delmas and Pertuiset 1959 p. 267). In this particular specimen (Fig. 2.24), a NOP-like orientation cut is shown and may be considered as being roughly parallel to the anthropologic line. The topometric results derived from the work of Delmas may, therefore, be used in imaging interpretation of the slices oriented according to the NOP as defined by Cabanis et al. (1978).

2 Topometric and Biometric Findings

One of the great advantages of the NOP reference plane is the possibility to perform oculo-orbital topometry (Cabanis et al. 1980, 1982). Numerous distance measurements have been defined with respect to an external bicanthal line, joining the lateral orbital rims in the NOP, and these are used in routine practice. An overview of these biometric data is given in Chap. 9.

Many authors have proposed reference planes for visualizing the intraorbital optic nerves with the least partial volume effect phenomena and with reduction of the amount of radiation to the lens during slice acquisition. Different approaches have been proposed. Most of the procedures reported are based on simple calculations of the orbital references with respect to the reference cranial baselines previously defined, the OM (–20°) and the anthropologic line (Van Damme et al. 1977; Hilal and Trokel 1977; Vining 1977; Cabanis et al. 1978; Unsöld et al. 1980).

Actually, the mean angle between the NOP and the Frankfurt-Virchow plane (FVP) is about –7° (Fig. 2.25). As a reminder, the orbitomeatal plane, which is

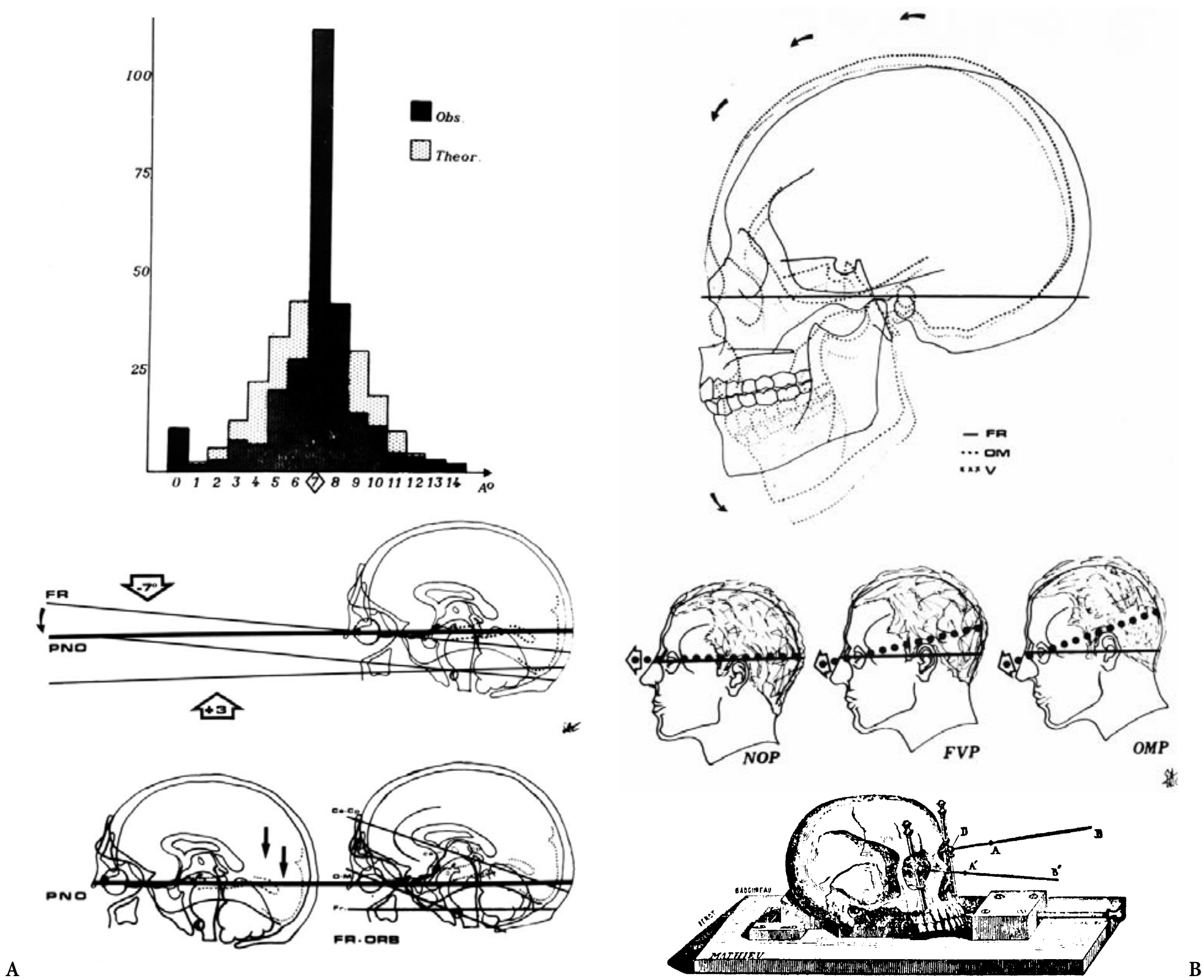


Fig. 2.25A,B. The neuro-ocular plane; biometric and topometric findings. (From Cabanis et al. 1982)

the classic radiologic reference plane (WFN 1962), is angled at approximately +10° relative to the FVP. Moreover, exhaustive work on the relation of the orbital axis plane to several craniofacial reference lines has been reported, including the important contribution from the comparative anatomy laboratory of Dr. Fenart in Lille (1982) to this field (Fig. 2.26, Table 2.7). Close parallelisms of the NOP with the alveolar-condylar plane, the hard palate plane and the prosthion-opisthion line (Saban 1980; Fenart et al. 1982), which may be used as external cranial landmarks to orient the slices on a lateral scout view of the skull by CT, may be retained and are actually helpful in routine practice.

In addition, such parallelisms explain the effectiveness of this cephalic orientation as a suitable reference for screening patients with diseases involving the orbitomaxillofacial region or the skull base.

The use of the NOP in comparative anatomic studies in vivo, reported in part in Chap. 9, and its angulation as compared to the FVP and the OM emphasizes its importance as a major anatomic and physiologic reference plane in hominids (Fig. 2.25). It is interesting to note also that the angle of the visual pathways with respect to the base of the skull changes with age due to the well-known occipital descent (Delattre and Fenart 1960). However, once maturation is complete, the angle between the visual pathways and the skull remains constant. Therefore, the angle between NOP and FVP becomes constant in the adult. As Delmas once stated: "...the vision of man rises to encounter the horizon".

D The Callosal Plane

The callosal plane was defined by Olivier et al. (1985, 1987) as the reference plane "passing by the lowest point of the genu and splenium of the corpus callosum and extending through the whole brain" (Fig. 2.3). The authors also defined orthogonal planes perpendicular to it. The planes tangent to the anterior border of the genu and to the posterior border of the splenium were named the anterior callosal and the

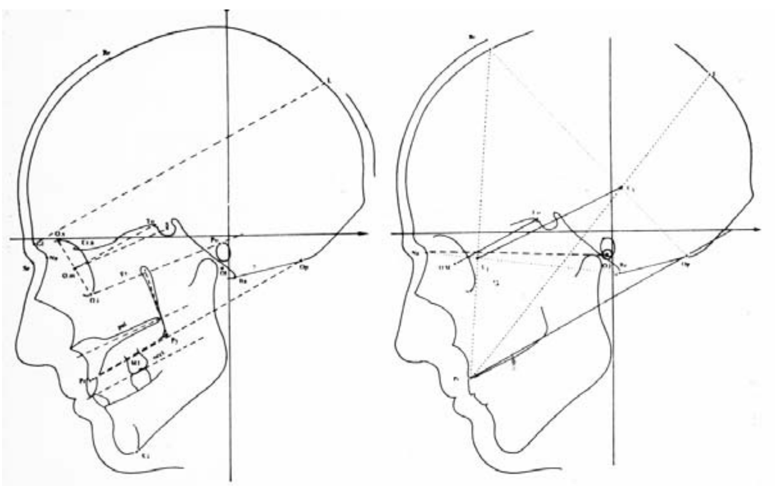


Fig. 2.26. The neuro-ocular plane, defined by the orbital axis (*OM-To*), as compared to various cranial reference lines. (According to Fenart et al. 1982; see Table 2.7 and Fig. 2.25). (In Cabanis et al. 1982)

Table 2.7. The orbital axis (*OM-To*) in relation to other cranial reference planes (from Fenart et al. 1982) (n=52)

Angle variations	Mean	Standard deviation
OM-To / midorbital axis – center of the sella turcica	6.27	1.47
OM-To / glabella-lambda plane	0.44	4.20
OM-To / prosthion-opisthion plane	−0.45	3.31
OM-To / Frankfurt-Virchow plane	7.08	4.12
OM-To / hard palate plane	4.63	3.91
OM-To / prosthion-pterygoalveolar (superior alveolar plane)	−2.19	4.23
OM-To / occlusal plane	2.05	4.15
OM-To / Cl-C3	3.32	4.70
OM-To / nasion-auricular plane	32.75	4.68

posterior callosal planes, respectively. A third perpendicular plane is drawn midway between the two and is called the midcommissural plane. The midcallosal plane, as defined, helps to localize the inferior part of the central sulcus (Fig. 2.27).

These landmarks are seen on midsagittal MR images and indirectly by digital subtraction angiography (DSA). The corpus callosum may be precisely localized on lateral projections showing both the arterial and venous phases. This permits the integration of MRI with angiographic data as well as data provided by positron emission tomography (PET), demonstrating that this reference is obviously suitable for multimodal imaging (Olivier et al. 1987).

The corpus callosum is the major telencephalic commissure influencing the shape of the adjacent cortical sulci, as may be demonstrated ontogenetically, emphasizing the suitability of this reference system for imaging within the telencephalon. It has been used for the preoperative identification of the central sulcus (Lehman et al. 1992). Integration of functional information with MR gyral data and stereotaxic implantation of depth electrodes for investigation of epilepsy have also been achieved using such coordinates.

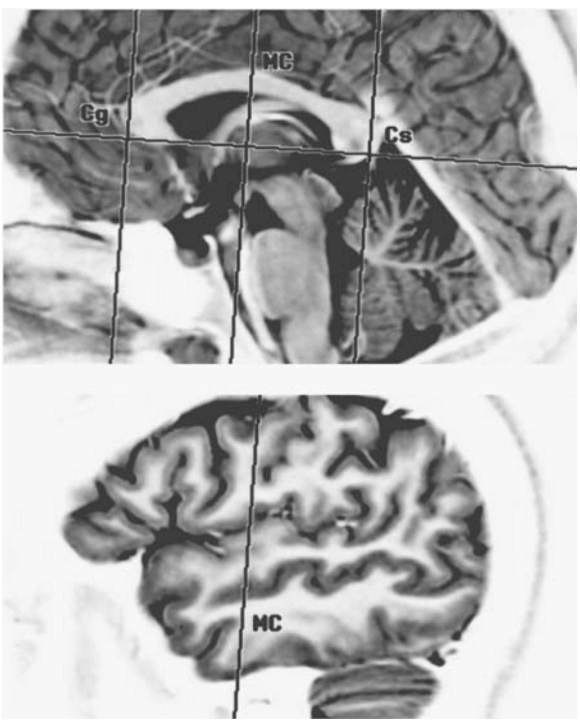


Fig. 2.27. The callosal reference plane. (After Olivier et al. 1985, 1987)

On the other hand, the relationship of this plane with the basal ganglia seems more tentative, as they are best analyzed using the AC-PC plane of Talairach.

E The Chiasmatico-Commissural Plane

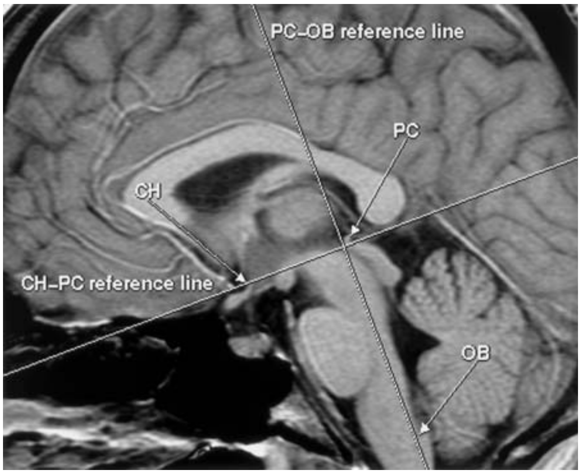
This horizontal reference line, the CH-PC, runs tangential to the superior border of the CH anteriorly, and to the inferior border of the PC posteriorly (Figs. 2.3, 2.28). These landmarks, based on brain commissures, are well depicted and easily recognized on an in vivo midsagittal cut of human, as well as all vertebrate, brains (Tamraz et al. 1989, 1990, 1991). The horizontal plane through this line can also be used in the comparative anatomy of vertebrates if needed.

The consistency of the angle between this line and the AC-PC, as demonstrated, serves to validate the choice of this pivotal line, situated as it is at the midbrain-diencephalic junction corresponding to the related flexure during ontogenesis. The plane has been shown to be truly horizontal in that it is perpendicular to the main axis of the brainstem, defined as the line tangential to the anterior border of the PC and joining the lowest extremity of the calamus in the floor of the fourth ventricle behind the obex (Fig. 2.29).

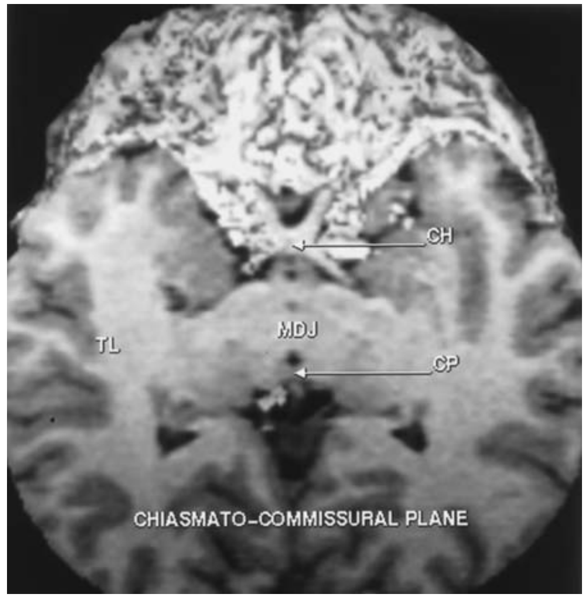
If the NOP is accepted as the anatomic and physiologic plane permitting erect posture in humans, the CH-PC, which is roughly parallel to it as compared to the direction of the temporal horn of the lateral ventricle, may be considered as the anatomic plane defining the temporalization of the brain. It is parallel to the direction of the parallel sulcus and, thus, to the lateral fissure, and orthogonal to the long axis of the brainstem. It is possible to consider that the CH-PC is for the brain what the NOP is for the position of the head, the former being perpendicular to the brainstem long axis and the latter being anatomically and physiologically related to the vertical axis of the body and cervical spine. Both reference planes present progressive variations throughout phylogenesis, as demonstrated by the progressive closure of the truncal angle.

1 Biometric Findings

To study the anatomic and anthropometric usefulness of the CH-PC, in vivo MRI findings in 100 patients were analyzed, using high field MRI (1.5 T). The statistical analysis of the in vivo measurements confirmed the consistency of the angle between the reference lines CH-PC and AC-PC.

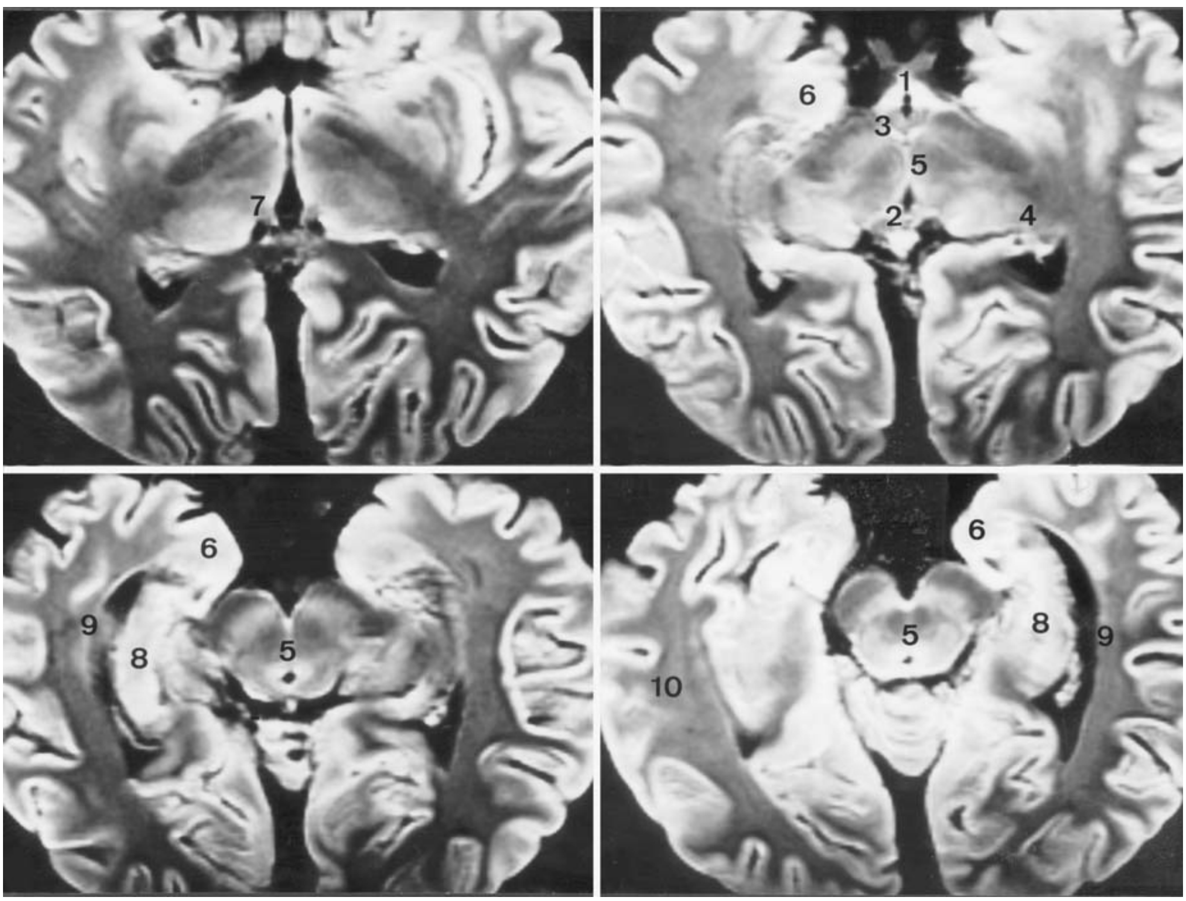


A



B

Fig. 2.28A,B. The chiasmatico-commissural (*CH-PC*) reference plane, defined as the plane tangent superiorly to the chiasmal point (*CH*) anteriorly, to the inferior border of the posterior commissure (*PC*) posteriorly, passing through the midbrain-diencephalic junction (*MDJ*) and showing the temporal lobes according to their long axis (*TL*). *PC-OB*, commissural-obex reference line. (Tamraz et al. 1990)



A B C D

Fig. 2.29A–D. The chiasmatico-commissural reference plane. Horizontal contiguous cuts (3 mm thick) of a formalin-treated specimen showing the anatomic landmarks of the CH-PC reference plane (**B**), passing through the chiasmal point (*1*), the mamillary bodies (*3*) and the posterior commissure (*2*), on the midline, and involving laterally the lateral geniculate bodies (*4*) at the midbrain-diencephalic junction (*5*). The upper contiguous cut (**A**) passes through the habenula (*7*) and the lower part of the thalamus; the lower cuts (**C**, **D**) are oriented along the long axis of the temporal lobes (*10*) and temporal horns (*9*) and show the amygdala (*6*) – hippocampus (*8*) complex

The results obtained were the following (Fig. 2.30):

a) The mean value of the angle formed by the lines CH-PC and AC-PC, called the commissural angle or CH-PC-AC (Fig. 2.31), averaged 24.26° (range 19–30°, SD 2.3282) in the first group of 50 patients. This fell to 18.16° (range 13–25°, SD 2.4020) in the second group of 50 patients, in whom the tangent to the inferior border of the AC, as advocated by Delmas and Pertuiset (1959), was used.
b) The angle formed by the CH-PC line and the brainstem long axis is named the truncal angle (Fig. 2.32). Two angles are measured according to the definition of the brainstem axis. The first joins the anterior border of the AC to the inferior extremity of the floor of the fourth ventricle behind the obex, the CH-PC-OB, and appears to be at right angles to the main axis of the brainstem, measuring about 93° (range 83–102°, SD 3.4). The second joins the superior insertion of the superior medullary velum to the obex (CH-VI-OB) with CH-PC and is more variable, averaging 85° (range 71–101°, SD 4.4).

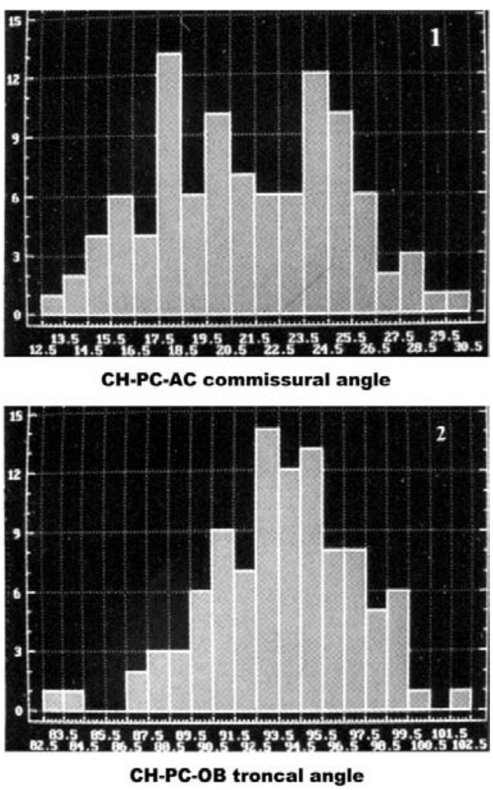


Fig. 2.30. The chiasmatico-commissural (*CH-PC*) reference plane: biometric findings. (From Tamraz et al. 1990)

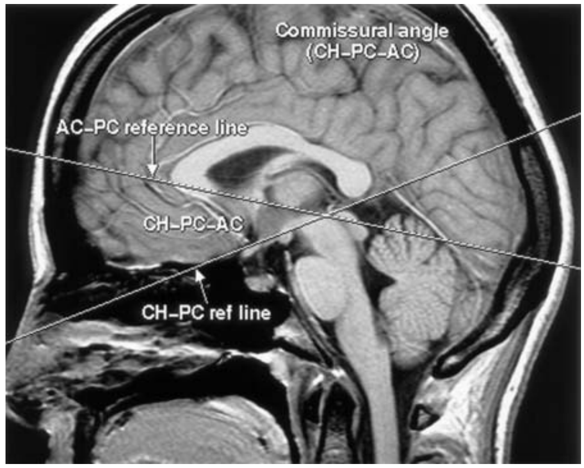


Fig. 2.31. The commissural angle (*CH-PC-AC*); biometric findings: average (24.26), median (24), standard deviation (2.32), minimum (19), maximum (30)

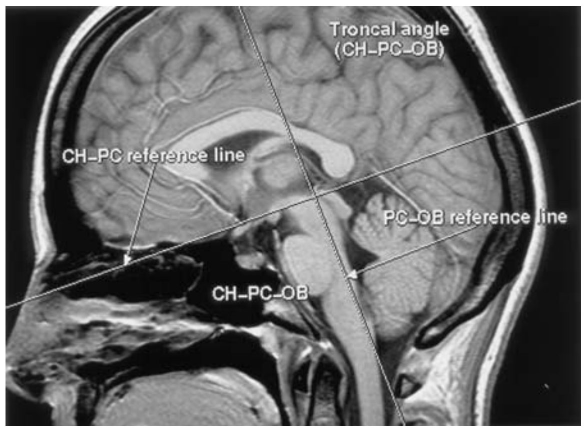


Fig. 2.32. The truncal angle (*CH-PC-OB*); biometric findings: average (93.7), median (94), standard deviation (3.42), minimum (83), maximum (102)

A measure of the distance between the chiasmal notch and the PC was quite uniform and averaged 26.23 mm (SD 1.58). This measure corresponds to the data reported by Lang (1987).

2 Anatomic and Imaging Correlations

The major anatomic correlations derived from the comparative analysis of the anatomy in the successive MR sagittal cuts were the following. First was the close parallelism of the CH-PC plane and the plane defined by the posterior branch of the lateral sulcus excluding its ascending terminal segment. In fact, the lateral projection of the plane on successive cuts, oriented parallel to CH-PC, shows close parallelism with the superior temporal sulcus (Fig. 2.33). Moreover, the projection onto the insular triangle of the parallel to the CH-PC line proves to be the same as the projection of the lateral fissure. The "lateral fissure plane" can thus be projected onto the median plane (Fig. 2.33).

This parallelism is demonstrated by the observed correspondence between the value of the angle CH-PC-AC (24°) and that of the angle formed by AC-PC and the lateral fissure, which averages 23–25° according to Szikla et al. (1977). The inclination of the central sulcus to the "sylvian plane" averages 58° according to these authors. Note that in the CH-PC orientation, the terminal portion of the central sulcus is approximately found at the junction of the anterior two-thirds and the posterior third, in the upper horizontal supraventricular cuts, contrary to what is observed in a bicommissural orientation of the axial cuts (Fig. 2.34).

It is, therefore, possible that this brain reference line is naturally the orientation of choice for horizontal cuts, particularly in the investigation of the temporal lobes, the superior temporal sulcus receiving the lateral projection of the CH-PC line and being recognized at the level of the carotid bifurcations on MR angiograms. The lateral temporal sulci are therefore displayed along their anterior-posterior long axis (Figs. 2.33, 2.35). The exploration of the perisylvian areas benefit even more significantly from such an orientation. Comparative evaluation of the planum temporale and studies of brain dominance are, therefore, best achieved with respect to this reference (Fig. 2.36). Moreover, angiographically, the arterial limits of the planum are depicted more precisely in the chiasmatico-commissural orientation than in the bicommissural plane (Szikla et al. 1977). MR angiography confirms such anatomical variations (Fig. 2.37).

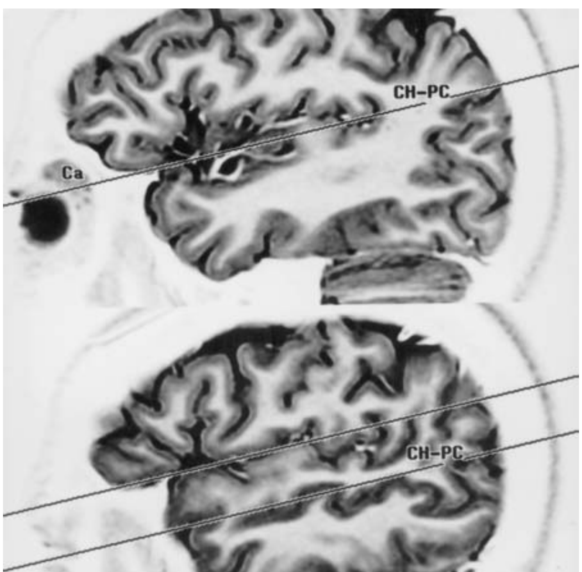


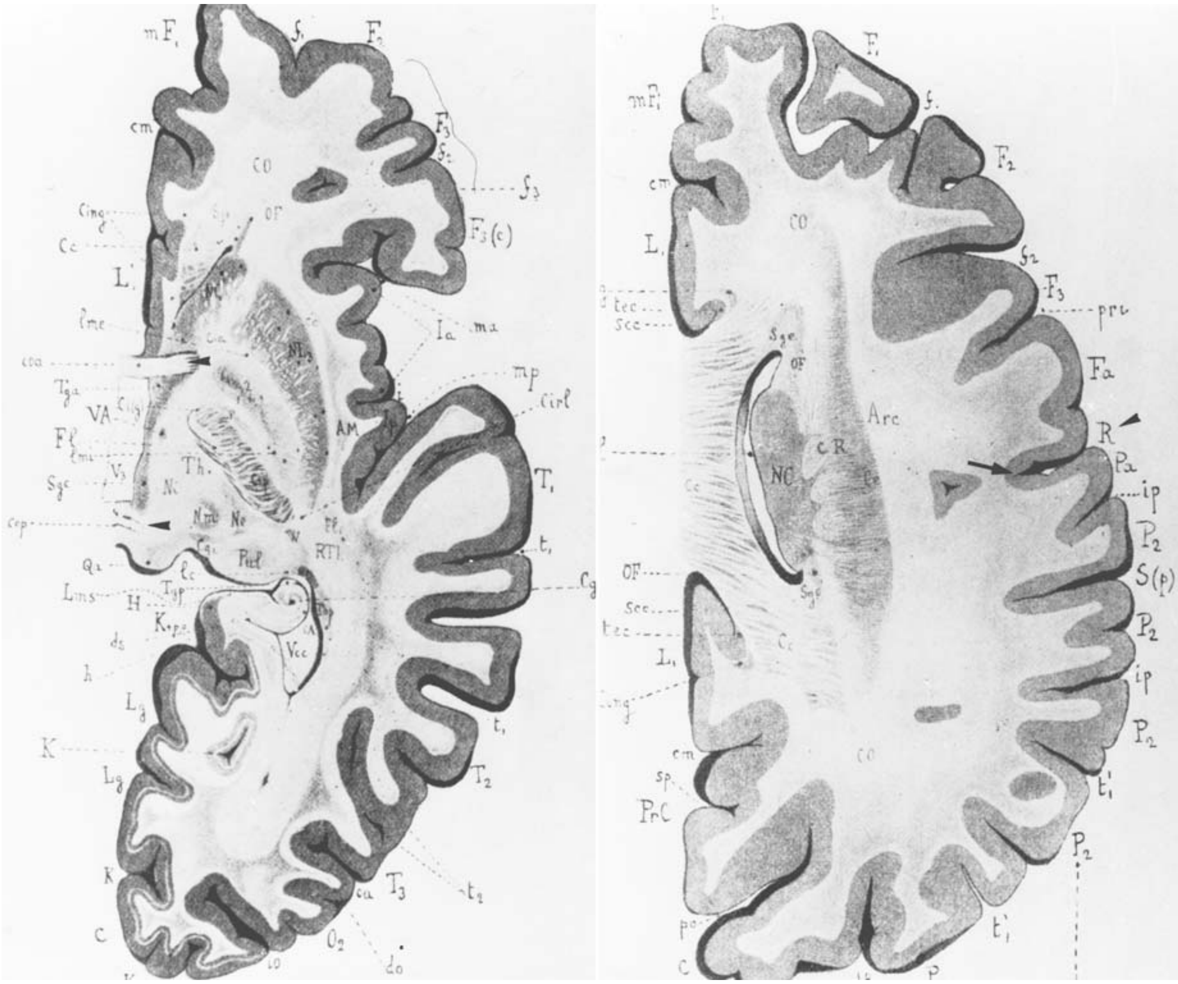
Fig. 2.33. The CH-PC plane: anatomic and imaging correlations, showing the close parallelism of the *CH-PC*, as projected on the parasagittal cuts, to the parallel sulcus (corresponding to the lateral projection of CH-PC), and to the sylvian fissure (*Ca*) with its correlated projection deeply onto the insular triangle. The CH-PC plane is therefore the ideal anatomic and angiographic reference for use when imaging the temporal lobes and the perisylvian regions

As a corollary, a close parallelism of CH-PC to the plane of the temporal horns of the lateral ventricles, and roughly to the choroidal fissure, seems obvious. It is, therefore, suitable for studying the hippocampus along its long axis (Fig. 2.38). Another interesting parallelism concerns the anterior portion of the body of the corpus callosum and its adjacent cingulate gyrus (Fig. 2.39).

The constant topography of the posterior prolongation of the CH-PC line passing through the ambient cistern between the inferior border of the splenium and the upper limit of the culmen and paralleling or intersecting the common stem of the parieto-occipital with the calcarine sulci also should be noted (Fig. 2.39). Thus, most of the calcarine fissure may reliably be found on the lower infra-CH-PC axial cuts in most circumstances. This plane therefore separates the cerebellum and the brainstem from the main mass of the cerebrum, except for the occipital lobes whose topography is a function of the cranial index and typology, as shown on this three-dimensional MR (Fig. 2.40). The CH-PC plane obviously separates the proencephalon (telencephalon and diencephalon) above, from the mesencephalon and rhombencephalon beneath, and is consequently of real embryologic, as well as phylogenetic, significance.

The coronal projection of the CH-PC plane to the commissural-obex vertical reference plane is constantly tangent to the superior border of the lateral geniculate bodies (Fig. 2.41), showing a constant topography at the diencephalon-mesencephalic junctional region, which is well displayed in the horizontal reference plane.

The last finding is that the CH-PC plane is almost perpendicular to the vertical long axis of the brainstem (Fig. 2.42). Thus, anatomic and clinical correlations, in the coronal and the axial cuts, of fine structures in the brainstem are possible and facilitated



A B

Fig. 2.34A,B. Topography of the central sulcus: anterior-posterior variations with respect to the axial reference plane used and considering the supraventricular cuts. **A** Axial cuts through the anterior and posterior commissures and transcallosal (**B**). (From Déjerine 1895)

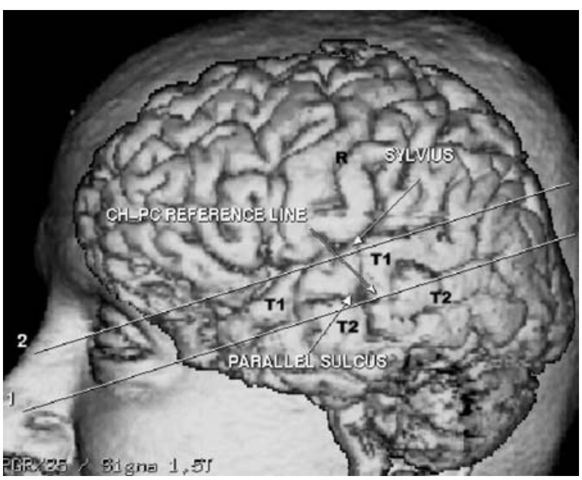
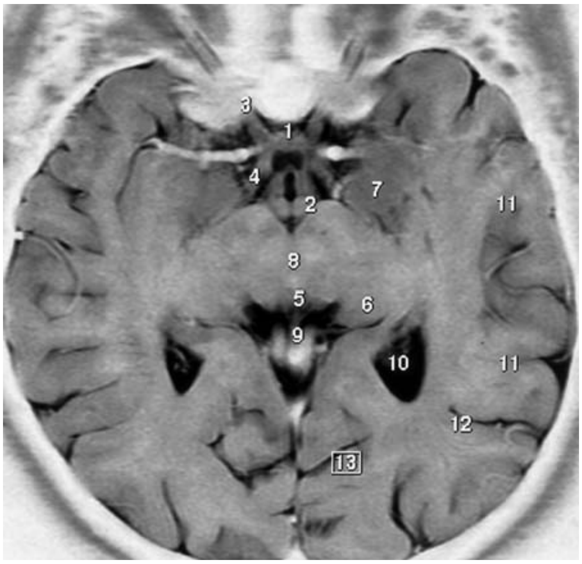


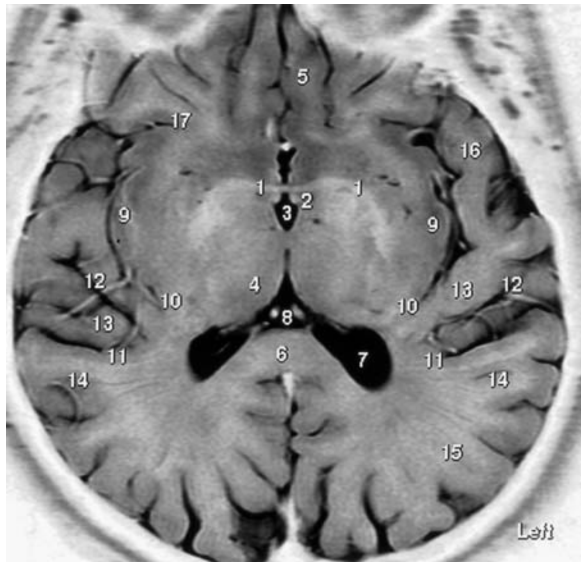
Fig. 2.35. The CH-PC reference plane as a "sylvian" orientation plane, most suitable for the study of the perisylvian region and the temporal lobes

(see Chap. 8). There is, as well, an easier and more definite reference to the tegmental areas beneath the floor of the fourth ventricle and, therefore, to the underlying nuclei and related fiber bundles.

On the other hand, in order to develop an in vivo morphometric approach to the brain, numbers of parallelisms to the CH-PC and PC-OB lines have been evaluated in a preliminary study in an attempt to determine the morphometric peculiarities and the eventual proportional variations that may help to differentiate individual brains (Fig. 2.43). All the parallel lines defining reference planes are chosen according to major anatomic landmarks found on the midsagittal MR cut and are considered as roughly parallel to the horizontal CH-PC reference plane. Three planes are defined dorsoventrally on each side of the CH-PC line, perpendicular to the PC-OB reference line.



A



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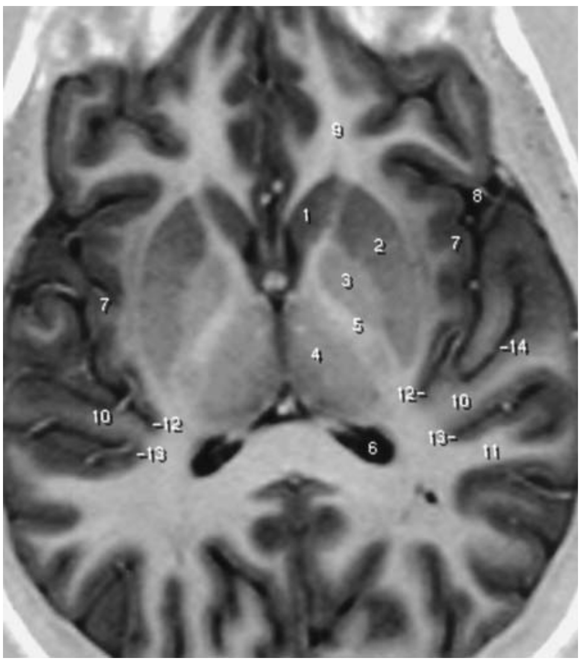
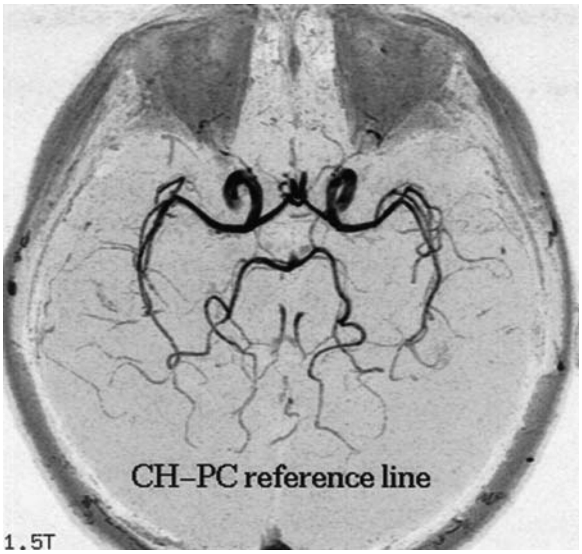


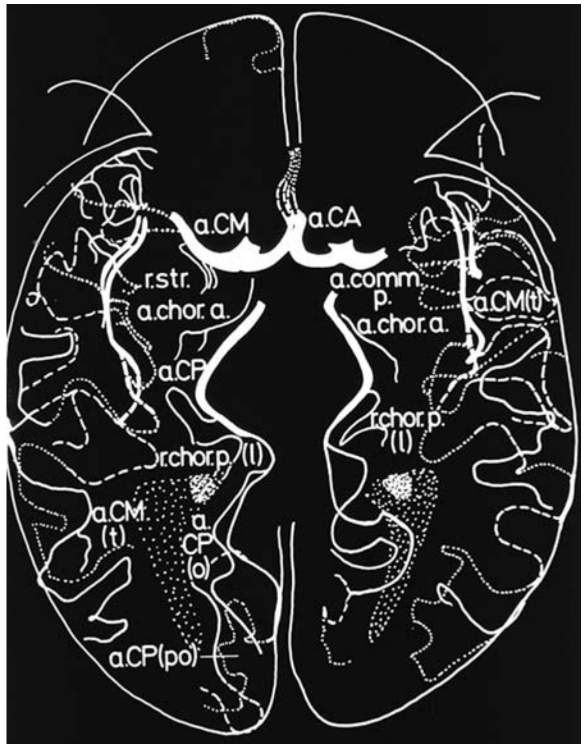
C

Fig. 2.36A–C. The planum temporale, imaging according to the CH-PC reference. **A** At the CH-PC reference level (case 1): *1*, Optic chiasm; *2*, mamillary bodies; *3*, canalicular and cisternal optic nerve; *4*, optic tract; *5*, posterior commissure; *6*, pulvinar; *7*, amygdala; 8, midbrain-thalamic junction; *9*, ambient cistern; *10*, atrium of lateral ventricle; *11*, lateral fissure; *12*, parallel sulcus; *13*, calcarine sulcus. **B** At the level of the anterior commissure (case 1): *1*, anterior commissure; *2*, anterior columns of fornix; *3*, third ventricle; *4*, thalamus; *5*, gyrus rectus; *6*, splenium of corpus callosum; *7*, atrium of lateral ventricle; *8*, ambient cistern; *9*, insula; *10*, posterior border of circular sulcus; *11*, transverse supratemporal sulcus; *12*, intermediate transverse supratemporal sulcus; *13*, Heschl gyrus (transverse supratemporal gyrus); *14*, planum temporale; *15*, supramarginal gyrus; *16*, temporal operculum; *17*, anterior border of circular sulcus. **C** At the midthalamus and basal ganglia level (case 2): *1,* caudate nucleus; *2,* putamen; *3,* pallidum, lateral part; *4,* thalamus; *5,* internal capsule, posterior limb; *6,* atrium of lateral ventricle; *7,* insula; *8,* lateral fissure; *9,* frontal lobe; *10*, superior temporal gyri of Heschl; *11*, planum temporale; *12*, circular sulcus, posterior border; *13*, transverse supratemporal sulcus; *14*, intermediate sulcus

Among the angles evaluated, one merits particular attention. It is defined as the basal callosal angle formed between the CH-PC plane and the tangent to the base of the corpus callosum. The importance of the latter in encephalometric studies has been stressed by Ariens Kappers in his work on racial differences in the brain (1947). The in vivo MR value of this CH-PC-CC angle, as determined statistically on a series of 86 normal exams (Tamraz 1991), averages 16.2209° (range 8–22°, SD 3.3690). The interesting anatomic correlation observed concerns its relation with the major telencephalic reference, defined by the callosal plane as described by Olivier et al. (1985). Actually, the mid-callosal plane of Olivier also shows some relation to the mamillary bodies, which are known to be very constant topometrically and are contained in the CH-PC plane (Fig. 2.44). Note the other interesting anatomic correlations, as projected on parasagittal cuts involving the hippocampal formation: the topography of the midcallosal plane, as pointed out by Olivier between the amygdala and the hippocampus; and the projection of the CH-PC plane approximately tangential superiorly to the amygdala and the tail of the hippocampus pass-



A



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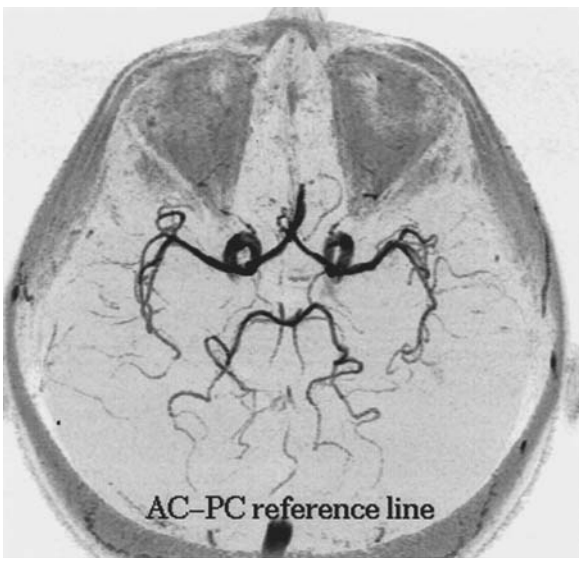


C

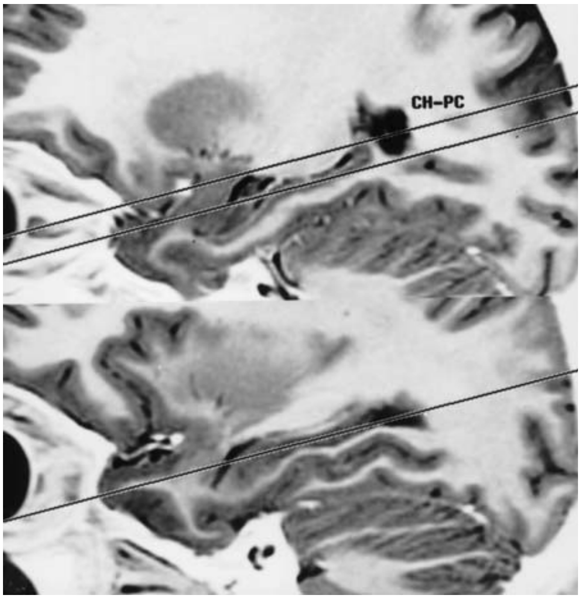
Fig. 2.37A–C. MR angiography according to the chiasmatico-commissural reference plane (*CH-PC*), suitable for multimodal imaging and for the investigation of the perisylvian region and the supratemporal plane (**A**) as compared to the bicommissural (*AC-PC*) orientation (**C**). The MR result is close to the angiogram obtained in the "sylvian" orientation (**B**) and shown by Cabanis and Iba-Zizen (in Szikla et al. 1977)

ing through the limen insulae. Such interrelations between the callosal reference and the CH-PC reference plane seem promising but need further anatomic and functional evaluations.

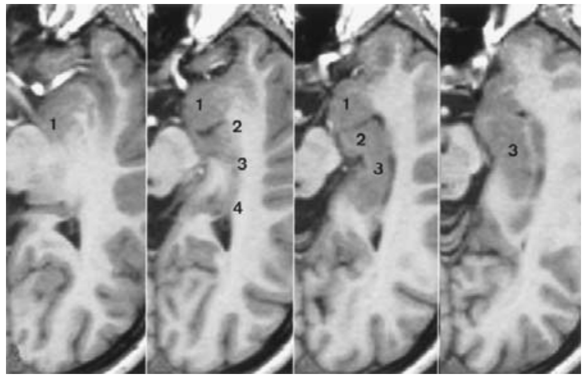
Finally, it appears that the CH-PC corresponds well with the anatomic facts, both anthropologically and phylogenetically. The consistent angulation with the AC-PC of neurosurgical stereotaxy, the close parallelism with the parallel sulcus and the lateral fissure, and the perpendicular relationship with the vertical long axis of the brainstem will facilitate both comparative biometric analysis of the living and the fixed brain, as well as the study of ontogenesis and phylogenesis of the brain based on a sylvian orientation.

F Anatomic and Physiologic Reference Planes

Anatomic and physiologic planes are mainly represented by the "horizontal vestibular plane", which is the plane of equilibration defined by Girard, Perez, Delattre and Fenart, and the "plane of the orbital axis", described by Broca, which corresponds to the "plane of the horizontal vision".



A



B

Fig. 2.38A,B. Close parallelism of CH-PC plane to the inferior horn of the lateral ventricle and to the hippocampal long axis, as shown on the lateral projections of the reference and its parallel through the hippocampal formation (**A**). The contiguous 2 mm axial cuts proceeding downward from the upper CH-PC level display the amygdala-hippocampal complex (**B**). *1*, amygdala; *2*, head; *3*, body; *4*, tail

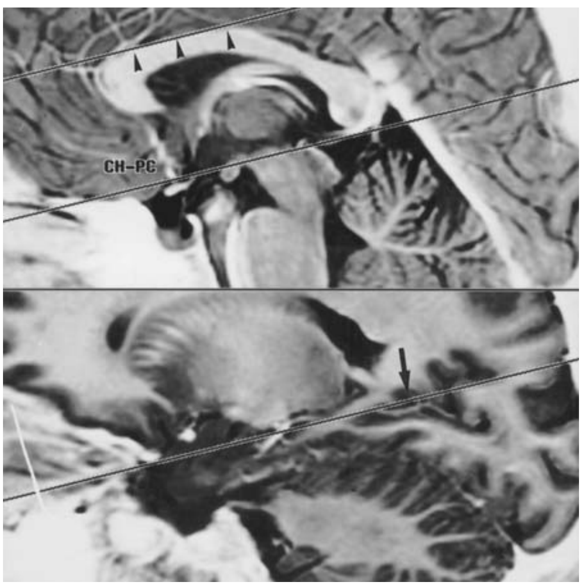
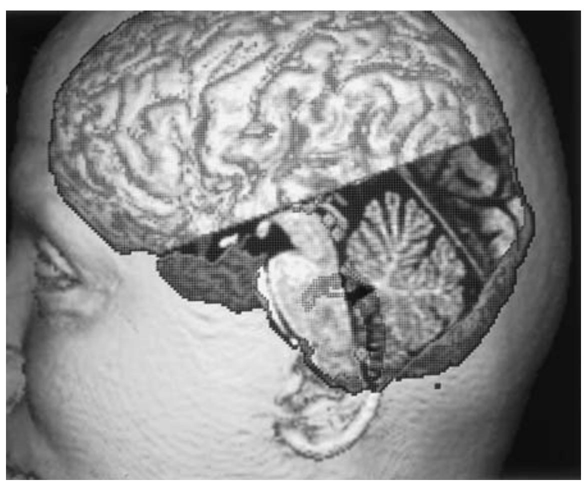


Fig. 2.39. Close parallelism of the CH-PC plane to the anterior part of the corpus callosum and the anterior cingulate gyrus (*arrowheads*). The posterior extension of the reference plane parallels approximately the common stem of the parieto-occipital and the calcarine sulci (*arrow*)

A



B

Fig. 2.40A,B. The chiasmatico-commissural plane, situated at the midbrain-diencephalic junction roughly separates the brainstem and the cerebellum from the main mass of the cerebral hemispheres

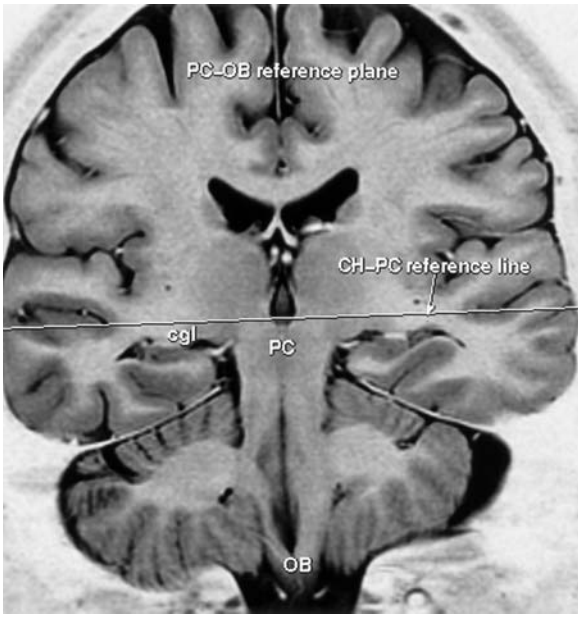


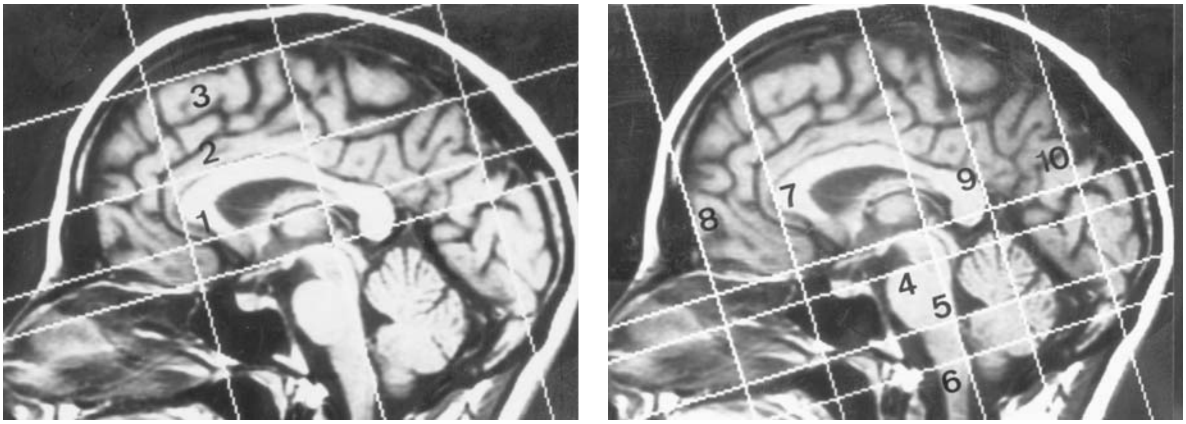
Fig. 2.41. The CH-PC reference plane is a pivotal plane at the midbrain-diencephalic junction; its projection onto the coronal commissural-obex (*PC-OB*) reference plane is constantly found tangent to the topometrically stable lateral geniculate bodies (*cgl*)

A

B

C

Fig. 2.42A–C. The CH-PC plane is almost perpendicular to the brainstem vertical long axis as defined by the parallel anterior to the PC-OB reference line (*arrows*) showing the whole brainstem-diencephalic continuum. The corticospinal tracts are nicely displayed in this orientation of the coronal cuts, as demonstrated routinely with MR (*arrowheads*)



A B

Fig. 2.43A,B. Brain morphometry based on the orthogonal references: CH-PC and PC-OB planes, as defined in the encephalometric study of patients presenting with genetic diseases due to chromosomal aberrations (Tamraz 1991). Parallel planes are traced: the horizontal supra-CH-PC planes, tangent to the inferior border of the rostrum (*1*), to the superior border of the callosal body (*2*), and to the vertex (*3*); the horizontal infra-CH-PC planes, passing through the tip of the interpeduncular space and the lower aspect of the tectal plate (*4*), at the pontomedullary junction (*5*), and at the obex level (*6*); the vertical planes, anterior to PC-OB, tangent to the genu of the corpus callosum (*7*) and to the frontal pole (*8*), and posterior to PC-OB, tangent to the splenium (*9*) and passing through the inferior tip of the occipital lobe (*10*)

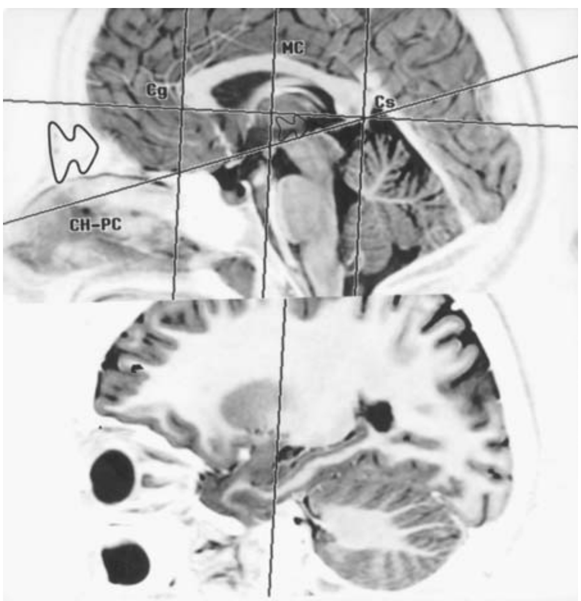


Fig. 2.44. The callosal angle (16°), as defined between the chiasmatico-commissural plane (*CH-PC*) and the callosal plane (*Cg-Cs*)

1 The "Plan Vestibulaire Horizontal"

Following the works of Girard (1911) and Perez (1922) on the relations existing in man between the labyrinth and erect posture, Girard defined, in 1923, the "plan vestibulaire horizontal" as the line joining the centers of both foramina of the lateral semi-circular canal from one side. In 1952, Saban provided another definition of this plane as that passing through the ampullary portion of the lateral semicircular canal. Methods based on the vestibian axis were consequently developed and applied more precisely in the field of comparative craniology (Delattre and Daele 1950; Delattre and Fenart 1960; Fenart et al. 1966). Numerous applications have been reported using this methodological approach, in comparative anatomy, orthodontics ontogenesis and human paleontology. The localization of this reference system in vivo is, unfortunately, sometimes very difficult.

On the other hand, Caix and Beauvieux (1962) proposed a vestibulo-visual plane based on the superior oblique muscle of the eye and the semicircular canals. In man, this musculoskeletal plane is defined by the fact that the superior oblique muscle is oriented in the same plane as the lateral semicircular canal, its reflected tendon being parallel to the posterior canal.

2 The "Plan des Axes Orbitaires"

In his writings on the projections of the head, Broca stated: "the direction of gaze is the only characteristic of the living by which it may be determined that the head is horizontal. When man is standing and his visual axis is horizontal he is in his natural attitude" (Broca 1862, 1873 p. 578). He went on, in 1873, to describe two orbital axes, determined by two needles fixed in the optic canals and considered by him as passing through the pupils (Fig. 2.45). This was considered by him as a "sufficient approximation of the horizontal direction of gaze" (Broca 1873). Extending his research to animals, Broca defined, in 1877, the horizontal plane as "the plane determined in mammals by the two visual axes in an animal looking in the horizon direction", corresponding to the bi-orbital plane as defined for the cranium in animals, including man. He also demonstrated that this cephalic orientation lies close to the alveolar-condylar plane.

One century after his death, Broca's ideas regarding horizontality of the visual pathways were validated by CT. The NOP defines this cephalic orientation and orients the anatomic cuts (Cabanis et al. 1978).

III Brain Vertical Reference Lines and Planes

Three reference lines based on brain anatomic and midsagittal landmarks are retained (Fig. 2.46) and include the PC-OB used as a standard reference for the coronal investigation of the entire brain, and two other vertical lines described and proposed for more restricted anatomic areas, which are based on the AC and the mamillary bodies (MB).

A The Anterior Commissure-Mamillary Planes

The anterior commissure-mamillary vertical reference planes are based on the AC and the MB as the midsagittal landmarks. The first reference line, named the commissuro-mamillary (CA-CM) baseline, was defined by Guiot and Brion (1958), in an attempt to localize exactly the medial border of the globus pallidus, as well as its anterior aspect, in order to complete a stereotaxic pallidotomy for parkinsonian syndrome. The other plane, close to the former, has been described more recently by Baulac et al. (1990), based on the same anatomic landmarks used for imaging of the basal forebrain.

These vertical reference lines and planes differ to some extent (Fig. 2.37) if compared and applied to imaging. The plane used by Guiot and Brion in their stereotaxic approach to medial pallidum is defined as the line tangent to the posterior border of the AC passing through the premamillary notch (Fig. 2.47). This plane, close to the PC-OB plane, differs significantly from the CA-CM line which is defined as joining the center of the AC to the center of the MB (Fig. 2.48).

1 The Commissuro-Mamillary Reference Line

In this brain orientation, and according to the important work of the authors, which we have routinely verified using the coronal approach according to the PC-OB line by MRI, the anterior columns of the fornix are vertical from the level of the AC to the level of the premamillary notch, about 1.5 mm behind the CA-CM line.

According to Guiot and Brion (1958), this reference line gives the anterior topographic limit of the medial pallidum and, more precisely, its medial tip. The distance between the two landmarks averages 9.6 mm (8.5–11.5 mm) measured in 25 cases. This length appears very constant. The other interesting anatomic finding concerns the topography of the optic tract, which seems to follow a roughly parallel route, as compared to the base of the globus pallidus, and extends from its origin at the optic chiasm to the level of the MB. The optic tracts are separated from

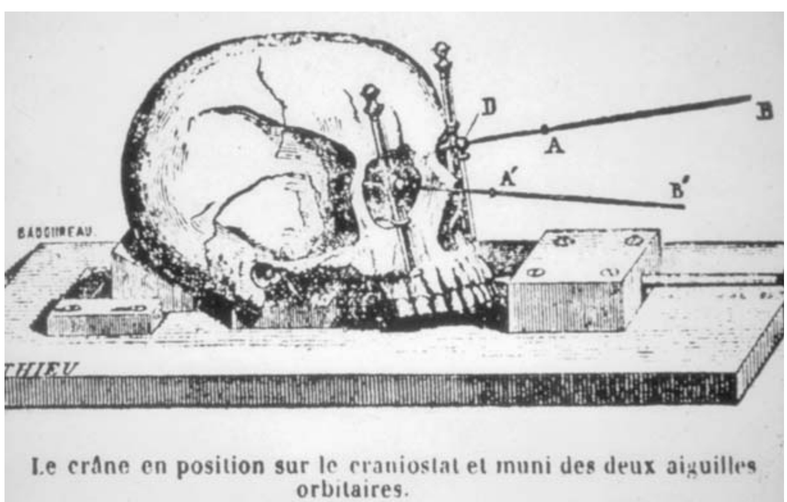


Fig. 2.45. The "bi-orbital" plane or the "plane of vision" of Broca (1873)

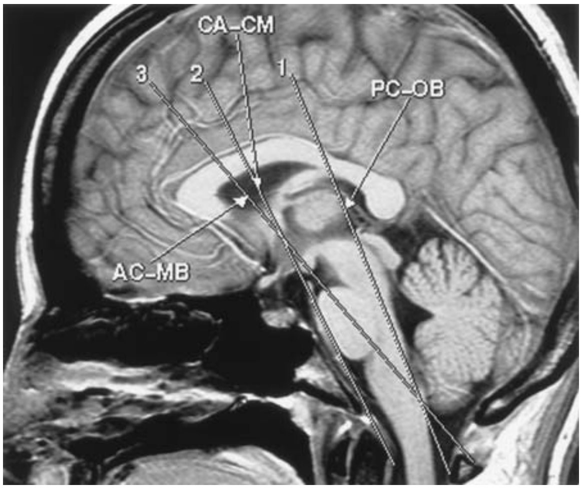


Fig. 2.46. Brain vertical reference lines and planes: *1*, PC-OB: commissural-obex plane (Tamraz et al. 1990, 1991); *2*, CA-CM: commissuro-mamillary plane (Guiot and Brion 1958); *3*, AC-MB: commissuro-mamillary plane (Baulac et al. 1990)

the basal aspect of the pallidum by 2 mm. This relationship explains, to some extent, the usual "X-shape" of the chiasm and tracts which are observed in the CH-PC line close to the perpendicular of the CA-CM line.

The CA-CM line shows constant topometric relation to the medial tip of the pallidum, which is difficult to localize anatomically due to its intrinsic relation with the pallidofugal bundles and the lenticular fasciculus. This is also true on MRI when contrast resolution is poor.

Considering the main anatomic correlations observed using this reference line, as it could be applied to brain imaging mainly for the basal ganglia, these results are close to the anatomic findings observed using the PC-OB reference line (see Sect. 10.IV) and, therefore, could be used as an alternative for coronal brain imaging whenever pathological conditions involve one of the brainstem (PC and OB) landmarks.

2 The Commissuro-Mamillary Plane

The obliqueness of the commissuro-mamillary plane is quite different from the former, even though it is based on the same anatomic structures, but joins center-to-center the AC and the MB, as is evident on the anatomic and MR cuts reported by Baulac et al. (1990) (Fig. 2.48).

This plane is utilized for the display of the anterior basal forebrain structures, from ventral to dorsal: the septum lucidum, the septal nuclei, the AC, the anterior columns of the fornix, and the MB projecting into the interpeduncular fossa. Note that this oblique plane is tilted more anteriorly as compared to the CA-CM line and, obviously, much more with respect to the parallel of the PC-OB plane, tangent to the posterior border of the AC (Fig. 2.49). It is interesting to note the similarity of these results with those obtained by Naidich et al. (1986) in their anatomic approach to the AC, which was considered a major landmark, at least in sagittal sections. According to these authors, the latter structure is nicely displayed in an axial oblique cut inclined 20–25° to the OM line.

Both orientations nicely display, from medial to lateral, the substantia innominata and the anterior perforated substance, easily seen beneath the AC. Note that the lateral temporal limbs of the AC are displayed in one single cut using the commissuro-mamillary orientation, its lateral extent being limited to the lateral aspect of the external pallidum, using the PC-OB orientation of the coronal cuts.

The anterior commissural plane, parallel to the PC-OB reference plane, may be considered as vertically limiting the anterior aspect of the ventral striatum and the CA-CM plane, defining more obliquely its rostrocaudal limit. Volumetric studies oriented to the study of the innominate substance of Reichert and, particularly, the basal nucleus of Meynert, in Alzheimer's disease or the various dementia syndromes of the Alzheimer type, may benefit from these landmarks.

A more extensive regional approach to cognitive and amnestic syndromes that may accompany the so-called extrapyramidal diseases would be more efficiently and globally evaluated on contiguous parallel slices oriented according to the vertical PC-OB reference line. This would cover an anterior-posterior region extending from the AC to the MB, involving the amygdala, or more largely from the chiasmal notch plane at least to the PC level (or the posterior callosal plane), to include the hippocampal formation as well as the septal-accumbens complex anterior to the AC (see the regional imaging approach to the septal-innominate and amygdalo-hippocampal structures, Chap. 6, and the synoptical atlas in the PC-OB orientation, chapt. 10.III).

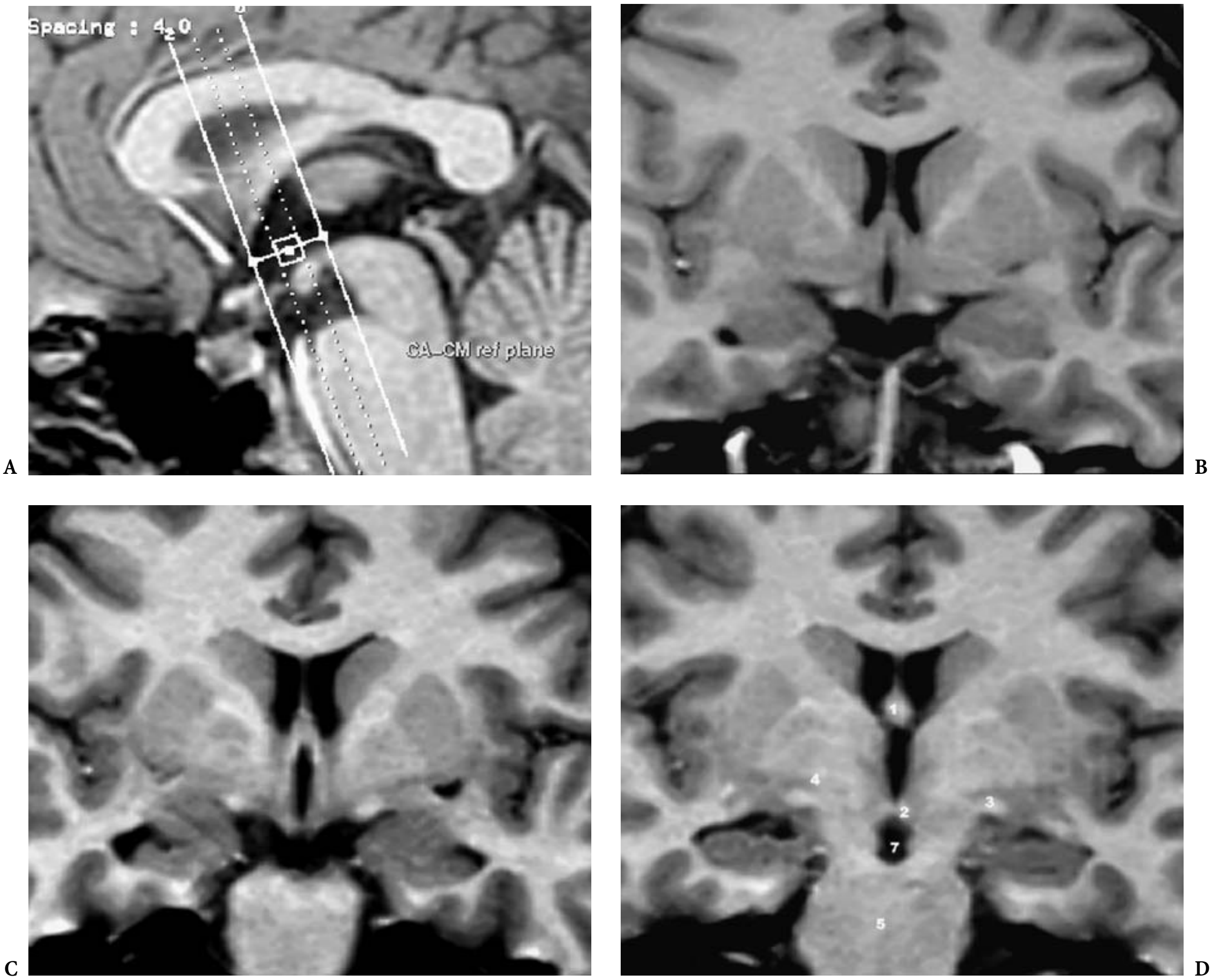


Fig. 2.47A–D. The CA-CM plane of Guiot and Brion (1958), defined as the line tangent to the posterior border of the anterior commissure and passing through the premamillary notch. This reference, defined to localize the medial tip of the medial pallidum, appears to be roughly parallel to the PC-OB reference plane and may therefore be used in regional imaging of the basal ganglia or the optic tracts and even the hippocampus. *1*, Anterior columns of fornix; *2*, mamillary bodies; *3*, pericrural optic tracts; *4*, tip of the medial globus pallidus; *5*, pons; *6*, medulla oblongata; *7*, interpeduncular cistern

B The Commissural-Obex Reference Plane

The commissural-obex reference line is defined as the line tangent to the anterior border of the PC, extending to the lower extremity of the calamus in the floor of the fourth ventricle behind the OB. This cephalic orientation describes, in our opinion, the main vertical axis of the brainstem and appears perpendicular to the CH-PC horizontal line, as previously demonstrated (Tamraz et al. 1990, 1991). With the sagittal plane, this line forms a coronal plane involving the brainstem cut along its long vertical axis (Fig. 2.46).

1 Biometric Findings

Two vertical reference lines are defined which could represent the vertical axis of the brainstem based on anatomic structures found in the midsagittal plane. They are reliable enough to permit reproducible alignment on follow-up exams if needed. The first line, called the PC-OB line, is tangent to the anterior border of the AC, superiorly, and extends to the inferior extremity of the floor of the fourth ventricle behind the OB, to which it is tangent anteriorly. The second line, called the VI-OB line, joins the superior insertion of the superior medullary velum at the

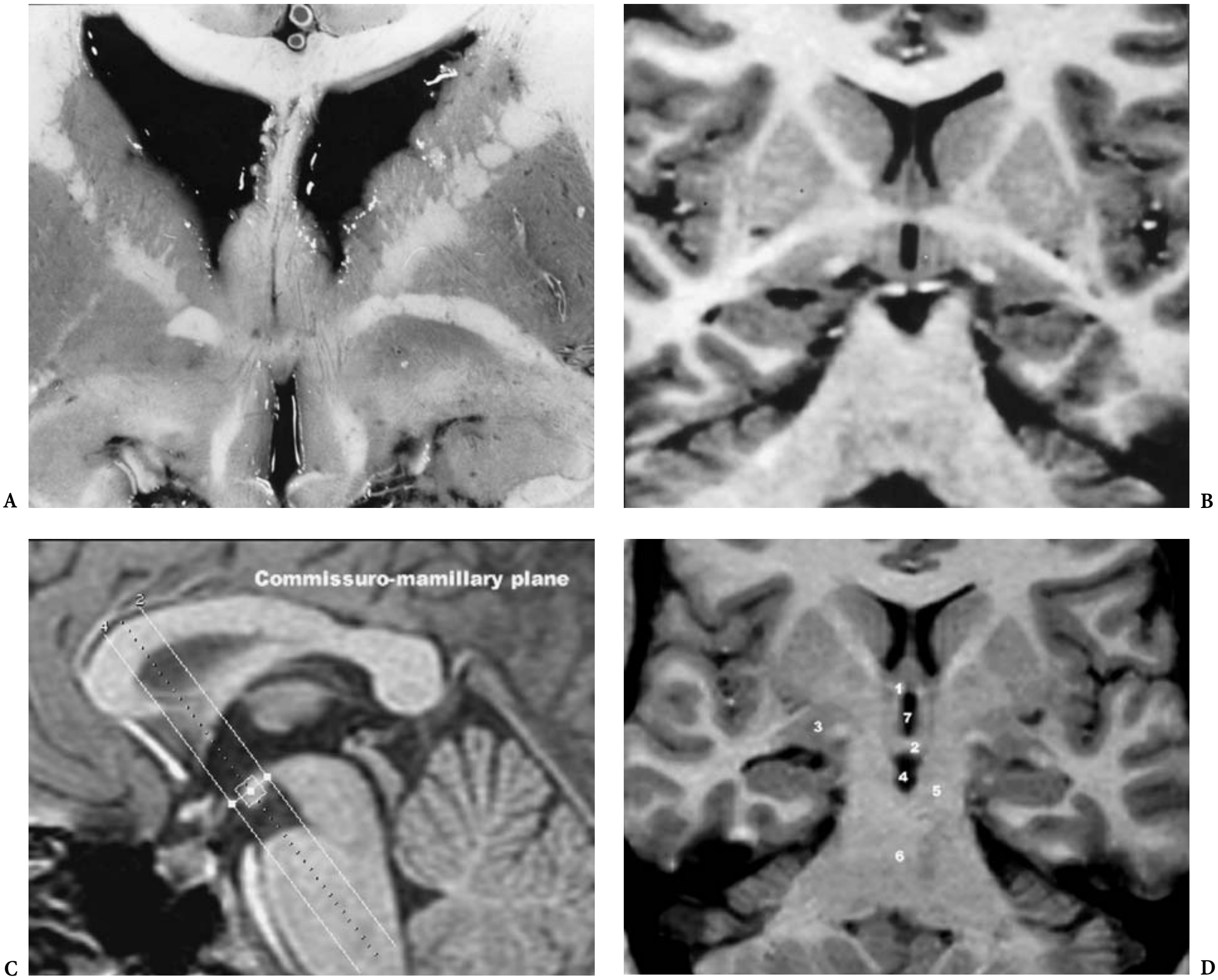


Fig. 2.48A–D. The commissuro-mamillary plane (Baulac et al. 1990), defined as joining the centers of the anterior commissure and the mamillary body, is proposed as the reference suitable for imaging of the anterior basal forebrain. The MR slice is 2 mm thick, T1 weighted, three-dimensional reformation. *1*, Anterior commissure; *2*, mamillary bodies; *3*, anterior basal forebrain; *4*, interpeduncular cistern; *5*, crus cerebri *6*, pons; *7*, third ventricle. (The anatomic cross-section provided by Baulac et al. 1990)

frenulum veli to the OB, to which it is tangent posteriorly. These lines intercept the horizontal CH-PC line with which they form two angles, CH-PC-OB and CH-VI-OB, respectively.

These two truncal angles were statistically evaluated and measured on a series of 100 in vivo MR exams. The CH-PC-OB angle appears to be at right angles to the main axis of the brainstem, measuring 93.7° (range 83–102°, SD 3.421). The CH-VI-OB proved to be more variable, averaging 85.54° (range 71–101°, SD 4.411). These two lines form an angle of about 8°. The former is retained as the brainstem vertical axis, approximately perpendicular to the CH-PC plane and considered as the reference for the coronal cuts of the brain.

2 Anatomic and Imaging Correlations

The PC-OB reference line intercepts, with the midsagittal plane, a PC-OB reference plane which laterally comprises the lateral geniculate bodies (Fig. 2.50). The lateral geniculate bodies, like the medial, are topometrically and volumetrically constant and do not show statistically significant variations between individuals, according to Delmas and Pertuiset (1959). They constitute lateral landmarks to this vertical reference, the horizontal CH-PC line projecting tangentially to their superior aspect.

Interestingly, the orientation of this plane is roughly parallel to the direction of the phylogenetically preserved, medial longitudinal fasciculi, easily

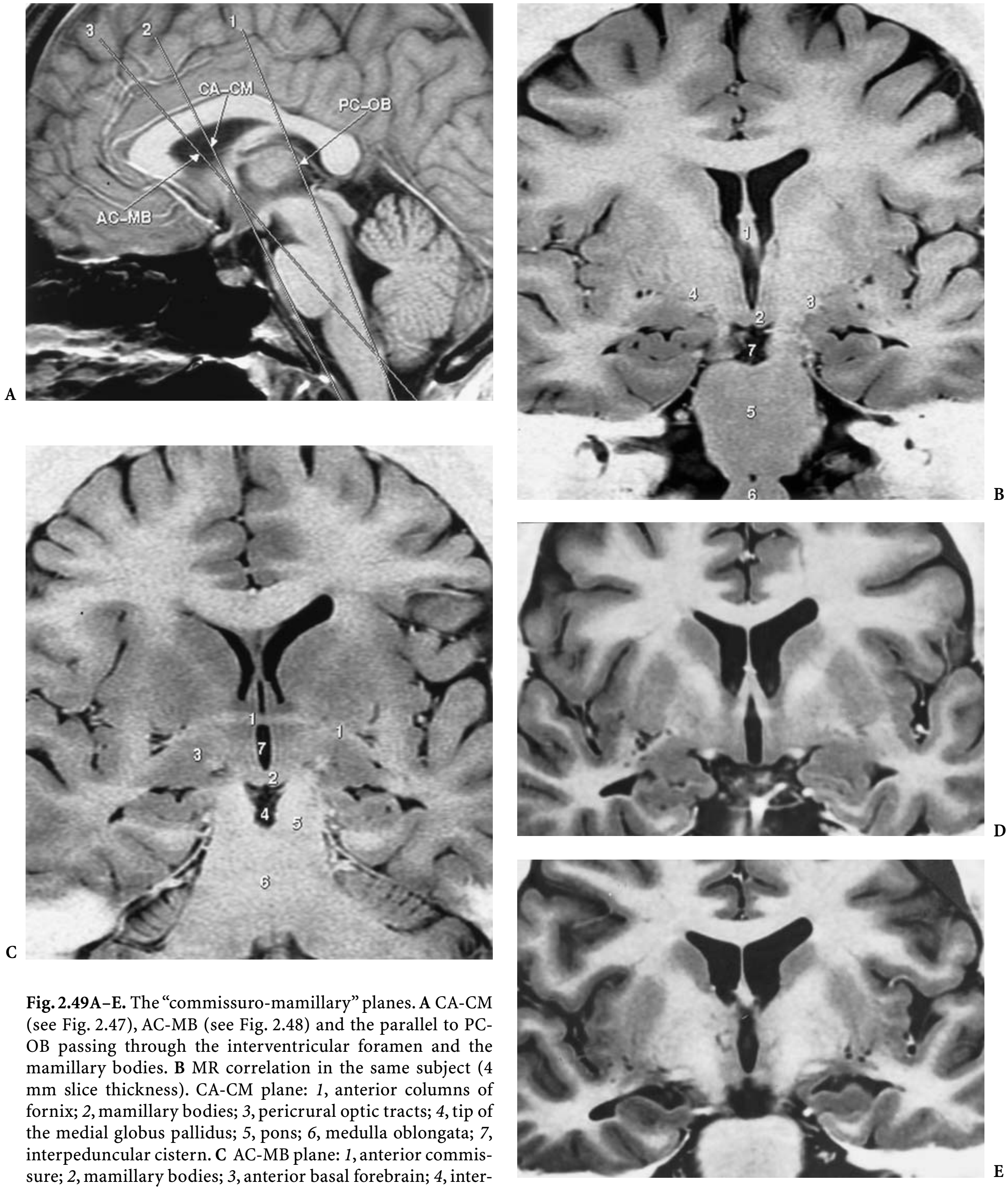
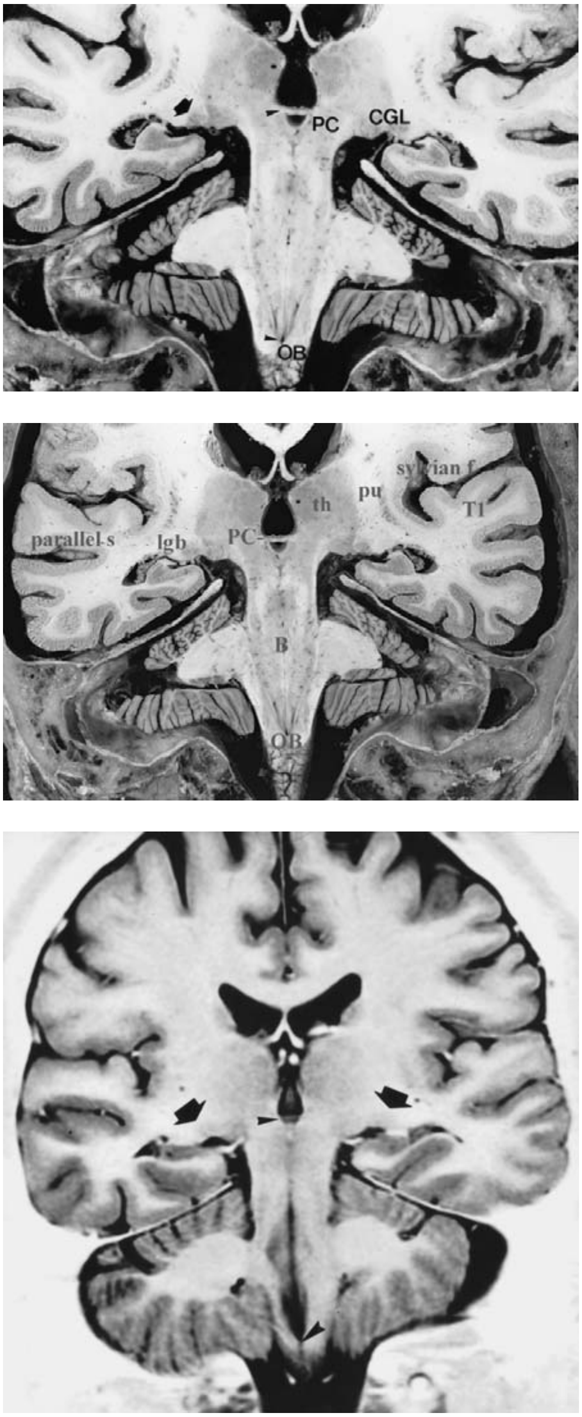


Fig. 2.49A–E. The "commissuro-mamillary" planes. **A** CA-CM (see Fig. 2.47), AC-MB (see Fig. 2.48) and the parallel to PC-OB passing through the interventricular foramen and the mamillary bodies. **B** MR correlation in the same subject (4 mm slice thickness). CA-CM plane: *1*, anterior columns of fornix; *2*, mamillary bodies; *3*, pericrural optic tracts; *4*, tip of the medial globus pallidus; *5*, pons; *6*, medulla oblongata; *7*, interpeduncular cistern. **C** AC-MB plane: *1*, anterior commissure; *2*, mamillary bodies; *3*, anterior basal forebrain; *4*, interpeduncular cistern; *5*, crus cerebri; *6*, pons; *7*, third ventricle. **D,E** Parallels to the PC-OB reference plane, passing through the anterior commissure and anterior columns of the fornix (**D**) and through the interventricular foramen and the mamillary bodies at their posterior notch (**E**)



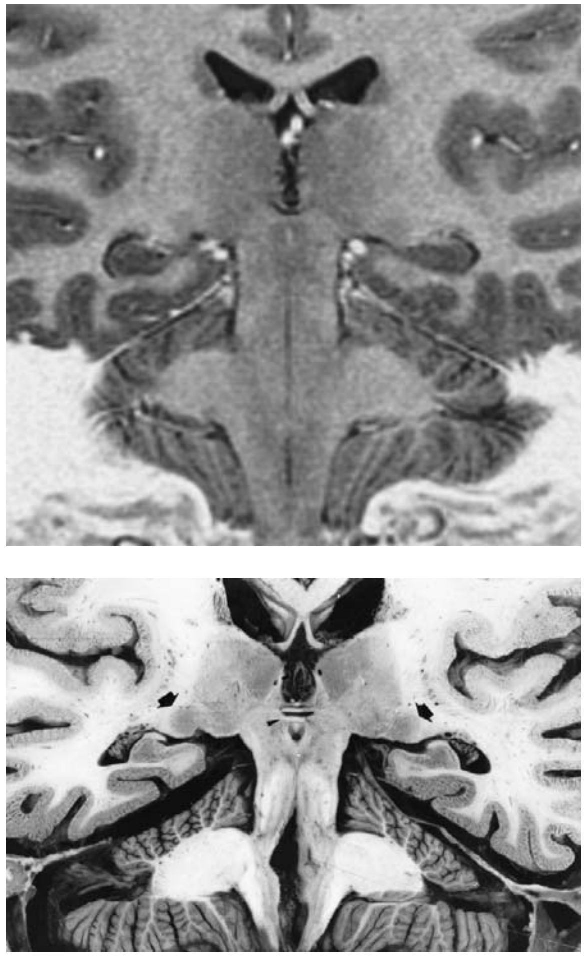


Fig. 2.50A–E. The commissural-obex (*PC-OB*) reference line: anatomic and MR correlations. The anatomic coronal cuts are separated by about 1 mm, showing the anatomic landmarks (*arrowheads*): the posterior commissure (*PC*) and the inferior extremity of the calamus behind the obex (*OB*). The lateral geniculate bodies (*CGL*) are contained in the cut, visualized laterally (*arrows*). Note that this reference cut limits the posterior boundary of the putamen and the insula

seen on the midsagittal cut (Fig. 2.51). Note that these tracts are found under the floor of the fourth ventricle, extending throughout the entire brainstem, and undergo a partial decussation in the PC, the upper landmark of the reference plane.

Such an orientation of the slices permits the study of the brainstem according to its vertical long axis, displaying both corticospinal tracts from the mid-brain-diencephalic junction to the inferior medulla at the level of their decussation. This is well shown on T2 weighted MRI in normal sections, as well as in degenerative or demyelinating diseased states (Fig. 2.52). Such an orientation differs from the perpendicular to both the AC-PC plane and the callosal plane, and is closely oriented to the intracerebral route of the cortico-spinal traets.

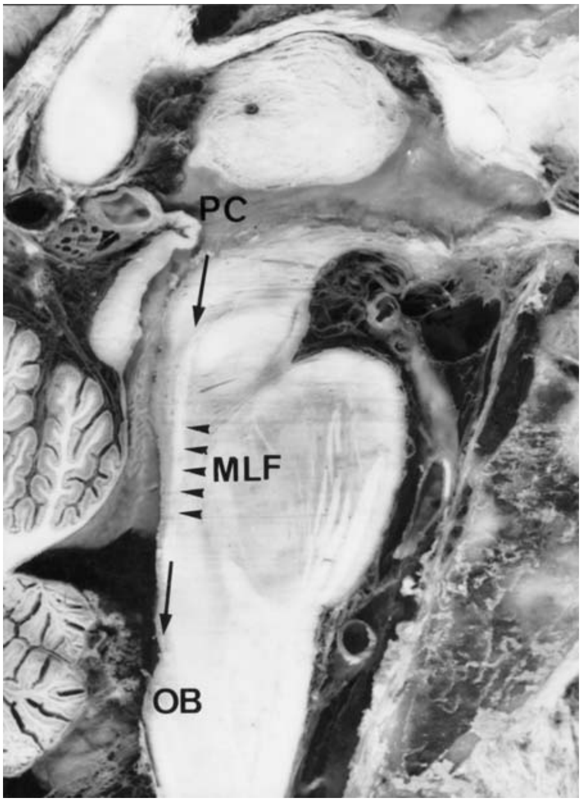
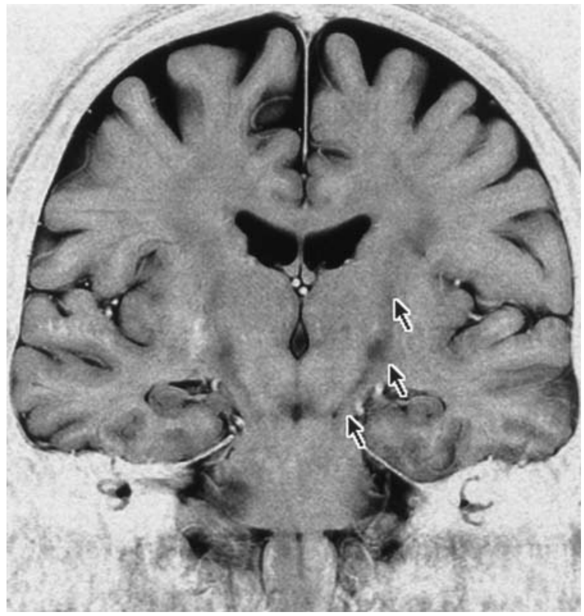


Fig. 2.51. The PC-OB plane follows roughly the direction of the sagittally oriented medial longitudinal fasciculi (*MLF*) (*arrowheads*)

Another significant parallelism is represented by the Monro-mamillary plane or cut, parallel to the PC-OB and comprising the interventricular foramina and the MB, both corresponding to highly constant anatomic structures that could be retained for imaging purposes as anterior alternative landmarks (Fig. 2.53). The topometric constancy of the MB is actually associated with the ontogeny of the interventricular foramina, as demonstrated by Delmas and Pertuiset (1959). This plane constitutes the anterior limit of the brainstem slices as well as the transthalamic limit (see Chap. 10).

The perpendicular relation of this reference to the CH-PC plane, as shown, explains its high accuracy for the study of the temporal lobes. The temporal pole is, in fact, usually included between the plane tangent to the genu of the corpus callosum (anterior callosal plane, CCg) or the "genu" of the cingulate sulcus (anterior cingulate plane, CSa) to include the tip of the temporal pole. The posterior extension, the posterior callosal plane (CCs), is arbitrarily provided by the plane tangent to the splenium of the corpus callosum. Both limiting planes are traced parallel to the PC-OB reference line.


A

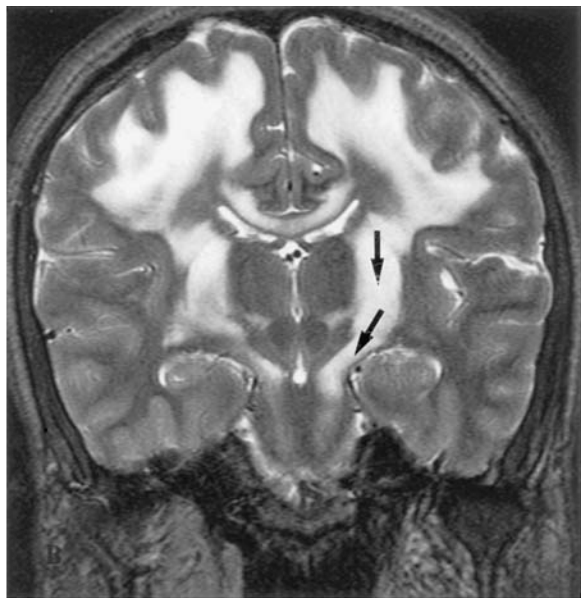
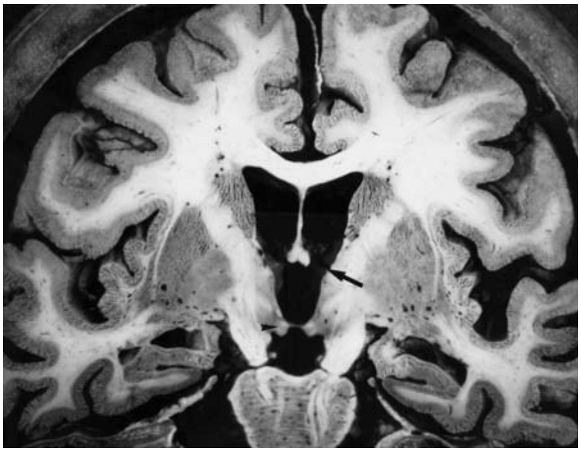
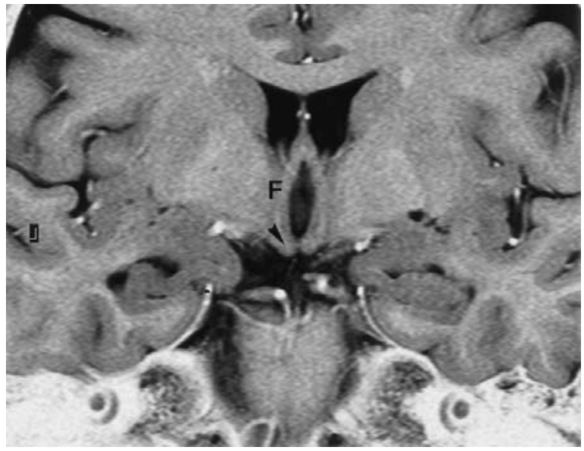

B

Fig. 2.52A,B. The PC-OB plane oriented roughly parallel to the corticospinal pathways displayed from the midbrain-diencephalic junction to the level of the medullary decussation, as shown on the MR coronal cut parallel to PC-OB (**A**) obtained from a patient presenting a toxic degeneration of these pathways, as compared to the perpendicular to the bicommissural plane (**B**)

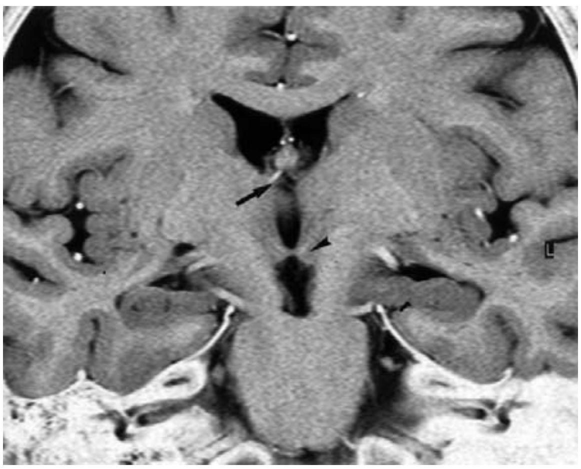
This posterior plane passes through the superior inflection of the cingulate sulcus-marginal ramus on the mesial aspect of the hemisphere and at approximately the region of origin of the ascending rami of the lateral fissure on the lateral aspect of the hemisphere. This latter plane may be considered the pos-



A



B



C

Fig. 2.53A–C. Close parallelism of PC-OB reference line to the Monro-mamillary plane: anatomic imaging correlation. Anatomic cut (6 mm thick) as compared to contiguous MR slices (3 mm thick) through the mamillary bodies, successively involving the anterior columns of the fornix (*F*) and, posteriorly, the interventricular foramen (*arrow*). Interventricular foramen of Monro (*arrow*); mamillary bodies (*arrowhead*)

terior boundary of the temporal lobe with the parieto-occipital inferior to the sylvian fissure.

The temporal pole may be arbitrarily limited posteriorly by the plane tangent to the genu of corpus callosum, passing anteriorly approximately through the anterior limit of the parallel sulcus.

The coronal slices from the CCg or the CSa anterior limiting plane to the CCs (Fig. 2.54) best evaluate the temporal gyri and sulci due to their approximate anterior-posterior parallelism and to the direction of the lateral fissure, surrounding the temporal horns of the lateral ventricles, at the lateral and inferomesial aspects of the cerebral hemispheres. The optic radiations coursing laterally along the external aspect of the temporal occipital horn are, consequently, well displayed in the white matter core, mainly on proton density or STIR sequences. Their relationship, with respect to the anterior temporal pole or to a temporal mass, may be evaluated as well in preoperative planning. The suprasylvian gyri may also benefit from such an orientation of the slices

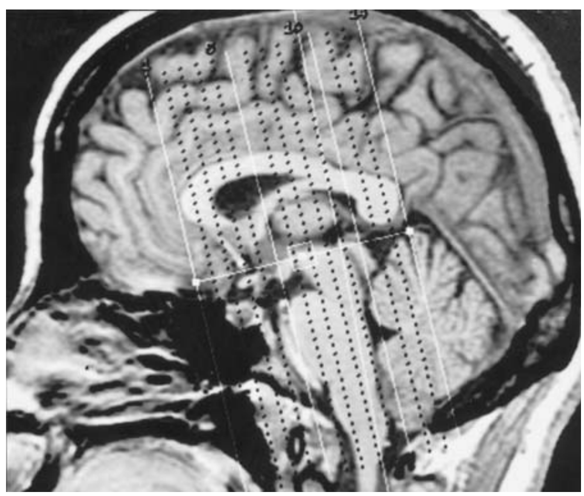
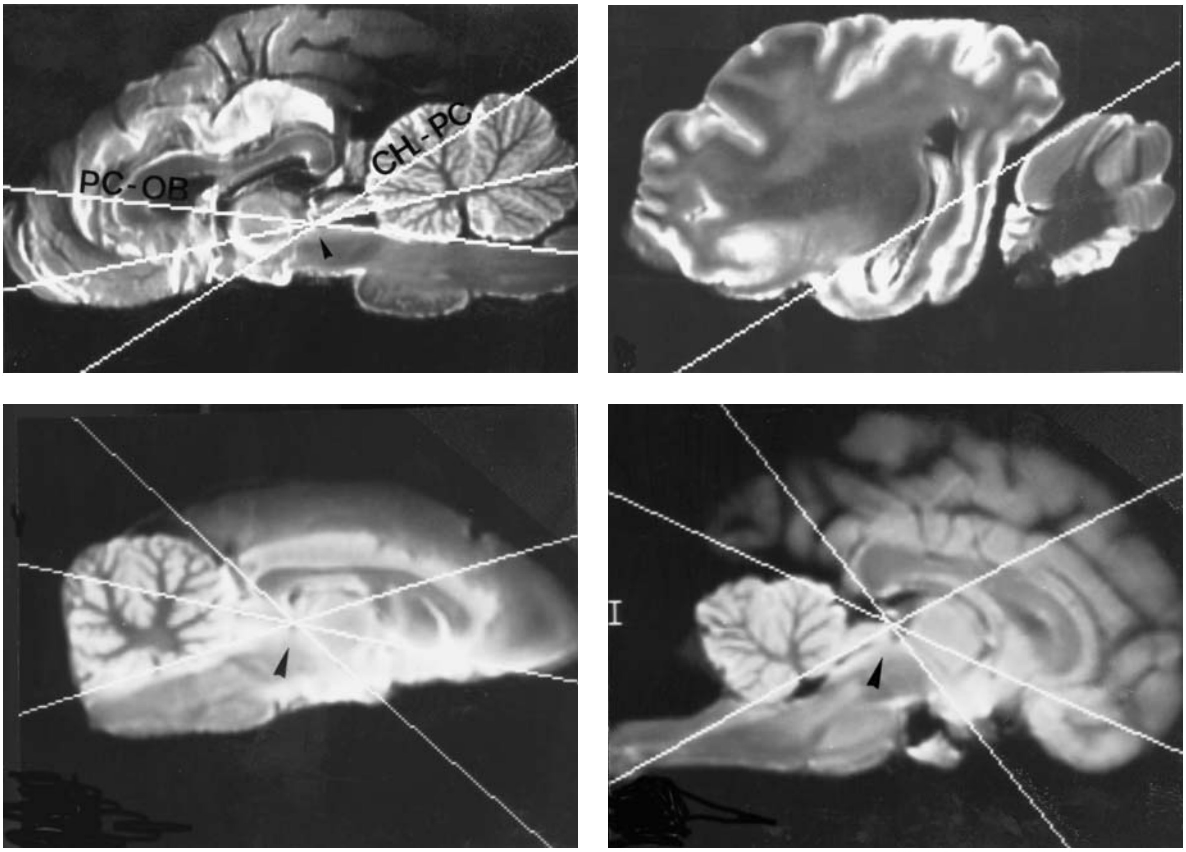
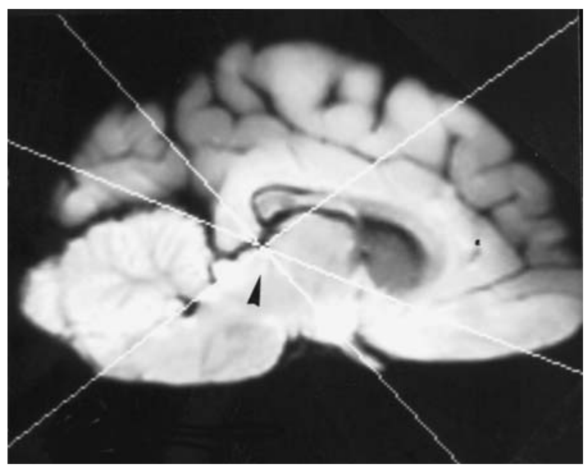


Fig. 2.54. Coronal imaging protocol for exploration of the temporal lobes according to the commissural-obex (*PC-OB*) brainstem reference plane



A B C D



E

Fig. 2.55A–E. The truncal angle (evaluated using MR of formalin-treated brains of mammals): suitable for the study of phylogenesis. Note the progressive closure of this angle during the processes of telencephalization and temporalization in the brain. These anatomic transformations tend to accompany the evolutionary process toward erect posture. **A,B** ursus; **C** lemur; **D** orangutan; **E** chimpanzee

due to the parallelism of some of the adjacent sulci, such as the inferior frontal sulcus.

On clinical and pathological grounds, such a reference allows the evaluation of degenerative atrophic processes, such as those associated with dementia syndromes or mental retardation (Tamraz et al. 1987, 1991, 1993). The accuracy of this plane for the investigation of temporal lobe epilepsy is obvious, as it permits the direct evaluation of the mesial temporal region, as well as the temporal cortex and lobe, cut perpendicularly to their anterior-posterior axis. This has been well demonstrated in the successive cuts presented in the synoptical atlas by Tamraz et al. (1990, 1991, 1988; Tamraz 1994; Chap. 10). The hippocampal formations are sectioned perpendicular to their global long axis. To some extent, the results are close to the anatomic cuts presented by Duvernoy (1995) in his coronal approach to the hippocampus.

On comparative anatomic grounds, the PC-OB and CH-PC references, which are based on commissural landmarks found in all vertebrates, may be easily used in phylogenetic studies using MR imaging for primates or other lower mammalian species (Fig. 2.55). Comparative anatomy studies in vivo and in vitro may be performed as well, using these reference lines. For example, in order to analyze, the major anatomic transformations completed during the phylogenetic process of telencephalization which accompanied evolution toward the erect position, we applied these references to a qualitative study of brains of primates and other mammals. We considered the well known modifications of the "truncal angle", as named by Ariens Kappers (1947; Ariens Kappers et al. 1936, 1967), and replaced it by the previously defined CH-PC-OB angle (Tamraz 1991). This angle, which in lower mammals is open superiorly, tends to progressively open inferiorly in the primates to reach 90° in humans. Such transformations, which correspond to a progressive closure of the truncal angle, are associated with a rotation of the cerebral hemispheres, causing a posterior to anterior displacement of the temporal lobes, rotating around a transverse axis and a verticalization of the brainstem (Delattre and Fenart 1960). This process may explain the diencephalon-mesencephalic flexure along which the CH-PC plane passes. All these ontogenetic and phylogenetic modifications accompanying the temporalization of the cerebral hemispheres might to be correlated with the erect posture achieved in humans.

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