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Sonography of the internal capsule and basal ganglia in infants: 1. Coronal sections.

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Sonography of the Internal Capsule and Basal Ganglia in Infants: 1. Coronal Sections

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Coronal sonograms in infants obtained with 3.5 and 5.0 MHz sector and linear-array transducers now depict the anterior limb, genu, posterior limb, and sublenticular parts of internal capsule; the caudate nucleus; the putamen; the lateral and medial nuclei of globus pallidus; the lateral and medial medullary laminae of the lenticular nucleus; the nucleus accumbens septi; and some of the thalamic nuclei. Correlation of sonograms obtained in vivo with gross and myelin-stained sections of human brain illustrates the configurations of these structures and the interrelations among them. Physicians familiar with this anatomy may now use sonography to localize focal lesions more accurately than has been possible previously.

During the last three decades, improvements in sonographic images have followed improvements in imaging technology from A-mode sonograms used for evaluation of midline shifts [1], through weakly focused transducers [2–4], to gray-scale sonography with static [5, 6] and real-time scanners [7–14]. Superior images of the normal neonatal brain have been obtained by Babcock et al. [5], Edwards et al. [6], Grant et al. [8], Shuman et al. [11], Rumack and Johnson [13], and Bowie et al. [14], among others. Within the last 18 months, further improvement in image quality has been achieved by placing image formation under total computer software control. Physicians using the new technology may now display and identify anatomic structures not previously resolved [15].

As early as 1962, Fry [16] predicted that sonography would display gray-white interfaces. Heimburger et al. were the first to distinguish the internal capsule between the thalamus and lenticular nucleus, initially via craniotomy defect in an adult [3] and subsequently in isolated, excised brains [17]. Since then, many authors have provided brief descriptions of the basal ganglia and internal capsule. None, however, has addressed the anatomy of this region in the detail necessary for understanding the images now obtainable with the Acuson 128 Computed Sonography System (Mountain View, CA). Our communication illustrates the fine anatomic detail now displayed by coronal sonography and specifically reviews the complex anatomy of this region to provide a basis for further identification of structures and for more precise localization of pathology. A subsequent communication (part 2) will address the anatomic relations observed in the sagittal plane.

Subjects and Methods

The study population consisted of 150 infants of 28–42 weeks' gestation and 36 children up to 19 months of age. Most examinations were performed at cribside, a small number in the sonographic suite. Sedation was not used in any case.

Coronal and sagittal sonograms were obtained with 3.5 and 5.0 MHz sector and/or linear-array transducers on the Acuson 128 Computed Sonography System using the anterior fontanelle as the acoustic window. Acoustic coupling was effected with Aquasonic 100 transducer gel (Parker Laboratories, Orange, NJ). Infrequently, though more commonly in the smallest infants, a compressible bolus of gel (Reston Flotation Pads, 3-M Company, St. Paul,
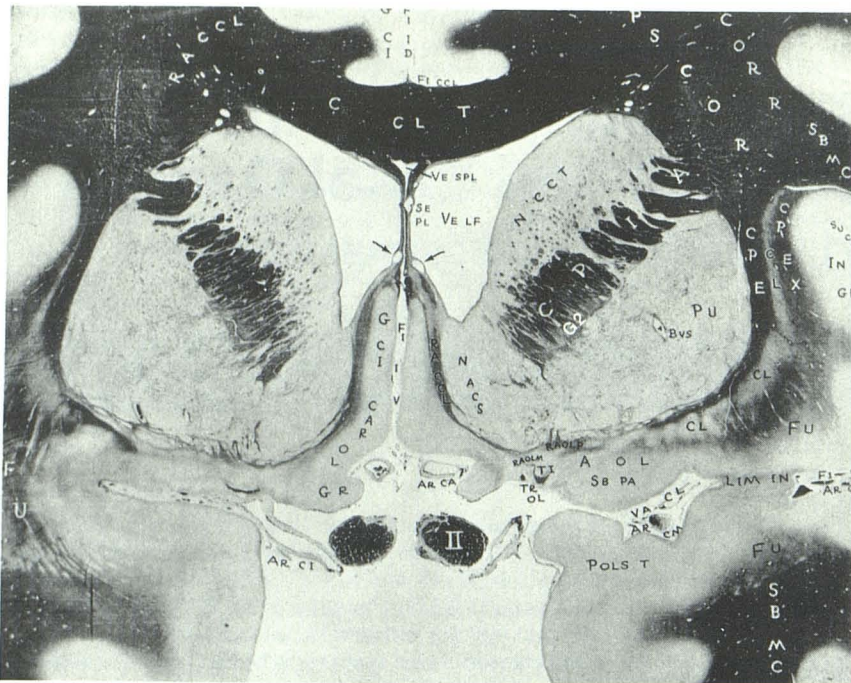
Fig. 1.—Coronal anatomic section at junction of caudate and lenticular nuclei. Myelin stain. (Reprinted from [18].) In this plane, densely staining, obliquely oriented anterior limb of internal capsule (CPIA) separates caudate head (NCCT) from putamen (Pu). Numerous bridges of caudatolenticular gray matter pass from caudate to putamen between fibers of anterior limb, creating multiple gray-white interfaces. Nucleus accumbens septi (NACS) lies inferomedial to internal capsule. Small portion of globus pallidus (G2) is interposed between internal capsule and putamen. Compact zone of corona radiata (PsCor) lies superolateral to internal capsule and inferomedial to corona radiata (CORR). Lateral to putamen are successive layers of external capsule (CPE), claustrum (CL), extreme capsule (CPEX), insula (island of Reil) (IN), and sylvian fissure (Su CIN). Beneath basal ganglia lie anterior perforated substance (SB PA) at base of frontal lobe, CSF between frontal and temporal lobes (i.e., vallecula cerebri lateralis) (VACL) containing middle cerebral artery (ARCM), and temporal pole (POLS T). In midline above frontal horns (VELF) lie dorsal part of interhemispheric fissure (FIID), callosal sulcus (FICCL), body of corpus callosum (CCLT), cavum septi pellucidi (VESPL), and septal veins (arrows). Below frontal horns lie ventral portion of interhemispheric fissure (FIIV), thin densely staining radiation of corpus callosum (RA CCL), and medial frontal cortex composed of cingulate gyrus (GCI), carrefour olfactiv (parolfactory gyrus) (CAR OL), and posteriormost portion of gyrus rectus (GR); optic nerves (II); and internal carotid artery (AR CI).
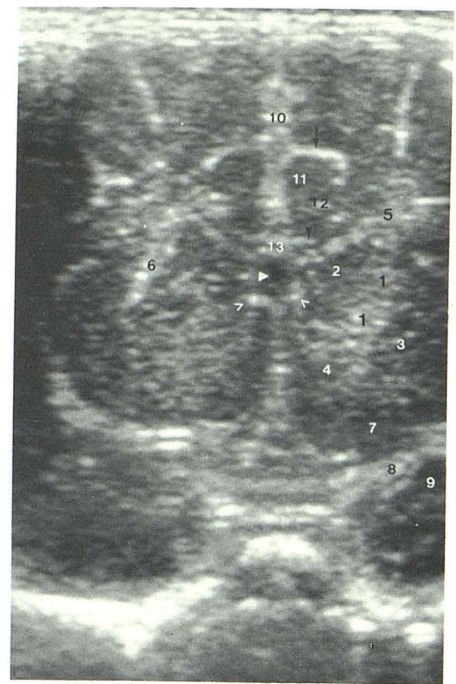
Fig. 2.—Coronal sonographic section comparable to fig. 1, 5.0 MHz linear-array transducer, 1-month-old girl. Echogenic, obliquely oriented anterior limb of internal capsule (1) separates modestly echogenic head of caudate nucleus (2) from modestly echogenic anterior pole of putamen (3). Nucleus accumbens septi (4) lies inferomedial to internal capsule. Internal capsule is continuous superolaterally with pes coronae radiatae (5) leading to stellate radiations into cerebral white matter. Spikelike echoes on right appear to correspond to external capsule (6). Beneath basal ganglia lie anterior perforated substance (7), CSF within vallecula cerebri lateralis (8), and temporal pole (9). In midline dorsally lie interhemispheric fissure (10) containing falx; hypoechoic gray matter (11) and echogenic white matter (12) of cingulate gyrus; hyperechoic cingulate sulcus (black arrow) and callosal sulcus (black arrowhead); body of corpus callosum (13); cavum septi pellucidi (white arrowhead), and septal veins (open arrowheads). In midline below cavum septi pellucidi lie echoic midline stripe of ventral portion of interhemispheric fissure and paramedian hypoechoic crescents of cingulate gyrus and carrefour olfactiv (parolfactory gyrus). Gyrus rectus is not distinguished and probably terminates just anterior to this section.

MN) was used to fit the flat surface of the linear-array transducer to the curved surface of the head and/or to displace the area of interest to the best focal zone of the transducer. Image quality was maximized by use of several key features of the Acuson scanner, described in a prior report [15].

Because "single" anatomic structures like the internal capsule manifested different echogenicities, different configurations, and different anatomic relations in the coronal planes employed, the coronal sections were standardized into three planes, one each through the anterior limb, the genu, and the posterior limb of the internal capsule. The sonograms were then correlated with gross and myelin-stained sections of human brain [18–22] to identify the specific structures displayed in each plane.

Results

In all cases, coronal sonograms displayed clearly the caudate and lenticular nuclei, the thalamus, and the internal capsule. In nearly every case, coronal sonography also displayed internal structure of the lenticular nucleus and thalamus.

Section 1: Coronal Plane through Frontal Horns, Head of Caudate Nucleus, Anterior Putamen, and Anterior Limb of Internal Capsule

The anatomic relations are illustrated in figure 1 and the corresponding sonographic section in figure 2. In this plane, the gray matter of the cerebral cortex appeared hypoechoic whenever it was sectioned at right angles to the gyrus. The central white matter cores of the gyri appeared hyperechoic. The deep frontal white matter exhibited a stellate echogenicity that radiated outward from the periventricular zone. This stellate pattern appeared to correlate with the radial arrangement of the periventricular arteries and veins [13] and the compact central part of cerebral white matter (pes coronae
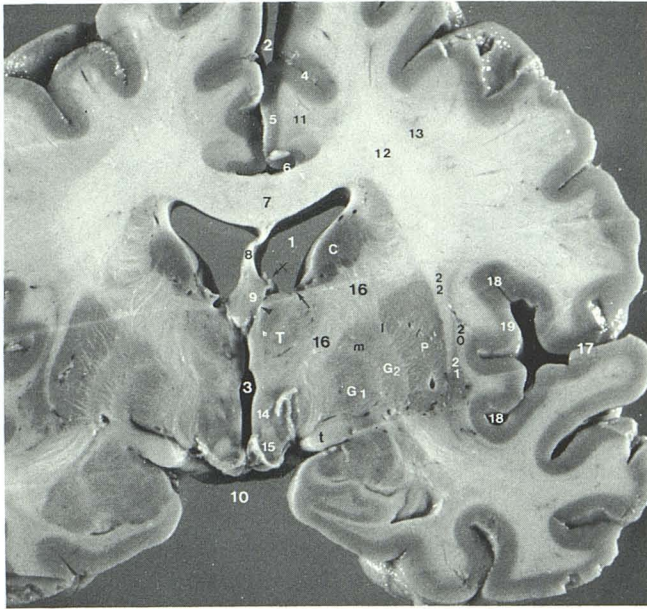
Fig. 3.—Gross, unstained coronal anatomic section through lateral ventricles (1), foramina of Monro (*arrowhead*), and third ventricle (3) displays interrelations among *midline*: dorsal interhemispheric fissure (2), cingulate sulcus (4), cingulate gyrus (5), callosal sulcus (6), body of corpus callosum (7), septum pellucidum (8), genu of the fornix (9), choroid plexus (*crossed arrow*) at foramen of Monro and basal cisterns (10); *paramedian structures*: white matter of cingulate gyrus (11), which is continuous laterally with pes coronae radiatae (12) and corona radiata (13); caudate head (C), striothalamic groove (*arrow*), thalamus (T), hypothalamus (14), and mamillary body (15); *genu of internal capsule (16)*, which is concave inferolaterally as it curves over lenticular nucleus; *"lateral wedge"*: sylvian fissure (17), circular sulcus (18) of insula (19), extreme capsule (20), claustrum (21), external capsule (22), putamen (P), globus pallidus (lateral nucleus) (G2), globus pallidus medial nucleus (G1), lateral medullary lamina (l), medial medullary lamina (m), and optic tract (t). Paraventricular structures medial to internal capsule, internal capsule itself, and structures of "lateral wedge" form three curving layers that are easily identified. Caudatolenticular bridges of gray matter are less numerous at this level. Cut ends of vessels are seen in periventricular white matter, striothalamic groove, and lenticular nucleus. White matter of temporal lobe appears stellate, with superomedial ray of star directed toward lenticular nucleus.
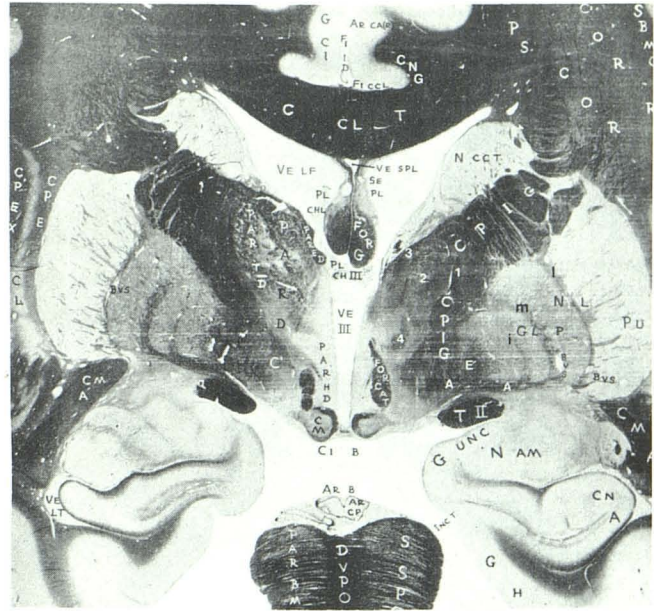

Fig. 4.—Myelin-stained coronal section similar to fig. 3. (Reprinted from [18].) Myelin stain distinguishes more clearly *white matter*: body of corpus callosum (CCLT), cingulum (CNG), pes coronae radiatae (PSCOR), corona radiata (CORR), distal white matter (SBMC), genu of internal capsule (CPIG), optic tract (T II), anterior column of fornix (FOR CAT), genu of fornix (FORG), and lateral portions of anterior commissure (CMA). *Gray matter*: cingulate gyrus (GCI), caudate head (NCCT), putamen (Pu), lateral and medial nuclei of globus pallidus (GLP), uncinate gyrus (GUNC), hippocampal gyrus (GH), amygdala (NAM), Ammon horn (CNA), and mamillary body (CM); *laminae within lenticular nucleus*: lateral medullary lamina (l) between putamen and lateral nucleus of globus pallidus, medial medullary lamina (m) between lateral and medial nuclei of globus pallidus, and incomplete (accessory) medullary lamina (i) within medial nucleus, efferent pallidal fibers (E), ansa lenticularis (A); and *thalamic structures*: lateral thalamic lamina (1) delimiting lateral border of thalamus, lateral nucleus (2) of thalamus, and rostral (3) and ventral (4) peduncles of thalamus. Broad crescent of putamen lies below and lateral to lateral edge of frontal horn (VELF) and above and medial to temporal horn (VELT).

radiatae) and its peripheral radiation as corona radiata.

The anterior limb of internal capsule appeared as a nearly linear, obliquely oriented stripe of increased echogenicity (figs. 1 and 2). The head of caudate nucleus appeared modestly echoic and, in this plane, was consistently less echoic than the anterior limb of internal capsule. The anterior part of putamen was modestly echoic and often appeared slightly more echogenic than the head of caudate nucleus. The nucleus accumbens septi could be demonstrated consistently as a hypoechoic zone situated at the confluence of the caudate and putamen, inferomedial to the anterior limb of internal capsule. In this plane, the small portion of the lateral nucleus of globus pallidus just inferolateral to the anterior limb of internal capsule could not be resolved as a separate structure. Additional important anatomic relations illustrated in figure 1 may also be displayed sonographically, in vivo (fig. 2).

Section 2: Coronal Plane through Bodies of Lateral Ventricles, Third Ventricle, Body of Caudate Nucleus, Widest Dimension of Lenticular Nucleus, Anterior Thalamus, and Genu of Internal Capsule

Gross and myelin-stained sections in this plane are illustrated in figures 3 and 4. The corresponding sonographic sections are illustrated in figures 5 and 6. The structures displayed in this plane have been divided into four groups: (1) midline structures, (2) paramedian structures, (3) the genu of internal capsule, and (4) the structures of the "lateral wedge" (fig. 3). The body of caudate nucleus, the anterior thalamus, and the hypothalamus form a paramedian crescent of modestly echoic tissue along the lateral walls of the lateral and third ventricles (fig. 5). In this plane, the genu of internal capsule was nearly isoechoic with these paramedian nuclei. It appeared as a broad, obliquely oriented crescent of tissue that was concave inferolaterally and that narrowed as it funneled downward between the paramedian nuclei (medially) and the lenticular nucleus of the lateral wedge (laterally).

Fig. 5.—Coronal sonogram through lateral (l) and third (3) ventricles comparable to figs. 3 and 4, 5.0 MHz linear-array transducer, 1-month-old girl. For ease of comparison structures are numbered in accord with fig. 3. Sonography depicts interrelations among *midline*: echogenic dorsal interhemispheric fissure (2), echogenic cingulate sulcus (4), hypoechoic cingulate gyrus (5), echogenic callosal sulcus (6), and hypoechoic body of corpus callosum (7); *paramedian structures*: echogenic white matter of cingulate gyrus (11), echogenic stellate pes coronae radiatae (12) and corona radiata (13), modestly echoic caudate head (C), thalamus (T), and hypothalamus (14); modestly echoic *genu of internal capsule* (16); *structures within "lateral wedge"*: hypoechoic sylvian fissure (17), echogenic "vertical" curves representing circular sulcus (18) and surface of insula, external capsule (22), lateral medullary lamina (l), and intercalated hypoechoic gray nuclei of claustrum, putamen (P), lateral nucleus of globus pallidus (G2), and medial nucleus of globus pallidus (GI). Thin hypoechoic line defines upper margin of lentiform nucleus. It is not known whether this is part of internal capsule or limiting lamina of lenticular nucleus. White matter of temporal lobe exhibits hyperechoic stellate radiations (cf. fig. 3).

Fig. 6.—Coronal sonogram through lateral (l) and third (3) ventricles and foramina of Monro (*arrow*), 5.0 MHz linear-array transducer, 3.5-month-old, 3.6 kg girl with seizures after *H. influenzae* meningitis. Structures labeled as in fig. 3. Markedly increased echogenicity of white matter of cingulate gyrus (11), pes coronae radiatae (12), internal capsule (16), and adjacent lateral thalamus (T). Increased echogenicity of extreme capsule (20), external capsule (22), and lateral (l) and medial (m) medullary laminae delineate hypoechoic, intercalated gray matter of claustrum, putamen (P), lateral nucleus of globus pallidus, and medial nucleus of globus pallidus. Greater gray-white differentiation is believed to be due to white-matter edema with increased echogenicity of white tracts and lamellae. Thin, hypoechoic stripe (*arrowheads*) delimiting superomedial border of lentiform nucleus may correspond to uninvolved part of internal capsule and/or efferent pallidal fibers.

The overall shape of the lateral wedge consistently resembled a horn or a cornucopia with its wide end directed laterally. Anatomically (figs. 3 and 4), the lateral wedge is composed of crescentic layers of tissue arranged in vertical stripes. From lateral to medial these layers are the sylvian fissure, the circular sulcus of the insula, the insular cortex, the extreme capsule, the claustrum, the external capsule, and the lenticular nucleus. The lenticular nucleus is itself composed of the vertical crescents of putamen, lateral medullary lamina, lateral nucleus of globus pallidus, medial medullary lamina, and medial nucleus of globus pallidus. Medially, the lenticular nucleus is delimited by the efferent pallidal fibers, the inferior end of genu of internal capsule as it approaches the cerebral peduncle, and the ansa lenticularis.

Sonographically (figs. 5 and 6), the structures of the lateral wedge appeared as interleaved crescents of increased and decreased echogenicity. The vertical heights of these crescents characteristically decreased from lateral to medial, since the entire lateral wedge narrows as it passes medially. The hyperechoic circular sulcus and surface of insula, the external capsule, and the lateral medullary lamina were displayed most commonly (fig. 5). The extrem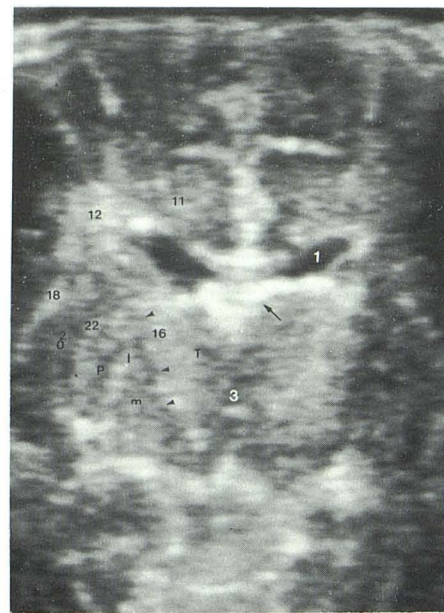e capsule, medial and accessory medullary laminae of the lenticular nucleus, the efferent pallidal fibers, and the ansa lenticularis were observed less often. The nuclei of the lateral wedge were identified as the modestly echoic crescents of tissue interposed between the hyperechoic surface of the insula and the hyperechoic white matter capsules and laminae of the lateral wedge (figs. 5 and 6). As expected, echogenic stripes from perforating vessels were also observed and had to be discounted in determining the anatomic locations of the nuclei (figs. 3–6). Additional important antomic relations are illustrated in figures 3–6.

Section 3: Coronal Plane through Bodies of Lateral Ventricles, Third Ventricle, Body of Caudate Nucleus, Posterior Portion of Lenticular Nucleus, Midthalamus, and Posterior Limb of Internal Capsule

The anatomic relations in this plane are illustrated in figure 7 and the corresponding sonographic appearance in figure 8. In this plane, the posterior limb of internal capsule is displayed as a hypoechoic crescentic structure that curves medially around the thalamus and subthalamus to merge into the cerebral peduncle. Lateral to the internal capsule, the lenticular nucleus is formed by the putamen and a small portion of the lateral nucleus of globus pallidus. It is modestly echoic

Fig. 7.—Coronal anatomic section through caudal limit of globus pallidus. Myelin stain. (Reprinted from [18].) In this plane densely staining posterior limb of internal capsule (CPIP) is thinner, more laterally positioned, and concave medially as it curves around thalamus (PAR TD), subthalamus (PARSD), and tegmentum of midbrain (PARTM) to become cerebral peduncle (PSP). Globus pallidus (GLP) and putamen (Pu) of lenticular nucleus (NL) lie just lateral to posterior limb of internal capsule. Sublenticular part of internal capsule (CP ISL) lies just below lenticular nucleus and above temporal horn (VELT). Just medial to posterior limb of internal capsule lie two thin crescents of tissue: lateral medullary lamina of thalamus (LAMLTH) and reticular nucleus of thalamus (NRTH). Deep to these are two large thalamic nuclei: lateral nucleus of thalamus (NLTH) and ventrolateral nucleus of thalamus (NLVTH). Below this is subthalamic body (CSTH). Rostral peduncle of thalamus (1) curves superior to lateral nucleus of thalamus, between thalamus and body of caudate nucleus (NCCO). Anteroventral nucleus of thalamus (NAVTH) completes superior surface of thalamus at this level. Medial nucleus of thalamus (NMTH) lies adjacent to third ventricle (VE III) and is separated from lateral nucleus by medial medullary lamina of thalamus (2). Note difference in staining characteristics of diverse parts of thalamus. Red nucleus (NRUB), medial longitudinal fasciculus and radiations (3) of red nucleus, subthalamic body (CSTH), and substantia nigra (SBN) lie medial to cerebral peduncle (PSP). Medial pontine decussation (DMPO) lies just inferior to interpeduncular fossa (CIINC).
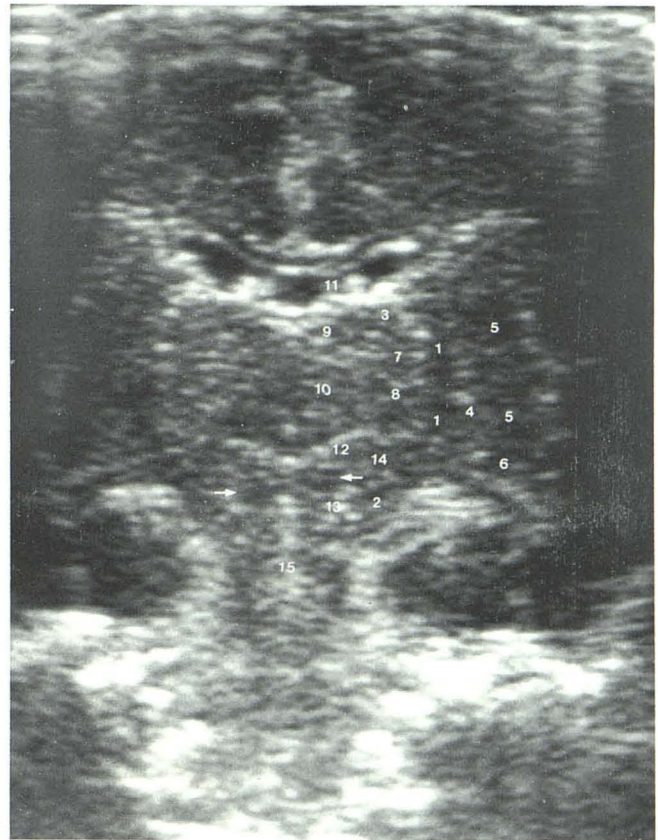
Fig. 8.—Coronal sonogram comparable to fig. 7, 5.0 MHz linear-array transducer. Thin, hypoechoic posterior limb of internal capsule (1) curves inferomedially into cerebral peduncle (2) and superomedially toward rostral peduncle (3) of thalamus. Globus pallidus (4) and putamen (5) of lenticular nucleus lie lateral to internal capsule. Acoustic shadowing from edge of fontanelle causes spuriously low echogenicity of lenticular nucleus (cf. fig. 9D). Sublenticular part of internal capsule (6) forms horizontal hypoechoic band beneath lenticular nucleus and above temporal horn. Lateral (7), ventrolateral (8), anteroventral (9), and medial (10) nuclei of thalamus may be identified by their position with respect to midline, posterior limb of internal capsule, and ventricles. Superiorly, corpus callosum, lateral ventricles, cavum, and fornices (11) are well shown. Inferiorly, one sees round, hypoechoic zones that most likely represent red nuclei (*arrows*), surrounding echoic "wings" (12) that may correspond to medial longitudinal fasciculi and radiations of red nucleus, inferolateral hyperechoic streaks that may represent substantia nigra (13), subthalamic body (14), and midline hyperechoic zone (15) that may represent interpeduncular and perforating vessles and/or medial pontine decussation.

(fig. 9) when seen to best advantage. The sublenticular portion of internal capsule is displayed as a hypoechoic stripe inferior to the lenticular nucleus.

The body of caudate nucleus is isoechoic with the lenticular nucleus. The thalamus exhibits zones of differing echogenicity. The lateral and ventrolateral nuclei appear slightly more echogenic than do the anteroventral and medial nuclei of thalamus. The red nuclei, substantiae nigrae, and some of the radiations of the red nuclei are also displayed in this section.

Serial images in a single patient show the varying echogenicity and relations of the internal capsule and deep gray nuclei as the sonographic plane moves from anterior to posterior (fig. 9). Application of these relations to localization of focal lesions is illustrated in figure 10.

Discussion

The anatomic relations and the sonographic appearance of the internal capsule, basal ganglia, and portions of thalamus have been presented in the Results, the illustrations, and the captions. The complex terminology necessary for anatomic description and the interrelations among the deep gray nuclei and white matter tracts are discussed below.
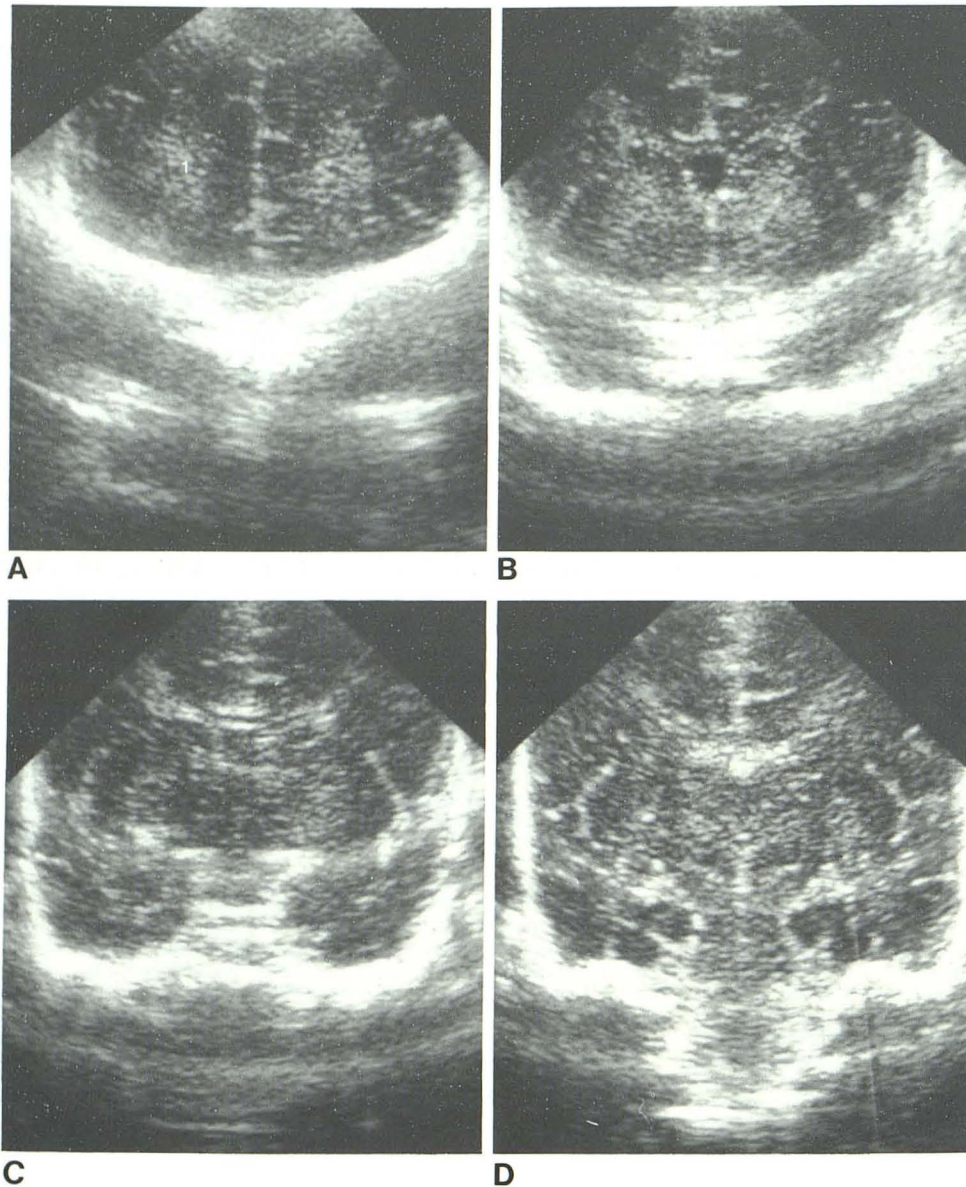
Fig. 9.—Sequential coronal sonograms of internal capsule and deep gray nuclei obtained at identical technical factors and displayed from anterior to posterior, 5.0 MHz sector transducer, 1-month-old, 30-week-gestation boy born by emergency cesarean section for placenta previa and fetal bradycardia. **A,** Anterior to ventricles and nuclei. Bilateral, symmetric hyperechoic zones (1) correspond to deep cerebral white matter and, perhaps, periventricular vascularity. **B,** Through frontal horns comparable to figs. 1 and 2. Anterior limb of internal capsule appears hyperechoic. **C,** Through bodies of lateral ventricles, third ventricle, and suprasellar cistern comparable to figs. 3–6. Genu of internal capsule is slightly less echoic than lenticular nucleus. Putamen and lateral nucleus of globus pallidus can be discerned individually. **D,** Through posterior limb of internal capsule, red nuclei, and brainstem comparable to figs. 7 and 8. Posterior limb of internal capsule and cerebral peduncle are hypoechoic. Putamen, lateral nucleus of globus pallidus, lateral and ventrolateral nuclei of thalamus, and other structures labeled in figs. 7 and 8 can be discerned individually.

Gray Matter: Collective Terms

The terms *subcortical nuclei* and *deep gray nuclei* signify all of the nuclear groups buried within the supratentorial brain, deep to the cortex. The term *basal ganglia* (synonym: basal nuclei) is used variably. Most often (and in this article) the term designates the caudate nucleus, lenticular nucleus, amygdala, and claustrum. Less often, the term is broadened to include, as well, the thalamus, tuber cinereum, geniculate bodies, and even the corpora quadrigemina [18]. The term *corpus striatum* (synonym: striate body) is also used variably. Most often it designates the caudate nucleus plus the putamen [23]. Less often the term is broadened to include the globus pallidus [24]. Other terms related to the striate body include the archistriatum (i.e., the amygdala), the paleostriatum (i.e., the globus pallidus), and the neostriatum (i.e., the caudate and putamen).

The term *lenticular nucleus* (synonym: lentiform nucleus) includes the putamen plus the globus pallidus.

Gray Matter: Individual Structures

The *caudate nucleus* (Latin: tailed nucleus) is an elongated, curved mass of gray matter consisting of an anterior thick portion (the head) that projects into the anterior horn of the lateral ventricle, a thinner body, and an elongated, thin tail that curves downward and backward in the roof of the temporal horn [18, 23]. The head of the caudate nucleus is fused ventrally with the putamen but is separated from putamen laterally by the anterior limb of internal capsule [18]. Bridges of gray matter penetrate between the bundles of the internal capsule to connect the caudate nucleus with the putamen. These resemble "striations," whence the term cor-

A

B
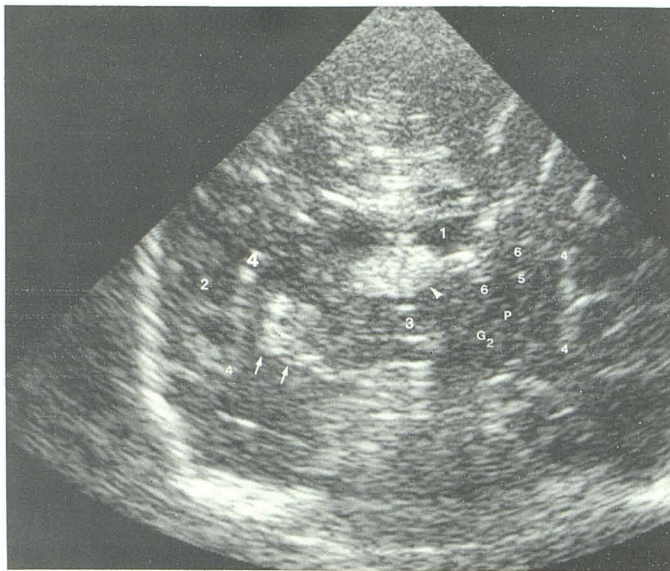
Fig. 10.—Ganglial encephalomalacia. **A**, 6-month-old term infant, birthweight 8.8 kg, now 4 months after group B streptococcal meningitis. Coronal sonography in plane similar to fig. 3, 3.5 MHz transducer. Lateral ventricle (1), third ventricle (3), sylvian fissure (2), circular sulcus (4), external capsule (5), modestly echoic internal capsule (6), lenticular nucleus with putamen (P) and globus pallidus (G2), and focal, hyperechoic lesion (*arrows*) situated at external capsule, putamen, and lateral nucleus of globus pallidus. Increased echogenicity (*arrowhead*) between lateral and third ventricles is believed to represent choroid

plexus. **B**, 9-day-old, 33-week gestation girl, birthweight 2.3 kg, with group B streptoccal meningitis and seizures. Coronal sonogram in plane similar to fig. 7, 5.0 MHz transducer. Lateral ventricles (1), sylvian fissure (2), circular sulcus (4), sublenticular part of internal capsule (5), slightly increased echogenicity of posterior limb (6) of internal capsule bilaterally, putamen (P), small, hyperechoic lesion (*arrow*) of lateral nucleus of globus pallidus on right, and larger lesion (*crossed arrow*) of globus pallidus and part of internal capsule on left.

pus striatum. A ventral, caudal prolongation of the head of the caudate nucleus lies adjacent to the base of the septum pellucidum and is designated the nucleus accumbens septi [18]. The body of the caudate nucleus lies in the lateral portion of the floor of the lateral ventricle, dorsal to the lateral margin of the thalamus, and lateral to the striothalamic groove [18]. The tail of the caudate nucleus begins at and follows the curve of the caudal portion of thalamus. It runs along the lateral margin of thalamus, lateral to the striothalamic groove, to terminate in the amygdala [18].

The *putamen* (Latin: shell) is the largest and most lateral portion of the lenticular nucleus. It is bounded laterally by the external capsule and medially by the lateral medullary lamina of the lenticular nucleus [24]. The *globus pallidus* (synonyms: pallidum, paleostriatum) is the smaller, more medial and lighter gray portion of the lenticular nucleus [18, 23, 24]. It is bounded laterally by the lateral medullary lamina, bounded medially by the internal capsule, and subdivided into two parts by the medial medullary lamina of the lenticular nucleus. The portion of globus pallidus situated between the lateral and medial medullary laminae is the lateral nucleus (synonyms: pars externa, crus II). The portion of globus pallidus situated medial to the medial medullary lamina is the medial nucleus (synonyms: pars interna, crus I). The medial nucleus may be further subdivided by an additional incomplete (accessory) medullary lamina.

The *thalamus* (Greek: inner chamber) is a large ovoid mass of gray matter with a flattened inner (medial) surface that

forms the lateral wall of the third ventricle [23]. It lies posteromedial to the genu and posterior limb of internal capsule. It contains many individually named nuclei arrayed in a fashion too complex to address herein. More detailed discussion and diagrams may be found in Nieuwenhuys et al. [25].

The *claustrum* (Latin: barrier) is the thin layer of gray matter situated between the external and the extreme capsules.

White Matter

The *corona radiata* (synonym: centrum semiovale) is the great fanning mass of corticopetal and corticofugal fibers formed by the projection and callosal systems of the medullary substance of cerebrum. These fanning fibers are interlaced with the great association bundles of the hemisphere [18]. The base of the corona radiata is formed by compact bundles of capsular fibers as they emerge from the internal capsule and by the radiations of the corpus callosum before they spread out to form corona radiata [18]. This more compact portion of corona radiata is given a special name: *pes coronae radiatae* (synonym: fasciculus compactus coronae radiatae).

The *cingulum* is the medullary substance of the cingulate and hippocampal gyri. It lies within the medullary core of the cingular gyrus, dorsal to the radiations of the corpus callosum [18].

The *internal capsule* is a fanlike mass of afferent and efferent white fibers of the cerebral cortex and the thalamic

peduncles (except for the inferior thalamic peduncle) [18, 24]. The internal capsule separates the caudate nucleus, thalamus, and hypothalamus medially from the lenticular nucleus laterally. The internal capsule joins with the external capsule in front of and behind the putamen, forming a white capsule of the lenticular nucleus. It is continuous caudally with the crus of the cerebral peduncle (synonym: pes pedunculi) and cephalically with the corona radiata.

The internal capsule has an anterior limb, genu, posterior limb, retrolenticular part, and sublenticular part. The anterior limb (synonym: caudolenticular division) contains the rostral peduncle of thalamus and the frontopontine tract. It is crossed by caudatolenticular bridges of gray matter and by fibers from the caudate nucleus to putamen and pallidum. The genu of internal capsule contains the corticonuclear tract. The posterior division of internal capsule (synonym: lenticulothalamic division) contains the dorsal thalamic peduncle, the corticospinal tract, the parietotemporo-(occipito-) pontine tract, and other tracts and fasciculi [18]. The retrolenticular part of the internal capsule contains the caudal peduncle of thalamus, the visual projection system, the geniculocalcarine radiation, the optokinetic fibers, and the temporal and occipital contributions to the parietotemporo-(occipito-) pontine tract [18]. The sublenticular part of internal capsule contains the ventrocaudal thalamic peduncle, the auditory radiations, and the temporal contingent of the parietotemporo-(occipito-) pontine tract [18].

The *extreme capsule* is a thin sheet of medullary fibers that separates the insular cortex from the claustrum. It is composed principally of short association fibers from the cortex of the insula and fibers from the claustrum. The *external capsule* is a thin sheet of medullary fibers that separates the lenticular nucleus medially from the claustrum laterally. The *lateral medullary lamina* of the lenticular nucleus (synonyms: lamina laterales [externa] [limitans] pallidi; stria medullaris lateralis) is a thin layer of medullary substance that separates putamen from globus pallidus. It is formed by fibers originating in the putamen and caudate nuclei, destined for globus pallidus [18].

The *medial medullary lamina* of the lenticular nucleus (synonyms: lamina mediales [interna] pallidi; stria medullaris medialis) is a thin sheet of medullary substance that separates the lateral nucleus of globus pallidus from the medial nucleus of globus pallidus. It is formed by striatopallidal fibers and by fibers arising in the globus pallidus destined for regions outside the corpus striatum via the ansa lenticularis [18].

The *efferent pallidal fibers* (synonyms: fibrae efferentes pallides; radiatio corporus striati) arise in the globus pallidus and are gathered into several medullary laminae that deliver their constituent fibers onto the dorsal and ventral surfaces of pallidum. The efferent fibers that emerge dorsally form the limiting laminae of pallidum. The efferent pallidal fibers that emerge from the medullary laminae of the pallidum and from its medial and ventral surfaces sweep medially around the pes pedunculi as the principal portion of the *ansa lenticularis*. A dorsolateral portion of the ansa lenticularis is formed by fibers that leave the medullary laminae and the dorsal and medial surfaces of the pallidum and penetrate between fibers of the pes pedunculi throughout its length [18].

Variable Echogenicity of the Internal Capsule

The gradation of echogenicity of the internal capsule from hyperechoic anterior limb through modestly echoic genu to hypoechoic posterior limb is a reproducible observation in both premature and term infants. This gradation could result from differing orientations of the sonic beam with respect to the white-matter fibers and from reflection by the crossing bridges of caudatolenticular gray matter. The caudatolenticular bridges are most numerous, most closely spaced, and most nearly perpendicular to the sonic beam in sections obtained through the anterior limb of internal capsule. The multiple perpendicularly oriented gray-white interfaces might thus be expected to contribute to the increased echogenicity observed.

The fibers of the posterior limb of internal capsule are more nearly aligned with the sonic beam. They curve gently through the sonographic plane and, perhaps for that reason, appear relatively anechoic.

Effect of Myelination

Even in term infants, myelination is sparse and largely confined to the subcortical nuclei and their fiber tracts [20]. The posterolateral ventral thalamic nuclei are myelinated in nearly all term infants and in most of those weighing 2000–2460 g [20]. The posterior limb of internal capsule is myelinated in those infants with myelination in the thalamus [20]. The posterior part of globus pallidus is well defined by myelinated tracts in most infants over 2000 g. In infants weighing less than 2000 g only the lenticular fasciculus (± the ansa lenticularis) is myelinated. It is our impression that the external and extreme capsules and the white lamellae of the lenticular nucleus are somewhat better seen in older infants, but, thus far, we have been unable to confirm a consistent evolution of the sonographic appearance with advancing age and myelination. We cannot even be certain whether the perforating lenticulostriate arteries and inferior striate veins contribute significantly to the vertical echoes interpreted herein as white-matter capsules and lamellae.

Conclusions

Recent improvements in sonographic equipment have permitted the physician to display internal capsule, basal ganglia, and thalamus more clearly than possible previously. With further application of current technology and advances to come, sonography is expected to display (nearly) all significant anatomic features of the infant brain. Proper use of this new technology and exploitation of its full potential will then require that the physicians who interpret these studies increase their knowledge of neuroanatomy commensurately. Our analysis of sonograms and anatomic sections represents one step toward this goal.

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