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## The Cerebellum in Sagittal Plane—Anatomic-MR Correlation: 2. The Cerebellar Hemispheres

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Thin (5-mm) sagittal high-field (1.5-T) MR images of the cerebellar hemispheres display (1) the superior, middle, and inferior cerebellar peduncles; (2) the primary white-matter branches to the hemispheric lobules including the central, anterior, and posterior quadrangular, superior and inferior semilunar, gracile, biventer, tonsil, and flocculus; and (3) several finer secondary white-matter branches to individual folia within the lobules. Surface features of the hemispheres including the deeper fissures (e.g., horizontal, posterolateral, inferior posterior, and inferior anterior) and shallower sulci are best delineated on T1-weighted (short TR/short TE) and T2-weighted (long TR/long TE) sequences, which provide greatest contrast between CSF and parenchyma. Correlation of MR studies of three brain specimens and 11 normal volunteers with microtome sections of the anatomic specimens provides criteria for identifying confidently these structures on routine clinical MR.

MR should be useful in identifying, localizing, and quantifying cerebellar disease in patients with clinical deficits.

The major anatomic structures of the cerebellar vermis are described in a companion article [1]. This communication discusses the topographic relationships of the cerebellar hemispheres as seen in the sagittal plane and correlates microtome sections with MR images.

### Materials, Subjects, and Methods

The preparation of the anatomic specimens, MR equipment, specimen and normal volunteer scanning protocols, methods of identifying specific anatomic structures, and system of anatomic nomenclature are described in our companion article [1]. The pulse sequences illustrated in this article comprise proton-density-weighted images, 3000/20/4 (TR/TE/excitations); T1-weighted images, 600/20/4; and cardiac-gated T2-weighted images, 3642/70/2.

### Results

#### *Gross Anatomic Features of the Cerebellar Hemispheres*

**Lobar and lobular divisions.**—The cerebellar hemispheres are two large, lateral masses separated from the midline vermis by paired shallow surface indentations, the paramedian sulci [2]. The tentorium cerebelli, a transverse fold of the dura mater, stretches horizontally over the superior aspect of the hemispheres separating them from the overlying occipital lobes of the cerebrum. The posterior, inferior, and lateral surfaces of the hemispheres lie adjacent to the meninges overlying the occipital bone. The precentral fissure separates the anterior paramedian aspect of each hemisphere from the posterior aspect of the pons and junction of the pons and midbrain [1]. Further laterally, the cerebellopontine angle cistern separates the anterior surface of each cerebellar hemisphere from the dorsal aspect of the petrous ridge [2].

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### Key to Abbreviations Used in Figures

An	anterior aspect of section
Ant Lobe	anterior lobe of hemisphere
ao	atlantooccipital joint
Bi	biventer
Ce	centralis
cl	clivus
Cm	corpus medullare
CP	collicular plate
cpa	cerebellopontine angle cistern
Cu	culmen
D	dentate nucleus
De	declive
F	flocculus
FF	floor of fourth ventricle
fm	foramen magnum
Fo	folium vermis
Gr	gracile lobule
hpr	hemisphere primordium
iac	internal auditory canal
IC	inferior colliculus
icp	inferior cerebellar peduncle
jv	jugular vein
Li	lingula
M	medulla
mcp	middle cerebellar peduncle
No	nodulus
P	pons
pb	petrous bone
PF	pontine flexure
pr	cerebellar primordium
pt	primary white-matter tract
Py	pyramis
Qu P	quadrangular lobule, posterior portion
Rh	rhombic lip
Ro	roof of fourth ventricle
sc	semicircular canal
Se I	semilunar lobule, inferior portion
Se S	semilunar lobule, superior portion
tmj	temporomandibular joint
To	tonsil
Uv	uvula
Tu	tuber vermis
vpr	vermis primordium
1	precentral fissure
2	preculminate fissure
3	primary fissure
4	superior posterior fissure
5	horizontal fissure
6	prepyramidal fissure (vermis only)
6'	inferior posterior fissure (hemisphere only)
6''	inferior anterior fissure (hemisphere only)
7	secondary fissure
8	posteriorlateral fissure

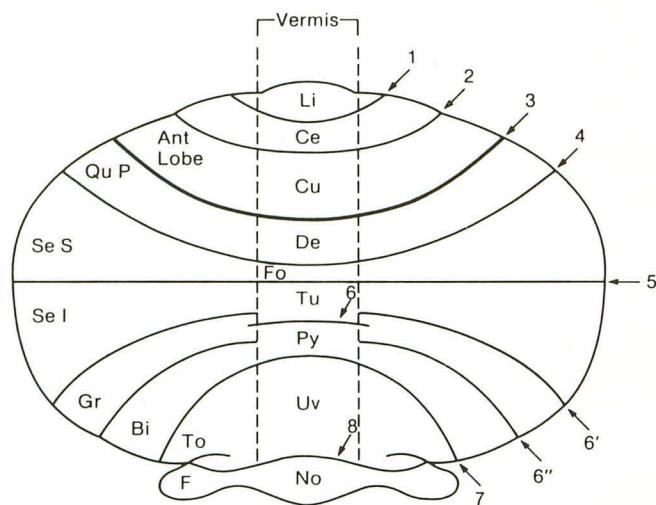


Fig. 1.—Diagram of lobar and lobular structures of cerebellum. This modification of a standard anatomic diagram of the human cerebellum [3] permits rapid identification of the locus of any given term used here and in our companion report [1]. Abbreviations used to designate the anterior lobe of the hemisphere as a whole, and each of the individual lobules of the posterior lobe of the hemisphere and flocculus, are positioned on the left side of the diagram. Arranged on the right side of the diagram are the numerals used to designate the major fissures subdividing the cerebellum. Confined by the central pair of broken lines are abbreviations used to designate the lobules of the vermis. The bold line of the primary fissure (3) represents the boundary between the anterior and posterior lobes of the cerebellum. See key for abbreviations.

The deep primary and posterolateral fissures extend outward from the vermis into the cerebellar hemispheres dividing them also into three portions: the anterior and posterior lobes and the hemispheric component of the flocculonodular lobe, the flocculus (HX) (Fig. 1) [1, 3]. Additional, shallower fissures subdivide the anterior and posterior lobes of the hemispheres into a series of lobules (HII–HIX). No hemispheric counterpart of vermian lobule I exists in humans [3, 4].

The lobules of the anterior lobe of the hemisphere (HII–HV) are bounded by the precentral cerebellar fissure and cerebellopontine angle cistern anteriorly and the primary fissure posteriorly (Fig. 1). The preculminate fissure separates the central lobule (HII and HIII) from the anterior quadrangular lobule (HV and HV) [3, 4].

The lobules (HVI–HIX) of the posterior lobe of the cerebellum are bounded by the primary fissure (which separates them from the anterior lobe) and the posterolateral fissure (which separates them from the flocculus). Three additional fissures within the vermis extend also into the hemispheres to separate several of the five lobules of the posterior lobe of the hemisphere from one another: the superior posterior fissure separates the posterior quadrangular lobule (HVI) from the superior semilunar lobule (HVIIA), the horizontal fissure separates the superior semilunar lobule from its inferior component (also HVIIA), and the secondary fissure separates the biventer (HVIII) and tonsil (HIX). Two remaining fissures are present within the hemispheres only and subdivide the remainder of the lobules of the posterior lobe: the inferior posterior fissure separates the inferior semilunar lobule and

**Fig. 2.**—Plane 1, through the brainstem and anterior and posterior lobes of the cerebellum. See key for abbreviations.

**A**, Sagittal microtome section of specimen brain. (Luxol fast blue-cresyl violet myelin stain)

**B**, Corresponding sagittal proton-density-weighted image (3000/20/4) of same specimen brain before sectioning.

**C** and **D**, Sagittal T1-weighted, 600/20/4 (**C**), and cardiac-gated T2-weighted, 3642/70/2 (**D**), images of 38-year-old male volunteer.

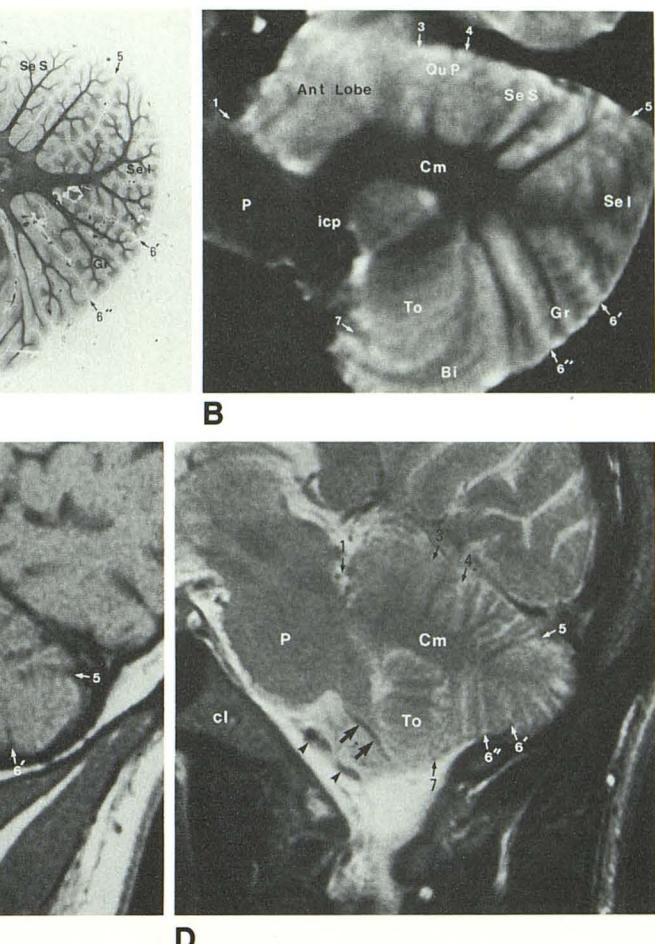
Pons and cerebellar hemisphere are continuous. Corpus medullare and superior and inferior cerebellar peduncles arch over tonsil. Primary white-matter tracts innervating posterior quadrangular, semilunar, and gracile lobules and posterior portion of the biventer are well delineated on proton-density-weighted image of anatomic specimen and T2-weighted image of volunteer. Note hatchmarklike arrangement of gray and white matter within tonsil (**A**, **B**, and **D**). Several primary white-matter tracts to anterior lobe of hemisphere are obscured due to volume averaging on **B** and **D**. For the same reason, characteristic undulating contour of dentate nucleus is identifiable only on thin (15- $\mu$ m) anatomic image (**A**). Gray and white matter have similar signal intensity on T1-weighted image; however, margins of hemisphere and fissures are well defined on this image. Extraparenchymal landmarks in this plane include a paramidline section through the clivus, intraarachnoid course of vertebral artery (arrowheads), and lateral medullary segment of posterior inferior cerebellar artery (arrows).

gracile lobule (HVIIIB) and the inferior anterior fissure separates the gracile lobule and biventer (Fig. 1) [3, 4].

The flocculus is a separate lobe of the cerebellar hemisphere and contains only one lobule (HX). It represents the hemispheric component of the flocculonodular lobe of the cerebellum and is bounded posteriorly by the posterolateral fissure and anteriorly by the cerebellopontine angle cistern [3, 4].

Two prominent fissures that do not form a boundary between hemispheric lobules are mentioned here to avoid confusion when viewing the anatomic and MR sections: (1) the intrabiventral fissure divides the biventer into anterior and posterior portions and (2) the intracrural sulcus 1 divides the superior semilunar lobule (HVIIA) into anterior and posterior portions [5].

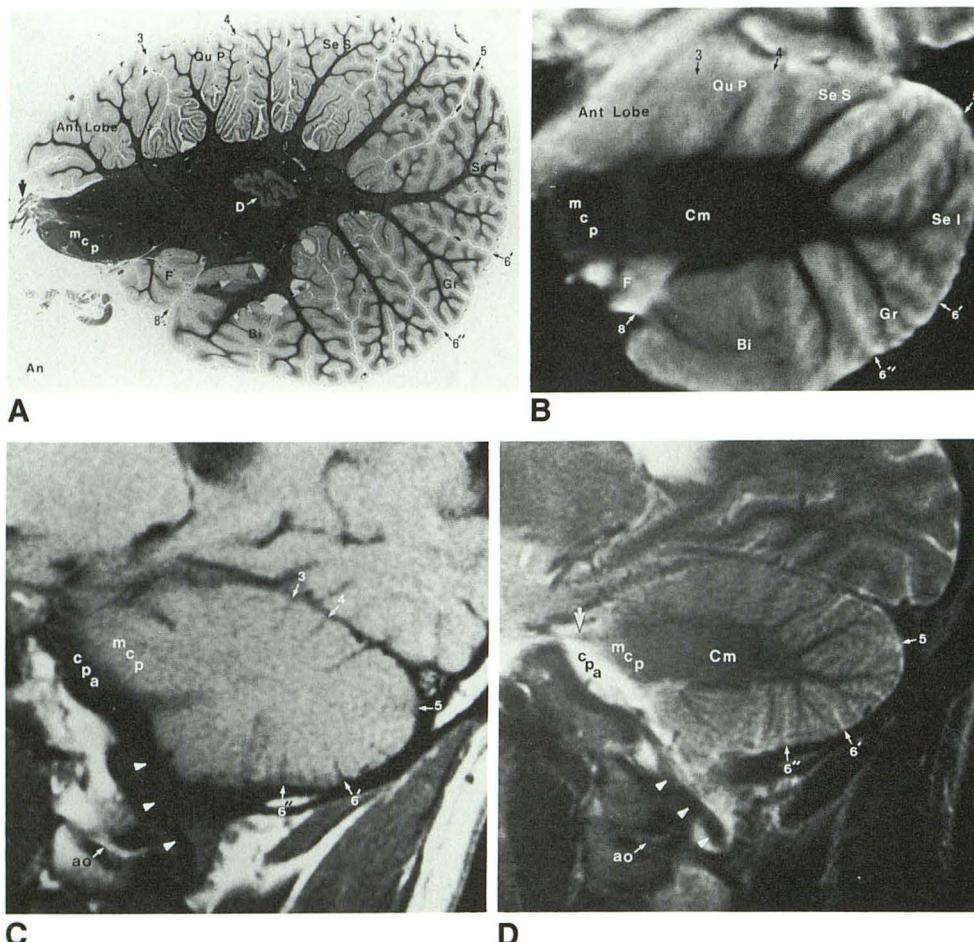
**Sublobular and folial divisions.**—Each lobule of the cerebellar hemispheres contains from one to three sublobules; each of these contains many folia. As is the case with the vermis of the cerebellum, the folium represents the minimum unit of structure of the cerebellar hemispheres [1, 4]. Each cerebellar hemisphere in humans contains 330 folia [4]. A more detailed description of the sublobular divisions of the hemispheres can be found in other sources [4, 5].



**Organization of the white matter.**—The white matter of each cerebellar hemisphere radiates proximally into the brainstem and distally into the lobules of the hemisphere from a central confluence known as the corpus medullare. This central body of white matter extends posterolateral to the fourth ventricle on each side and is much larger within the hemispheres than within the vermis [1, 3].

Three major white-matter bundles emanate from the anterior aspect of each corpus medullare to connect the cerebellar hemispheres with the three segments of the brainstem [3]. Axons of the superior cerebellar peduncles slope gently upward adjacent to the superolateral aspect of the fourth ventricle to decussate within the midbrain just beneath the red nuclei. Fibers of the middle cerebellar peduncles project anteromedially as they exit the cerebellum to decussate in the tegmentum of the pons. Fibers of the inferior cerebellar peduncles turn sharply inferiorly just medial to the middle cerebellar peduncles to enter the posterolateral aspect of the low pons and medulla (Figs. 2A and 3A).

Smaller bands of white matter radiate from the corpus medullare to the hemispheric lobules. Thin (15- $\mu$ m) paramedian sagittal microtome sections reveal that three primary tracts enter the anterior lobe (HII-HV) (Figs. 2A, 3A, and 4A),



**Fig. 3.—Plane 2, through anterior and posterior lobes of cerebellum, middle cerebellar peduncle, and trigeminal root and/or flocculus. See key for abbreviations.**

**A**, Sagittal microtome section of specimen brain. (Luxol fast blue-cresyl violet myelin stain)

**B**, Corresponding sagittal proton-density-weighted image (3000/20) of same specimen brain before sectioning.

**C** and **D**, Sagittal T1-weighted, 600/20 (**C**), and cardiac-gated T2-weighted, 3642/70 (**D**), images of 38-year-old male volunteer.

In plane 2, lateral to brainstem and tonsil, corpus medullare becomes oval in shape. Middle cerebellar peduncle extends from corpus medullare to anterior aspect of hemisphere. Biventer alone is sectioned at anteroinferior aspect of hemisphere (compare with Figs. 1A and 1B). Anterior lobe of hemisphere is smaller than in plane 1. Flocculus may appear as a small, globular lobule at anteroinferior aspect of corpus medullare (**A** and **B**). Posterolateral aspect of dentate nucleus appears as a complete ring within corpus medullare and is best seen on anatomic image (**A**). Within superior aspect of cerebellopontine angle cistern is trigeminal nerve root (arrows, **A** and **D**), which courses over petrous bone to end in Meckel cave (**D**). Extraparenchymal landmarks identified in vivo include atlantooccipital joint and vertebral artery (arrowheads) passing over posterior arch of C1 to enter cranial cavity.

whereas six or seven primary tracts enter lobules HVII–HVIII of the posterior lobe (Fig. 3A). Both the tonsil (lobule HIX of the posterior lobe) and the flocculus (HX) receive a single primary tract from the corpus medullare (Figs. 2A and 3A) [3].

#### Anatomic Features of the Cerebellar Hemispheres on Sagittal Microtome and MR Sections

Inspection of the cerebellar hemispheres revealed that sagittal sections would display its lobules and white-matter tracts in discontinuous segments. There are three reasons for this:

1. The complex organization of the cerebellum as a whole. The greater portion of the cerebellum is a composite of multiple transverse lobules, each of which is crescent-shaped with a wedgelike cross section that widens toward the periphery (Fig. 1). The cerebellar parenchyma may be thought of as a stack of such crescents, with the spaces between them analogous to the various fissures. At the center of the stack of crescents lies the fourth ventricle and cerebellar vermis forming its roof. Posterolateral to the fourth ventricle on each side are the paired corpora medullare, which send white-matter tracts into each of the hemispheric lobules.

2. The varying radii of curvature of the different lobules. The anterior lobules (e.g., HII and HIII), having a smaller radius of curvature than the posterior lobules, would be seen on the

most medial sagittal sections only (Figs. 2A, 3A, and 4A), whereas the larger posterior lobules (e.g., HVIIA and HVIIIB) would be present on all sagittal sections (Figs. 2A, 3A, 4A, 5A, 6A, and 7A).

3. Unlike the stacked crescent-shaped lobules, the flocculus and tonsil are significantly smaller, ovoid lobules that protrude from the anterior and inferomedial surfaces of the hemispheres, respectively, and would be seen on a limited number (one or two) of sagittal images (Figs. 3A and 4A) only.

Analysis of the anatomic relationships of the cerebellar hemisphere in six sagittal sections revealed sequential and reproducible changes in the contours and relationships of the individual lobules, corpus medullare and smaller white-matter branches, brainstem, adjacent cisterns, and cerebellar fissures. The individual components of the hemispheres could be identified confidently and consistently on sagittal MR sections by using the intrinsic configurations and signal intensities of these structures and by using secondary clues from the positions and configurations of the surrounding noncerebellar structures.

Several observations can be made if the sagittal anatomic or MR sections are considered in sequence from the paramedian plane (plane 1) toward the lateral plane (plane 6).

#### Surface features:

- The shape of the normal hemisphere in plane 1 (Fig. 2) is similar to an isosceles triangle with rounded corners. The

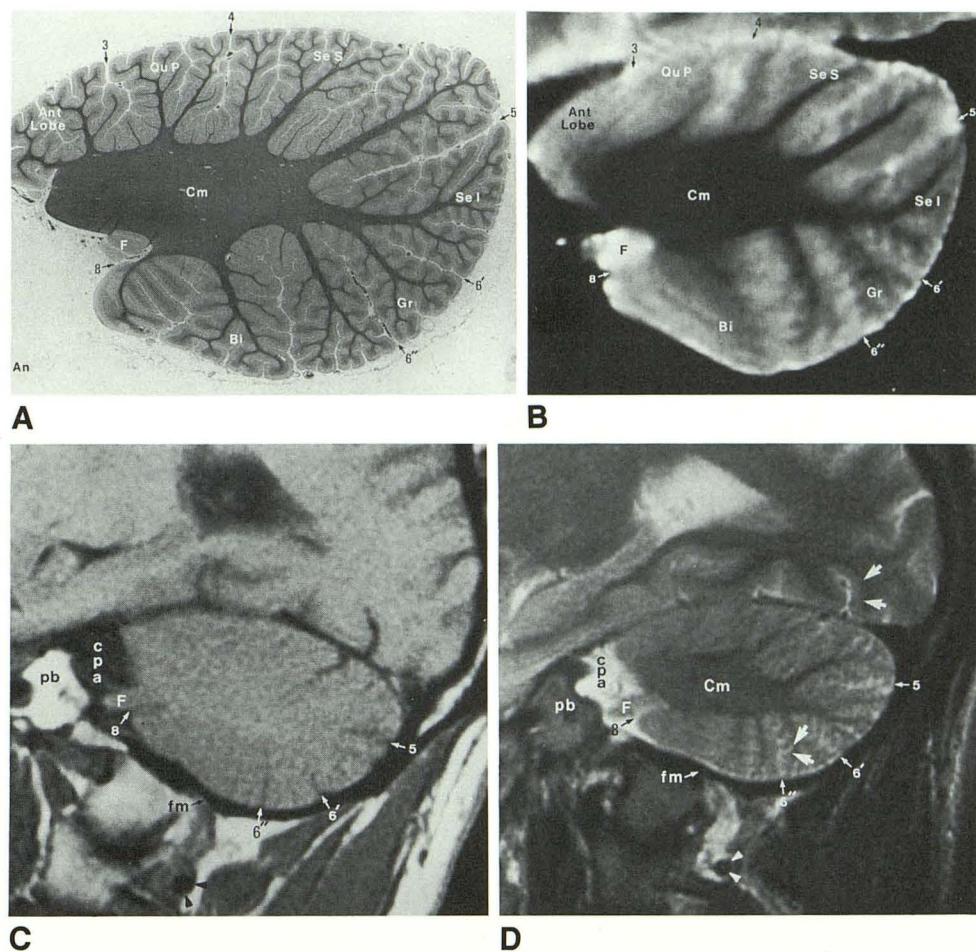
**Fig. 4.**—Plane 3, through anterior and posterior lobes of hemisphere (lateral to middle cerebellar peduncle), and through flocculus (hemispheric portion of flocculonodular lobe). See key for abbreviations.

**A.** Sagittal microtome section of specimen brain. (Luxol fast blue-cresyl violet myelin stain)

**B.** Corresponding sagittal proton-density-weighted image (3000/20) of same specimen brain before sectioning.

**C and D.** Sagittal T1-weighted, 600/20 (C) and cardiac-gated T2-weighted, 3642/70 (D), image of 38-year-old male volunteer.

This is the final section to include a portion of the anterior lobe of the hemisphere. Dentate nucleus is not present in A. Flocculus protrudes tongue-like into inferior aspect of cerebellopontine angle cistern (C and D). Three-layered cortex of cerebellum is thinner than six-layered cortex of inferior occipital lobe (arrows, D). Extraparenchymal landmarks identified in this plane *in vivo* include apex of petrous bone anterior to porus acusticus, lateral edge of foramen magnum, and vertebral artery (arrowheads).



side of the triangle adjacent to the brainstem (anterior leg) is formed by the upper margin of lobules HII and HIII superiorly, the anterior aspect of the cerebellar peduncles in the middle, and the anterior aspect of the cerebellar tonsil (HIX) inferiorly. The superior aspect of lobules HIV-HVIIA forms the superior leg of the triangle. The inferior leg is formed by the inferior aspect of lobules HVIIA-HIX.

In plane 2 (Fig. 3), the anteroposterior diameter of the cerebellar hemisphere exceeds the superoinferior diameter, and the hemisphere acquires an oval shape. The shape of the hemisphere becomes more rounded in planes 4-6 (Figs. 5-7) due to the progressive shortening of its anteroposterior diameter exceeding the shortening of its superoinferior diameter.

2. Because the inferior aspect of the tonsil may lie slightly closer to the midline than its superior aspect does, a variable portion of the adjacent biventer often appears as an arch beneath the tonsil in plane 1 (Fig. 2).

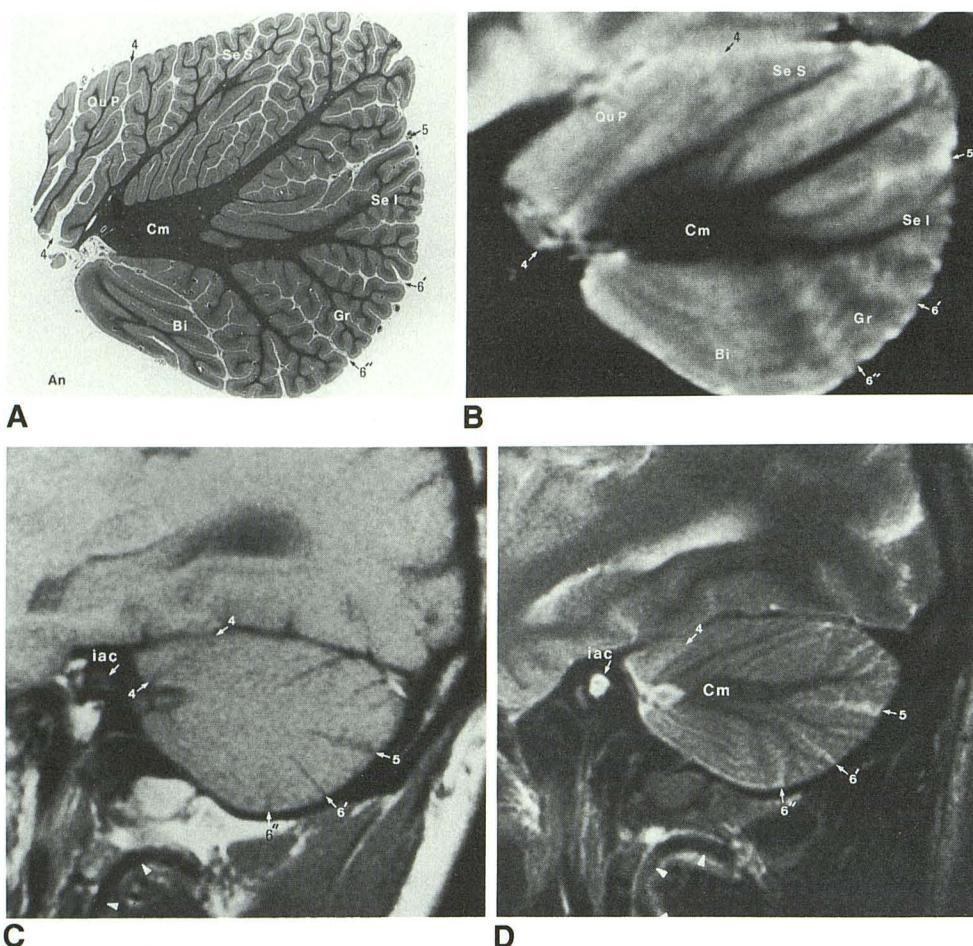
3. The cerebellopontine angle cistern is most prominent in planes 2 and 3. Traversing the superior aspect of the cistern is the trigeminal nerve root proceeding from its origin in the lateral tegmentum of the pons/middle peduncle junction region to Meckel cave (Figs. 3A and 3D). The flocculus extends into the inferior aspect of the cerebellopontine angle cistern; it appears as a tubular or globular, <1-cm mass protruding from the anterior aspect of the hemisphere at the lower margin

of the corpus medullare (Figs. 3A, 3B, and 4). The flocculus and cisternal segment of the trigeminal nerve are seen only in planes 2 or 3 or both.

4. The lower midbrain, pons, and corpus medullare are continuous in plane 1, joined by fibers of the cerebellar peduncles (Fig. 2). Depending on the precise plane of section and the size of the various structures in each patient, different portions of the peduncles will be included in this immediately paramedian section. Fibers proceeding anterosuperiorly from the cerebellum to the midbrain and pons within a thin (<1-cm transverse diameter) white-matter band are part of the superior peduncle. Fibers within a larger bundle proceeding anteroinferiorly toward the pons and medulla represent portions of the middle and inferior peduncles. This region is variable in appearance. No midbrain, lower brainstem, or tonsillar tissue is present on the more lateral sections.

#### Deep features:

1. Frequently, the white matter of the corpus medullare and cerebellar peduncles is seen as an arch over the top of the ovoid contour of the tonsil (HIX) in plane 1 (Fig. 2). The shape of the corpus medullare is distinctly different in planes 2 and 3 (Figs. 3 and 4), becoming a biconvex low-signal region within the center of the hemisphere. The fibers of the middle cerebellar peduncle are sectioned obliquely and form the anterior margin of the central white-matter mass in plane 2 (Fig. 3). In plane 4, the appearance of the corpus medullare



**Fig. 5.—**Plane 4, through posterior lobe of hemisphere and corpus medullare. See key for abbreviations.

**A,** Sagittal microtome section of specimen brain. (Luxol fast blue-cresyl violet myelin stain)

**B,** Corresponding sagittal proton-density-weighted image (3000/20) of same specimen brain before sectioning.

**C and D,** Sagittal T1-weighted, 600/20 (C), and cardiac-gated T2-weighted, 3642/70 (D), images of 38-year-old male volunteer.

Lateral to anterior lobe of hemisphere, corpus medullare becomes smaller, with linear upper and lower margins. Profile of hemisphere as a whole is more rounded. Flocculus is no longer present. Extraparenchymal landmarks identified in this plane in vivo include cranial nerves VII and VIII within internal auditory canal and vertebral artery (arrowheads) coursing posteromedially from transverse foramen to posterior arch of atlas.

changes again, becoming much smaller with linear upper and lower margins from which primary branches radiate into the superior and inferior semilunar lobules (Fig. 5). Planes 5 and 6 (Figs. 6 and 7) (beyond the lateral aspect of the corpus medullare) section obliquely along primary tracts of white matter within the superior and inferior semilunar lobules. Situated above and below the horizontal fissure, these primary tracts appear as diverging hypointense bundles surrounded by mantles of gray matter having higher signal intensity.

2. The gray-/white-matter distinction within lobules HII–HV of the anterior lobe and HVI and HVIII of the posterior lobe as well as the primary and superior posterior fissures may be obscured on sagittal MR images (Figs. 2B, 2D, 3B, and 3D) in comparison with gross and microtome sections (Figs. 2A and 3A). The reasons for this are (1) the relatively small radius of curvature of these structures, which causes them to be sectioned most obliquely on sagittal images; combined with (2) volume averaging inherent in obtaining 5-mm-thick MR sections. Thinner (15- $\mu$ m) microtome sections minimize these difficulties and depict the smallest anatomic details.

3. Situated within the corpus medullare posterolateral to the fourth ventricle are the paired deep nuclear structures of the cerebellum. From medial to lateral they are the fastigial, globose, emboliform, and dentate nuclei. In 5-mm-thick sag-

ittal MR images the deep nuclei of the cerebellum may be difficult to resolve due to their small size (fastigial, globose, and emboliform), serpentine configuration (dentate), and low signal intensity due to iron deposition (dentate); nevertheless, thinner anatomic sections display the dentate nuclei well. Each dentate nucleus has a characteristic undulating margin and a convex upward contour in paramedian plane 1 (Fig. 2A); the nucleus becomes a complete oval in plane 2 (Fig. 3A). The dentate is no longer present on sagittal sections lateral to plane 2 (Figs. 4A, 5A, 6A, and 7A).

4. Unique to the cerebellum is a relatively thin (0.7-mm) three-layered cortex consisting of a deep cellular (granular) layer containing closely packed granule cells; a middle monocular (Purkinje) layer containing Purkinje cells; and a superficial (molecular) layer containing mainly a feltwork of nerve fibers, dendrites, and glial processes [6, 7]. In contrast, the large majority of the cerebral cortex comprises thicker (1.45–4.5 mm) iso- (or neo-) cortex that contains six layers [7]. This histologic difference is detected on anatomic and MR sagittal sections as a thinner cortical mantle overlying the cerebellar vermis and hemispheres when compared with that overlying the adjacent gyri of the occipital lobes (Fig. 4D).

**Imaging landmarks on sagittal MR.**—Nonparenchymal landmarks consistently identified in each of the six imaging planes in our volunteers included (1) plane 1 (Figs. 2C and 2D):

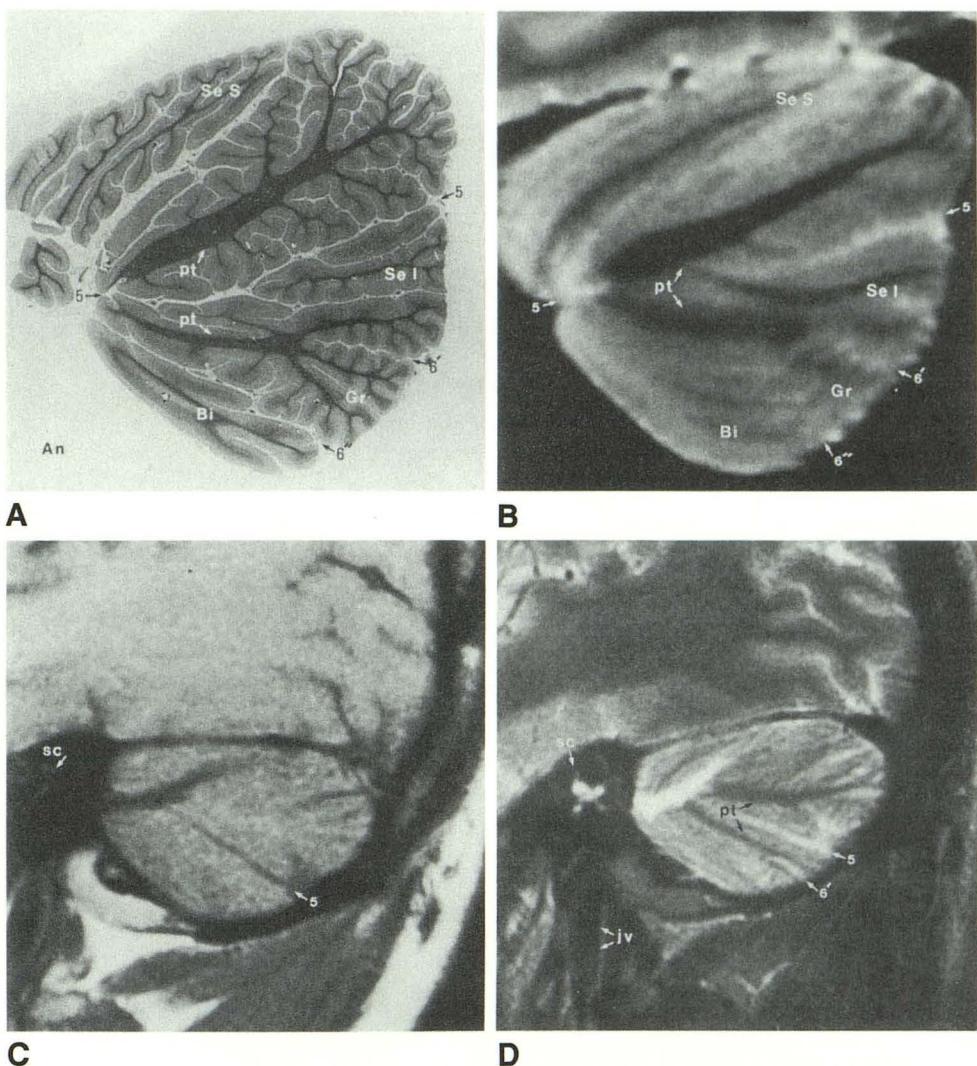
**Fig. 6.**—Plane 5, through posterior lobe of hemisphere lateral to corpus medullare. See key for abbreviations.

**A,** Sagittal microtome section of specimen brain. (Luxol fast blue-cresyl violet myelin stain)

**B,** Corresponding sagittal proton-density-weighted image (3000/20) of same specimen brain before sectioning.

**C and D,** Sagittal T1-weighted, 600/20 (C), and cardiac-gated T2-weighted, 3642/70 (D), images of 38-year-old male volunteer.

Primary white-matter tracts innervating superior and inferior portions of semilunar lobule diverge posteriorly. This is the final section to include a portion of the biventer and gracile lobules. Extraparenchymal landmarks identified in this plane include semicircular canals and vestibule within petrous bone and internal jugular vein.



paramedian section through clivus, intraarachnoid course of the vertebral artery, and lateral medullary segment of the posterior inferior cerebellar artery; (2) plane 2 (Figs. 3C and 3D): atlantooccipital joint and vertebral artery coursing over the posterior arch of C1; (3) plane 3 (Figs. 4C and 4D): petrous apex medial to porus acusticus and lateral edge of foramen magnum; (4) plane 4 (Figs. 5C and 5D): seventh and eighth cranial nerves within CSF-filled internal auditory canal and vertebral artery coursing superiorly and posteriorly through the transverse foramen of the atlas to reach the sulcus arteriosus on the superior surface of the posterior arch of C1; (5) plane 5 (Figs. 6C and 6D): semicircular canals and vestibule and internal jugular vein; and (6) plane 6 (Figs. 7C and 7D): temporomandibular joint. The vertical portion of the sigmoid sinus appears on the sagittal section just lateral to the cerebellar hemisphere.

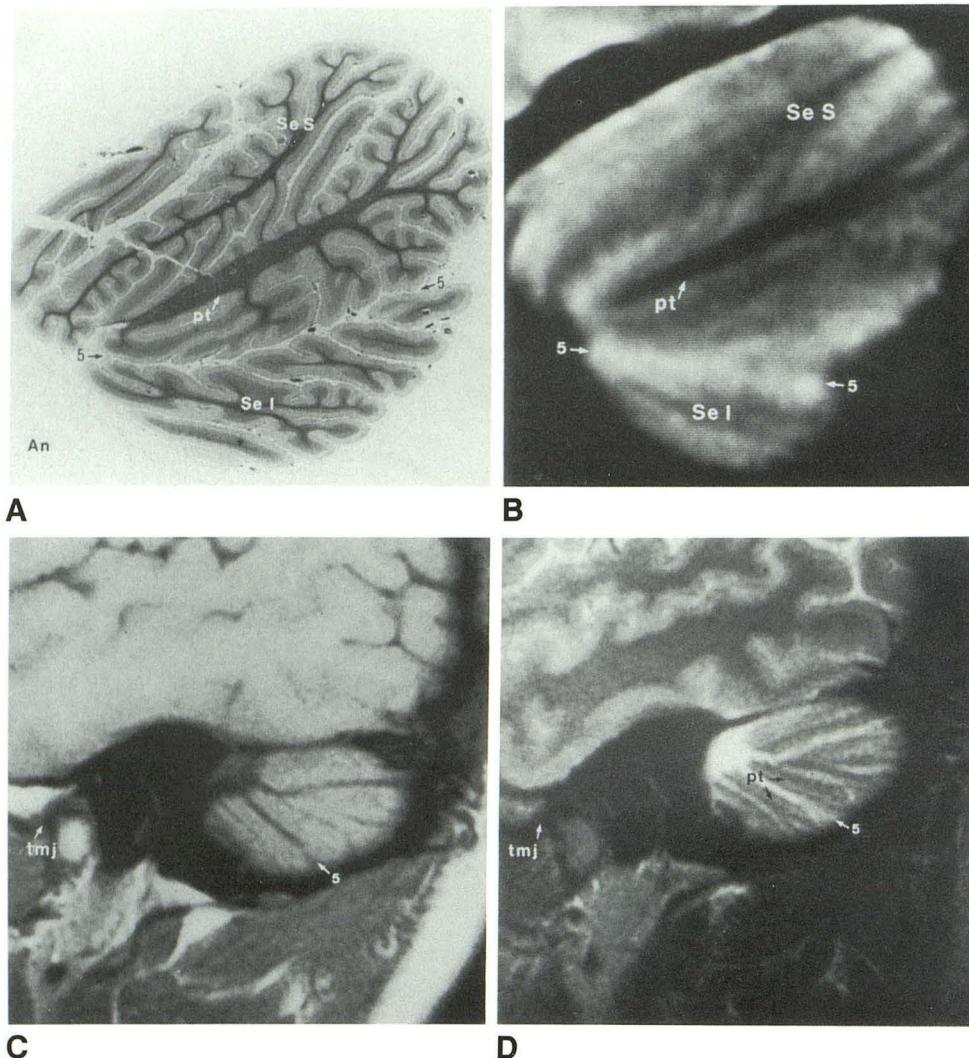
## Discussion

### Development of the Cerebellum

A brief review of key stages in the development of the cerebellum will contribute greatly to understanding its adult

appearance on sagittal MR. Neuroblasts, which form the cerebellum, derive ultimately from symmetric "alar plates" on both sides of the rhombencephalon beneath the roof of the fourth ventricle, sites of intense neuroblastic activity [6, 8]. At the beginning of the second month of life, the proliferating neuroblasts form paired rhombic lips (cerebellar rudiments) that thicken, project further into the fourth ventricle, and extend progressively toward the midline (Figs. 8A and 8B). At the end of the second month of gestation, the rhombic lips of the two sides fuse in the midline beginning rostrally, and the anterior lobe of the vermis is thereby formed before the posterior lobe. During the third month, the cerebellum acquires additional cells at such a rate that it begins to bulge extraventricularly (Figs. 8C and 8D). The middle regions of the vermis and hemispheres proliferate more extensively than the rostral or caudal extremes, and the simple linear structure of the developing cerebellum becomes mushroom-shaped [6, 8].

The growth of the cerebellum posterior to the roof of the fourth ventricle creates the posterolateral fissure early in the third month [6, 8]. All of the remaining horizontally oriented fissures, which divide the cerebellar vermis and hemispheres



**Fig. 7.—**Plane 6, through superior and inferior portions of semilunar lobule. See key for abbreviations.

**A**, Sagittal microtome section of specimen brain. (Luxol fast blue-cresyl violet myelin stain)  
**B**, Corresponding sagittal proton-density-weighted image (3000/20) of same specimen brain before sectioning.

**C** and **D**, Sagittal T1-weighted, 600/20 (C), and cardiac-gated T2-weighted, 3642/70 (D), images of 38-year-old male volunteer.

Horizontal fissure divides completely the remainder of the hemisphere into upper and lower portions containing lateral-most aspects of superior and inferior semilunar lobules, respectively. Temporomandibular joint is extraparenchymal landmark consistently identified in this plane in vivo.

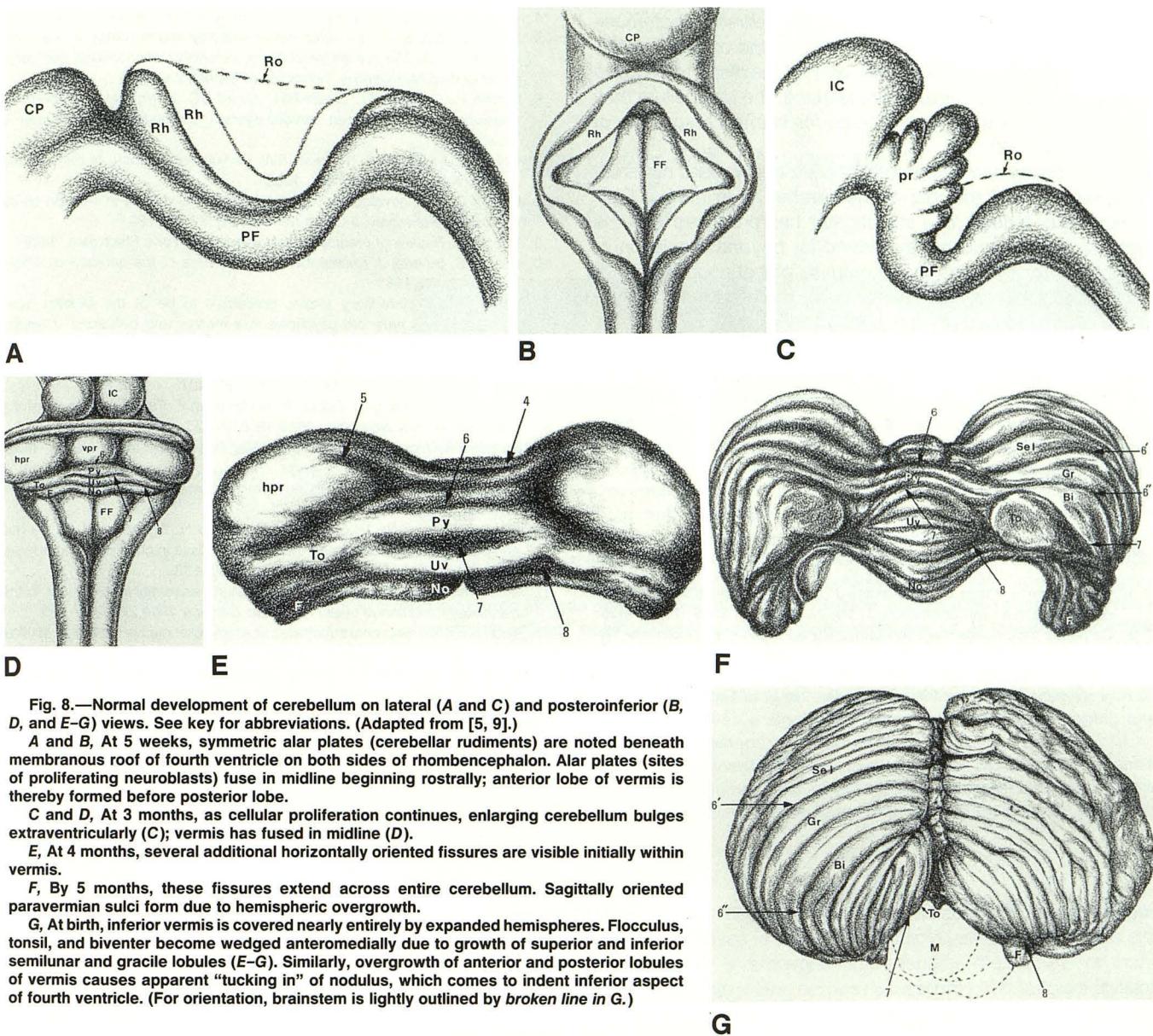
into transverse lobules, are visible by the end of the fourth month (Figs. 8E and 8F). Eventually, continued hemispheric growth outstrips growth of the vermis, creating the sagittally directed paravermian sulci between the hemispheres and the vermis (Fig. 8F). Moreover, to accommodate the expansion of lobules HVIIA and HVIIB, a shift in the hemispheric lobules occurs—the biventral lobules (HVIII), tonsils (HIX), and flocculi (HX) are pushed anteriorly, inferiorly, and medially from their initially lateral position, attaining their final position along the anteroinferior aspect of the hemispheres (Figs. 8E-8G). This shifting process, together with growth of the tonsils themselves, results in a sagittally directed furrow between them and the vermis [6-8].

#### *Functional Anatomy and Connections of the Cerebellar Hemispheres*

A major responsibility of the cerebellum is the coordination of motor responses. Through its synergistic action, reflex and voluntary motor acts become coordinated and effective [7].

In broad general terms, distinct clinical abnormalities can be referred to two major sagittal zones of function (midline and lateral) within the cerebellum that correspond closely to its anatomic organization. These zones have distinct (but overlapping) functions [10]. The midline zone, containing the vermis and fastigial nuclei, is related mainly to activities of the midline musculature of the body [10]. The functional anatomy, connections, and disorders of the midline zone are described more fully in our companion article [1].

The lateral (hemispheric) zone of the cerebellum consists of the hemisphere and the dentate, globose, and emboliform nuclei of each side. The cerebellar hemispheres are phylogenetically younger than the midline structures, and are concerned with movements of the proximal and distal extremities. Neurons of the lateral hemispheric cortex (including the most lateral region of the anterior lobe and the lateral portions of the superior and inferior semilunar lobules, HVIIA) project to the dentate nuclei, which then project to the ventrolateral thalamic nucleus [10]. Nerve fibers from this portion of the thalamus ascend to the precentral gyrus and influence finely coordinated movements of the distal extremities. Cortical



**Fig. 8.**—Normal development of cerebellum on lateral (A and C) and posteroinferior (B, D, and E–G) views. See key for abbreviations. (Adapted from [5, 9].)

A and B, At 5 weeks, symmetric alar plates (cerebellar rudiments) are noted beneath membranous roof of fourth ventricle on both sides of rhombencephalon. Alar plates (sites of proliferating neuroblasts) fuse in midline beginning rostrally; anterior lobe of vermis is thereby formed before posterior lobe.

C and D, At 3 months, as cellular proliferation continues, enlarging cerebellum bulges extraventricularly (C); vermis has fused in midline (D).

E, At 4 months, several additional horizontally oriented fissures are visible initially within vermis.

F, By 5 months, these fissures extend across entire cerebellum. Sagittally oriented paravermian sulci form due to hemispheric overgrowth.

G, At birth, inferior vermis is covered nearly entirely by expanded hemispheres. Flocculus, tonsil, and biventer become wedged anteromedially due to growth of superior and inferior semilunar and gracile lobules (E–G). Similarly, overgrowth of anterior and posterior lobules of vermis causes apparent "tucking in" of nodulus, which comes to indent inferior aspect of fourth ventricle. (For orientation, brainstem is lightly outlined by broken line in G.)

neurons of the medial portions of the cerebellar hemispheres project to the globus and emboliform nuclei. These nuclei project subsequently to the red nucleus and ventrolateral thalamic nucleus. The rubrospinal tract (originating from cells of the red nucleus) synapses with both medial and lateral groups of anterior horn cells of the spinal cord, thereby influencing the activity of proximal and distal limb musculature, respectively. This pathway is involved in several motor functions including phasic limb movements, maintained positions of an extremity, stance, gait, and posture [10].

Motor signs accompanying lesions involving mainly the cerebellar hemispheres include ipsilateral static and kinetic tremors of the extremities, dysmetria, dysdiadochokinesia (abnormal rapid alternating movements), excessive rebound, impaired check reflex, decomposition of movements, past-pointing, and hypotonia [10].

Clinical and basic research indicates that the cerebellum (particularly the posterior lobe of the hemispheres and vermis) regulates, integrates, and coordinates a wide variety of additional, nonmotor concerns including level of consciousness, learning, memory, and motivated behavior. For example, early investigators recognized that cerebellar damage occurring in adulthood may be associated with lethargy and coma [10] or psychosis [10, 11]. Others observed that retarded intellectual functioning is typically associated with developmental disorders of the cerebellum ranging from hypoplasia [12–14] to near total agenesis [15, 16]. In many such instances, lesions found in the CNS outside the cerebellum were insufficient to explain the severity of the mental retardation [12]. More recently, in a test of word meaning and association, the cerebellum was one of three sites of significant neural activity defined by positron emission tomography (Petersen SE, Fox

PT, Posner MI, Mintun MA, Raichle ME, personal communication). In addition, the posterior lobe of the cerebellum has been shown to be an "obligatory part" of the discrete adaptive response circuit for associative learning; the cerebellum may be the locus of the memory trace for learned responses of this kind [17, 18].

Such clinical data and experimental observations require a reassessment of the role of the cerebellum in normal CNS functioning. Indeed, one investigator has proposed that the role of the cerebellum may extend far beyond regulation of simple motor activities to encompass global coordination of many additional types of behavior for the purpose of optimizing information acquisition (sensory reception) during active exploration of the environment (Bower J, personal communication). MR will likely facilitate defining the bounds of the "expanding" role of the cerebellum by providing improved *in vivo* identification, localization, and quantification of cerebellar disease in patients whose clinical deficits can be thoroughly tested [19].

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