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Normal Infant Brain Anatomy: Correlated Real-Time Sonograms and Brain Specimens

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An investigation of the identifiable real-time sonographic features of the normal infant brain in the horizontal, coronal, inclined coronal, and midsagittal planes was undertaken. Correlations were made of sonograms of intact brains in vitro, corresponding brain sections, and sonograms in vivo. A large number of anatomic structures could be consistently depicted including cisterns, fissures, falx cerebri, tentorium cerebelli, ventricles, brainstem, cerebellum, basal ganglia, thalami, and corpus callosum. Pulsations of intracranial arteries, visible by real-time sonography, were of considerable help in identifying various structures. The investigation provides a reference of sonographic anatomy of the brain displayed in four clinically useful imaging planes.

Early investigators of diagnostic sonography were faced with the problems of small-aperture unfocused transducers. In 1967, White et al. [1] summarized these problems. In 1972, Kossoff and Garrett [2] reported intracranial detail in fetal echograms using a weakly focused 2 MHz transducer. They subsequently published a sonographic atlas of the normal brain of infants using a focused 3 MHz transducer-contact C.A.L. echoscope [3]. McRae [4] and White [5], however, questioned their ability to identify those intracranial structures. In 1976, Heimberger et al. [6], using large-aperture focused transducers, managed to display the outlines of the thalamus, internal capsule, and substantia nigra in isolated excised brains. Recently Johnson et al. [7] showed sonographic anatomy in the axial plane and examples of intraventricular hemorrhage in high risk infants using B-mode contact transducers.

The advent of versatile real-time transducers has stimulated us to do more detailed imaging in several planes to establish a basic anatomy for use in clinical work. Real-time as opposed to static scanning was chosen because:

1. Recognizable pulsations of the intracranial vessels within fissures and cisterns and of the choroid plexuses within the ventricles provides easier identification of these structures.
2. The real-time probe can be easily maneuvered so that the ultrasonic beam is perpendicular to the intracranial structure under study, therefore receiving stronger reflecting echoes for better images.

Skolnick et al. [8] used a servo-controlled real-time scanner to detect dilated ventricles and correlated the findings with computed tomography. We thought it would be more useful to correlate real-time sonography and anatomic sections, in planes available for clinical examination.

Materals and Methods

The sonographic examinations were performed by using either a linear phased array transducer operating at 2.25 MHz and displaying 84° fan-shaped images at a frame rate of 30/sec (Varian V-3000), or an annular array transducer operating at 2.25 MHz ± 15%

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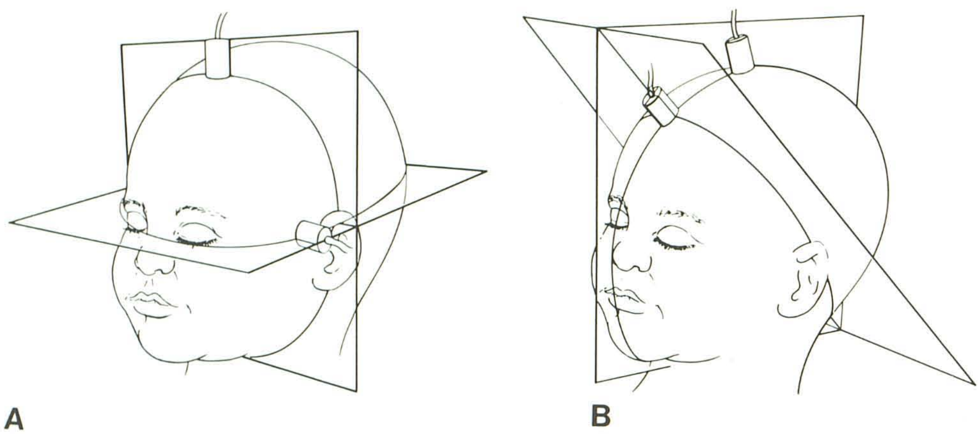


Fig. 1.—Transducer placement for multiplanar imaging.

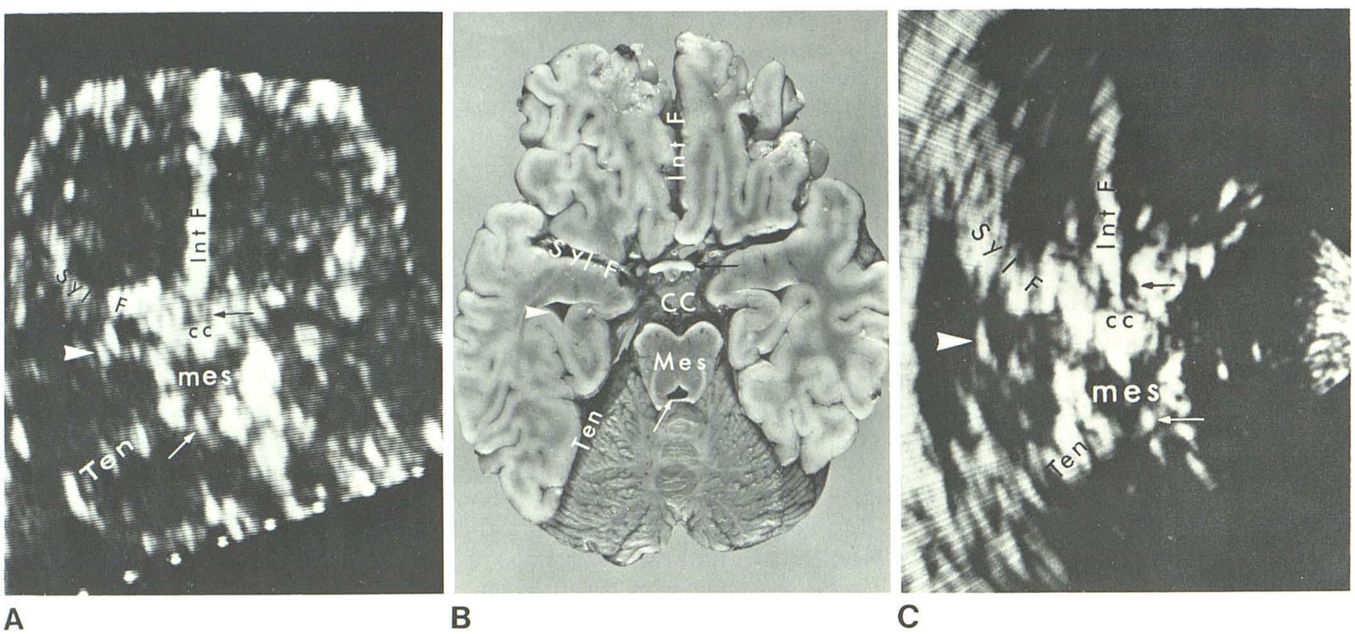


Fig. 2.—Horizontal plane at level of chiasmatic cistern. **A**, In vitro real-time sonogram. **B**, Anatomic section. **C**, In vivo. CC = chiasmatic cistern; Int F = interhemispheric fissure; Syl F = sylvian fissure. Mes = mesencephalon; Ten = tentorium. Optic chiasm (*black arrow*); aqueduct of Sylvius (*white arrow*); temporal horn (*arrowhead*).

and displaying 24° angle sector images at a selectable frame rate of 1 or 12/sec (Xerox 150 S-4).

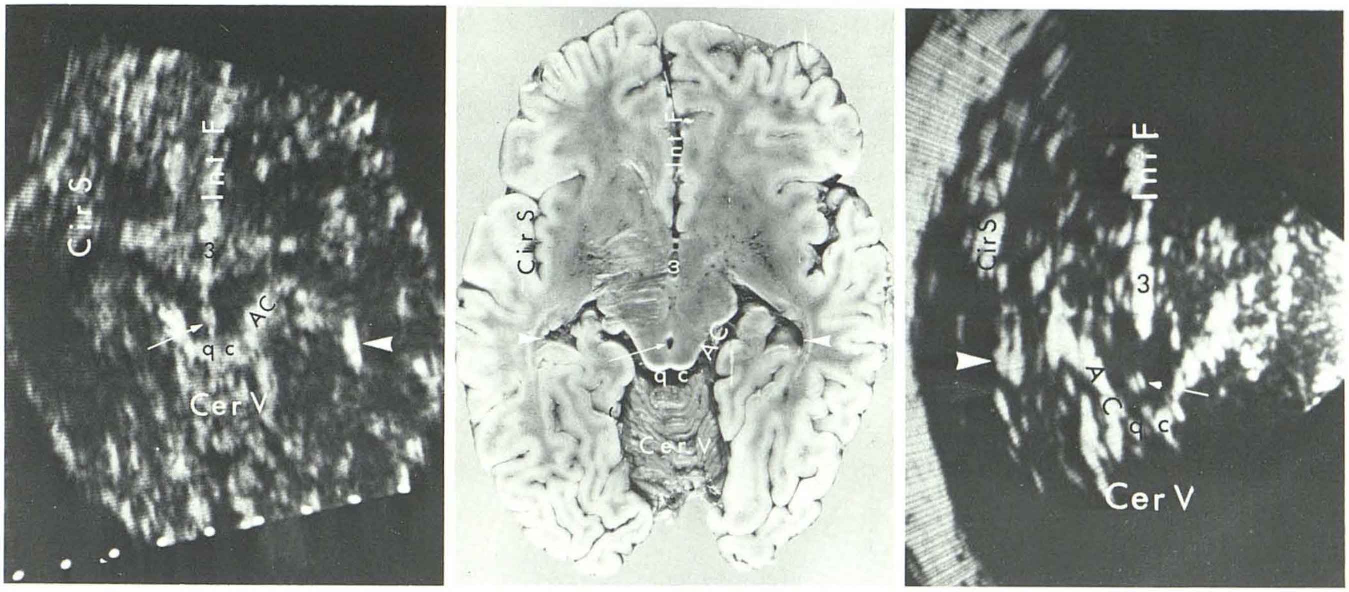
Three excised brain specimens were fixed in formalin for 2 weeks and then immersed in tap water. Care was taken to exclude air bubbles from the field of view. The probe (Xerox 150 S-4) was then placed over the temporal lobe and serial images were obtained in the horizontal plane at 1 cm increments from the level of the lower cerebellum to the high convexities of the cerebrum. For the next specimen, the probe was placed in a position assumed to simulate the anterior fontanelle and serial 1 cm images were obtained in the coronal plane. For the third specimen, the transducer was placed in the position of the anterior fontanelle and the beam was directed toward the fourth ventricle giving a modified coronal image (inclined coronal plane). Finally, images were obtained with the beam directed in the midsagittal plane. After the in vitro scanning was completed, the specimens were sectioned in the corresponding planes.

Fifteen normal infants aged up to 15 months (average, 5 months) were also examined. Each had a normal CT study. The probe (Varian V-3000) was placed over the temporal squama for the horizontal planes and over the anterior fontanelle for the coronal, inclined coronal, and midsagittal planes (fig. 1). Adequate ultrasonic gel was applied between the probe and skin for optimal acoustical coupling. No sedation or anesthesia was necessary. Postprandial scanning or the use of a pacifier was adequate to obtain optimal images. All real-time sonograms were displayed on a video screen and permanent records were made on Polaroid film and video tape.

Horizontal Plane

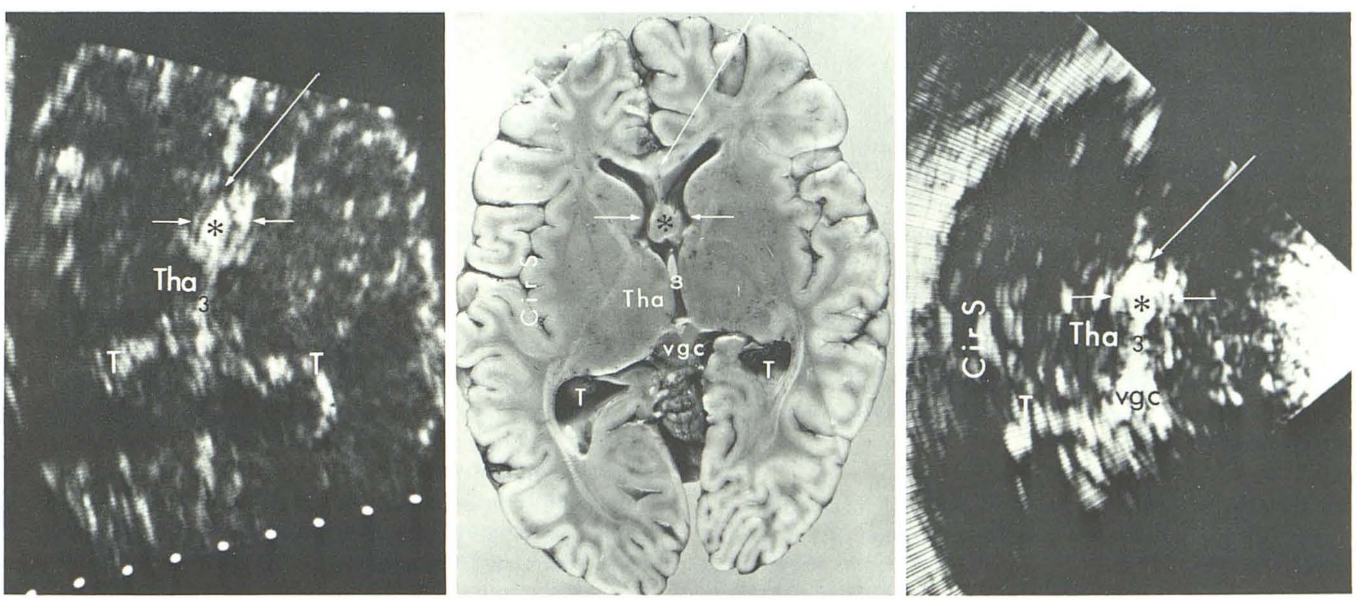
Level of the Chiasmatic Cistern

The chiasmatic (suprasellar) cistern is shown as a pentagonal, strongly echogenic structure in the center of the image, with the similarly echogenic interhemispheric and Sylvian fissures originating from the anterior and both lateral corners of the pentagon (fig. 2). Posteriorly, the circumme-



A B C

Fig. 3.—Horizontal plane at level of cerebral peduncles. **A**, In vitro. **B**, Anatomic section. **C**, In vivo. AC = ambient cistern; Cer V = cerebellar vermis; Cir S = circular sulcus; qc = quadrigeminal cistern; 3 = third ventricle; Int F = interhemispheric fissure. Choroid plexus of temporal horn (*arrowhead*); aqueduct (*arrow*).



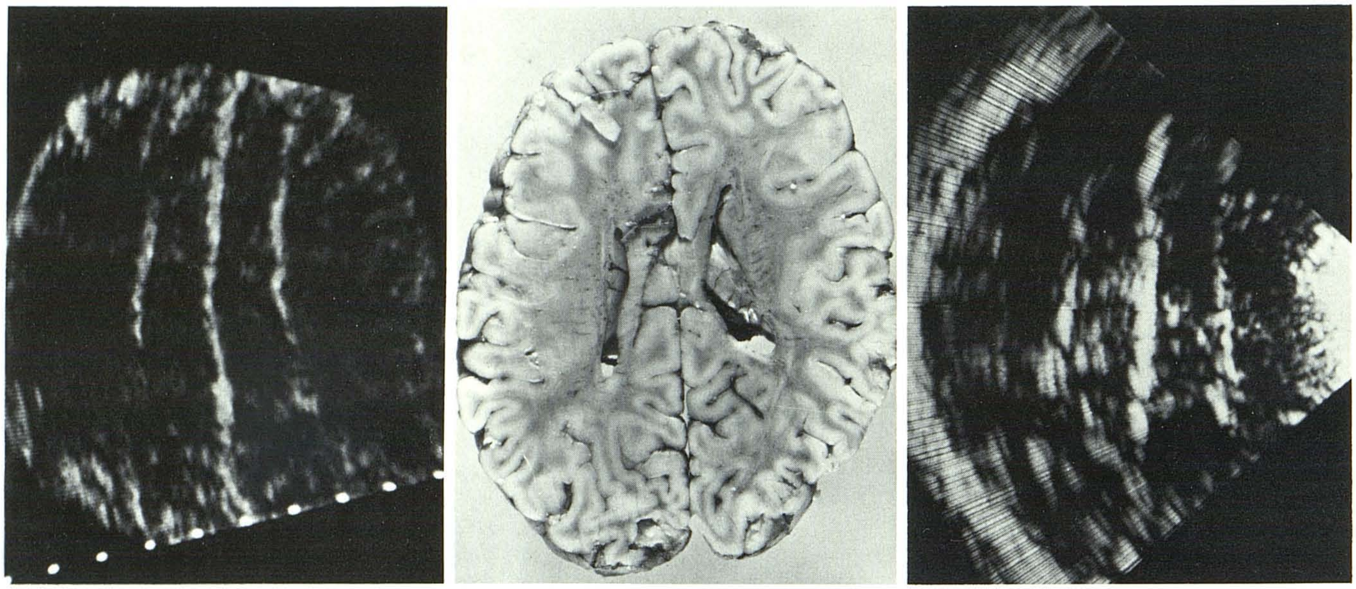
A B C

Fig. 4.—Horizontal plane at level of thalami. **A**, In vitro. **B**, Anatomic section. **C**, In vivo. T = trigone; Tha = thalamus; vgc = vein of Galen cistern; Cir S = circular sulcus. Fornix (*); corpus callosum (*long arrow*); anterior horns (*short arrows*).

sencephalic cisterns are continuous with the posterior corners of the cisternal pentagon and outline a V-shaped anechoic structure, the mesencephalon.

In the center of the pentagon, a low-amplitude-echo structure is constantly seen and represents the optic chiasm. The relatively hypoechoic optic chiasm appears to be divided by a thin midline linear echogenic structure which can be shown to be the anterior inferior part of third ventricle. Immediately ventral to the mesencephalon, the basilar artery can be seen to be pulsating within the interpeduncular cistern.

Pulsations are seen within the Sylvian, interhemispheric, and circummesencephalic cisterns from the middle cerebral, anterior cerebral, and circummesencephalic arteries, respectively. Posteriorly, the low amplitude echogenic cerebellum is outlined by obliquely oriented echoes representing the leaves of the tentorium. The frontal and temporal lobes are depicted by low amplitude echoes.



A B C

Fig. 5.—Horizontal plane at level of lateral ventricles. **A**, In vitro. **B**, Anatomic section. **C**, In vivo. Lateral wall of lateral ventricles (paramedian echoes); falx cerebri (midline echo).

Level of the Cerebral Peduncles

The anechoic V-shaped mesencephalon is in the center of the image, with the constantly seen single strong echo of the aqueduct of Sylvius in the center of the tectum (fig. 3). Posteriorly, the echogenic tentorial hiatus outlines the superior vermis, which is separated from the mesencephalon by the quadrigeminal cistern. The lateral margins of the mesencephalon are outlined by the ambient cisterns, which are situated medial to the parahippocampal gyri. The ambient cisterns appear to join the choroid plexuses of the temporal horns by their continuation with the transverse cerebral fissures. The linear echogenic structure in front of the midbrain represents a combination of third ventricle and interhemispheric fissure. The circular sulci are also seen as strong curvilinear pulsatile echoes at the medial aspects of the Sylvian fissures.

Level of the Thalami

The midline echogenic third ventricle is seen in the center of the image (fig. 4). Near its anterior end, the fornix, a bulbous hyperechoic structure, separates the posterior parts of the frontal horns and blends with the echoes of the septum pellucidum and interhemispheric fissure. On each side of the third ventricle, a well defined, low amplitude, oval structure represents the thalamus. Just posterior to the thalami, the transversely oriented, echogenic, retrothalamic fissures run toward the choroid plexuses of the ventricular atria and outline the calcar avis. The echogenicity of the lentiform nucleus is similar to that of the thalamus. The two structures are occasionally seen to be separated by the posterior limb of the internal capsule. Laterally the basal ganglia and thalami are distinctly outlined by the circular sulci.

Level of Lateral Ventricles

The midline, echogenic, interhemispheric fissure is seen accommodating the falx cerebri (fig. 5). Parallel, paramedial, linear echogenic structures are also seen which represent the lateral walls of the lateral ventricles. The inner table of the parietal bone is sharply defined. Soft echoes interposed between the falx cerebri and lateral wall of the lateral ventricle represent combination echoes of the medial wall of the lateral ventricle and of the parietal cortex.

Coronal Plane

Level of the Chiasmatic Cistern

The anechoic optic chiasm is readily seen within the strongly echogenic and pulsatile chiasmatic cistern (fig. 6). Superiorly, one can see the midline echo of the third ventricle. The roof of the third ventricle reflects strong echoes due to the tela choroidea. Just above it, a thin, anechoic, horizontal stripe is constantly seen which represents the corpus callosum. Superiorly, two pulsatile echogenic structures, the pericallosal and callosomarginal arteries, can be identified within the pericallosal and cingulate sulci. Laterally, the circular sulci mark the outer margins of the basal ganglia and thalami.

Level of Crural and Interpeduncular Cisterns

The centrally placed interpeduncular cistern "stands out" due to strong reflections from the pulsations of the basilar artery (fig. 7). Just inferior to this cistern, a faintly outlined brainstem is seen. On each side of the interpeduncular cistern, the medially convex crural cistern outlining the uncus continues laterally and blends with the echoes of the choroid plexus of the temporal horn. The low amplitude thalamic echoes are seen above the interpeduncular cistern

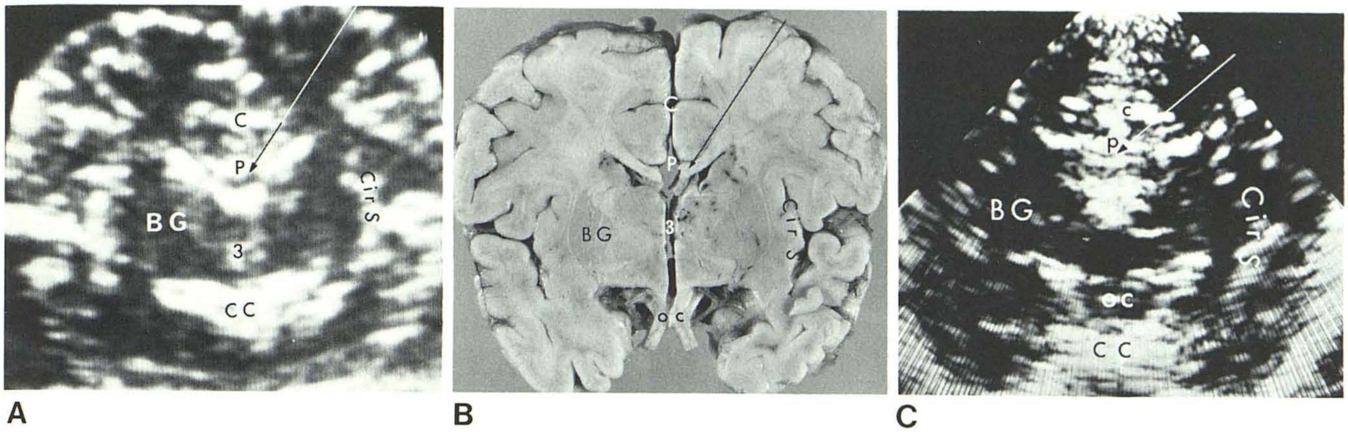


Fig. 6.—Coronal plane at level of chiasmatic cistern. **A,** In vitro. **B,** Anatomic section. **C,** In vivo. BG = basal ganglia; CC = chiasmatic cistern; C, c = cingulate sulcus; Cir S = circular sulcus; P, p = pericallosal sulcus; 3 = third ventricle; oc = optic chiasm. Corpus callosum (*arrow*).

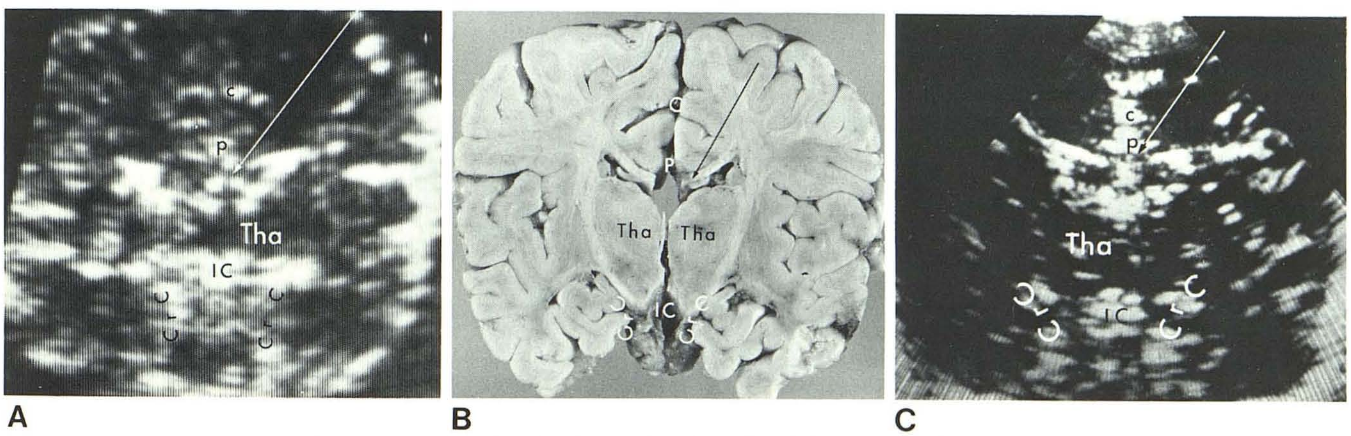


Fig. 7.—Coronal plane at level of crural and interpeduncular cisterns (IC). **A,** In vitro. **B,** Anatomic specimen. **C,** In vivo. Cr C = crural cistern; Tha = thalamus; C, c = cingulate sulcus; P, p = pericallosal sulcus. Corpus callosum (*arrow*).

and, more superiorly, the lateral ventricles, corpus callosum, and supracallosal sulci.

Inclined Coronal Plane

The inclined coronal plane (fig. 8) is extremely helpful in outlining the posterior fossa. The obliquely oriented echogenic tentorial leaves outline the upper cerebellum, which is characterized by uniform, low to medium amplitude echoes. The fourth ventricle is a round and highly echogenic midline structure.

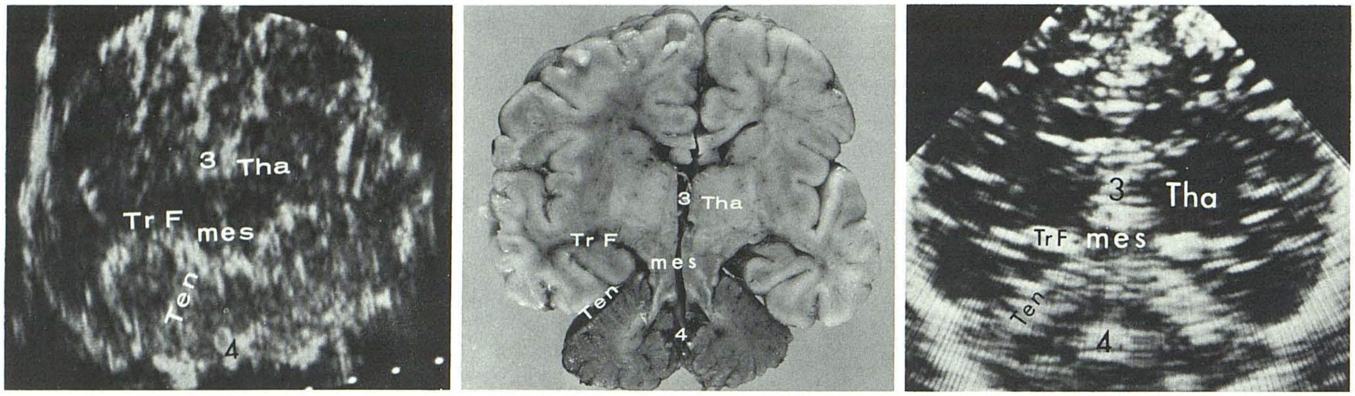
Midsagittal Plane

The midsagittal plane (fig. 9) exquisitely outlines midline structures such as the third ventricle, corpus callosum, and brainstem. It is interesting that the third ventricle is depicted in this plane as an anechoic structure except for the massa intermedia. Its anechoic appearance is probably explained by the sagittal orientation of the walls of the third ventricle and the depth of cerebrospinal fluid (CSF) within it. Often the optic and infundibular recesses of the third ventricle can be seen. Inferiorly, the mesencephalon, pons, and medulla oblongata are seen as fairly uniform, hypoechoic structures. Anterior to the brainstem are the echogenic and pulsatile interpeduncular, prepontine, and medullary cisterns. Posterior to the brainstem are the relatively high amplitude echoes of the cerebellar vermis.

Discussion

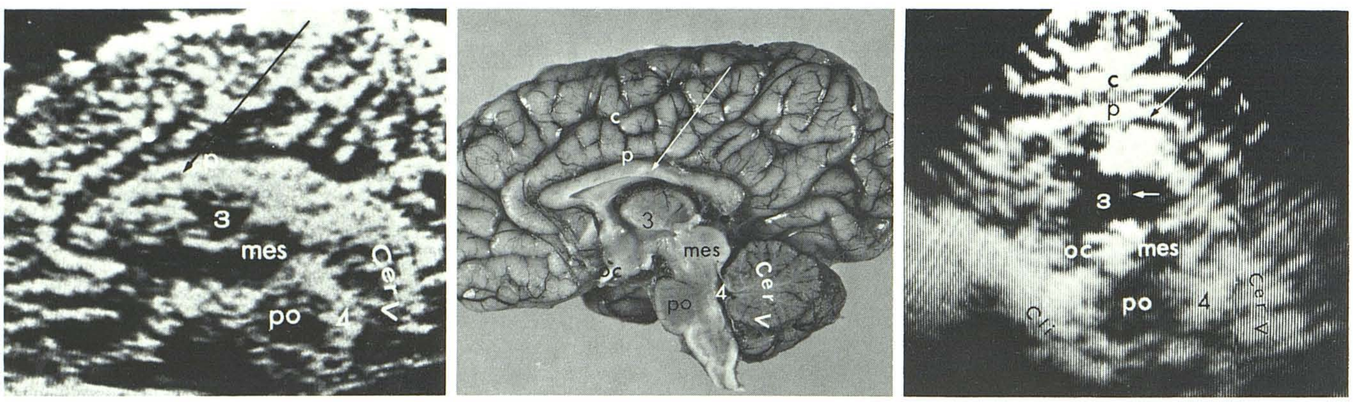
The echogenicity of an intracranial structure depends on its abrupt interface with neighboring structures. Structures with abrupt interfaces include: (1) lateral walls of lateral ventricles against the cerebrospinal fluid; (2) vessels and nerves within fissures and cisterns; (3) the myriad frondlike interdigitations of the ventricular choroid plexus within the cerebrospinal fluid; and (4) falx cerebri and tentorium against cerebrospinal fluid. Fissures, cisterns, choroid plexus, lateral ventricular walls, falx, and tentorium, therefore, are always depicted as strongly echogenic structures which can be used reliably as anatomic landmarks. The "crowded," strongly echogenic appearance of cisterns resulting from interposition of meninges, veins, and pulsating arteries is in contrast to the usual conception of their being "empty" CSF-filled spaces on computed tomography or pneumoencephalography.

In our experience, the midline third ventricle creates a single linear echo due to its closely spaced ependymal



A B C

Fig. 8.—Inclined coronal plane through anterior fontanelle, with beam directed toward fourth ventricle. **A,** In vitro. **B,** Anatomic section. **C,** In vivo. Tr F = transverse fissue; mes = mesencephalon; Ten = tentorium; Tha = thalamus; 3 = third ventricle; 4 = fourth ventricle.



A B C

Fig. 9.—Midsagittal plane. **A,** In vitro. **B,** Anatomic section. **C,** In vivo. Cer V = cerebellar vermis; C, c = cingulate sulcus; Cli = clivus; mes = mesencephalon; oc = optic chiasm; p = pericallosal sulcus; po = pons; 3 = third ventricle; 4 = fourth ventricle. Massa intermedia (*short arrow*); corpus callosum (*long arrow*).

surfaces. This is similar to the midline echo pattern of the uterine cervical canal on pelvic sonography. A slitlike anechoic third ventricle, in fact, represents an early dilatation of its lumen. The fourth ventricle is depicted as a rounded echogenic structure due to the enormous reflecting echoes of the choroid plexus and the rhomboid ventricular walls. Structures with homogeneous texture such as brainstem, thalamus, and corpus callosum, on the other hand, produce uniform low amplitude echoes.

The far side of the sonographic image (within the focal distance of the transducer) always shows more reliable information than the near side due to the inherent limited near-field resolution of the phased-array real-time transducers. Scanning through both temporal squama, therefore, is essential in order to obtain precise information from both hemispheres. While static scanning does show intracranial structures, real-time sonography has the advantage of quick and accurate structure identification because of vascular pulsations and instantaneous display.

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