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Review Article

Neurosonology: An Update

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Recent technological advances in diagnostic ultrasound have resulted in the development of high-resolution, portable real-time scanners. In neurological ultrasound, these devices have been particularly useful for detecting intracranial hemorrhage in premature infants. Sonography is now being used during neurosurgical procedures to help in localizing masses for resection and biopsy, as well as in the placement of shunt catheters. The applications of neurosonology and our experience with intraoperative neurosonology are reported in this review.

Diagnostic ultrasound has been used to image the human brain for the past 25 years. Initially, one-dimensional display of intracranial structures (A-mode) was used to detect the shift of midline structures or hydrocephalus (1-3). Echoencephalography with its inherent limitations was abandoned as a diagnostic method when computerized tomography became available in 1974 for widespread use.

The many applications of diagnostic ultrasound for abdominal, pelvic, obstetrical, and gynecological problems are well known. The major barrier to its use in imaging the head is its inability to transmit sound waves through the bony calvarium.

Recent technological advances in the field have resulted in the development of high resolution equipment with fast frame rates, which result in the constant display of sequential images (real-time). These real-time systems are easier to operate than static scanners, and because they are portable, they can be used at the patient's bedside or in nurseries and operating rooms. In recent years, these systems have been used to evaluate the neonatal head, since sound transmission is possible through openings in the bony calvarium, ie, sutures and fontanelles. A new application is their use in the operating room to aid in localizing masses for resection or biopsies or for the placement of shunt catheters.

Equipment

High resolution real-time sector scanners are best suited for transfontanelle scanning. The small size of the transducer head of sector scanners permits good contact between the equipment and the infant's head. The shape of the image (pie-shaped or inverted V) offers a wide field of view deep the point of contact. Two sector scanners for transfontanelle scanning are presently available in our laboratory: †ATL-Mark III and ‡Phillips-SDU 3000. Routinely, 5 MHz short internal focus transducers are used, but 3 MHz medium focus transducers are sometimes used with newborn infants. Our intraoperative studies have been performed with the Phillips sector scanner because it gives us better quality images, although the ATL instrument can be adapted to meet the needs in the operating room.

After a craniotomy or laminectomy has been performed, sonographic scanning of the brain or spinal cord is performed directly over the surgical field. The transducer is made sterile in the following manner: 1) acoustic coupling gel is placed over the transducer face; 2) the transducer is then placed within a sterile drape (microscope drape or plastic stockinette) which covers the transducer and its cable; and 3) sterile rubber bands are placed over the scanning head to secure a tight fit of the sterile drape over the transducer. The surgical field is bathed in saline to serve as a coupling agent, and the transducer is lowered into the surgical field. Sonographic imaging can be performed either over the intact dura or

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directly on the surface of the brain or spinal cord. We have used 5 MHz short internal focus transducers for brain studies, although the frequency can be varied up to 7 MHz with this system. A flat-faced superficial parts transducer, 5 MHz (7 MHz), with a short internal focus is used for imaging the spinal cord. Versatile transducers that can vary both frequency and focal zones may better accommodate the needs in the operating room. Miniaturized transducers, not yet available, will have significant use in the operating room, especially for carotid imaging and imaging of the brain through burr holes.

Normal Sonographic Anatomy of the Brain

Sonographic imaging is performed on both coronal (Figs. 1,2) and sagittal planes (Figs. 3,4). Axial scanning (similar to computed tomography) is not performed routinely because sound is attenuated by the bony calvarium, and details are obscured.

The brain parenchyma is moderately echogenic, and higher intensity linear echoes are present along the course of the brain fissures and sulci. The difference in the speed of sound transmission between the brain parenchyma and the intraventricular fluid results in a sharp delineation of the ventricular walls.

The cavum septum pellucidum (CSP) is a fluid-filled space located between the leaves of the septum pellucidum. Its posterior extension, referred to as cavum vergae (CV), is situated between the columns of the fornix. These embryologic structures are not lined by ependyma and do not communicate with the ventricular system. These spaces, seen in all premature infants, disappear in most patients during the second to fourth week after birth (4-6). In adults, however, these spaces persist in 15-20% of patients (4). In neonatal neurosonology, it becomes important to distinguish between the CSP and CV to avoid mistaking them for a dilated third ventricle. These fluid-filled spaces can be seen at midline between the lateral ventricles.

The lateral ventricles can be easily identified in both coronal and sagittal planes. To display the entirety of the lateral ventricles on sagittal images, the transducer is angled laterally approximately 30° to the base of the nose of the neonate. The third ventricle is not well seen on coronal sections, perhaps because the ultrasound beam projects parallel, rather than perpendicular, to its walls so that this thin structure is not delineated (6). The fourth ventricle can be seen on midline sagittal scans bordered by the brain stem anteriorly and the cerebellum posteriorly.

The choroid plexuses are very echogenic, paired, pyramidal-shaped structures within the ventricles. They extend from the level of the foramen of Monro to the atria of the lateral ventricules and into the temporal horns.

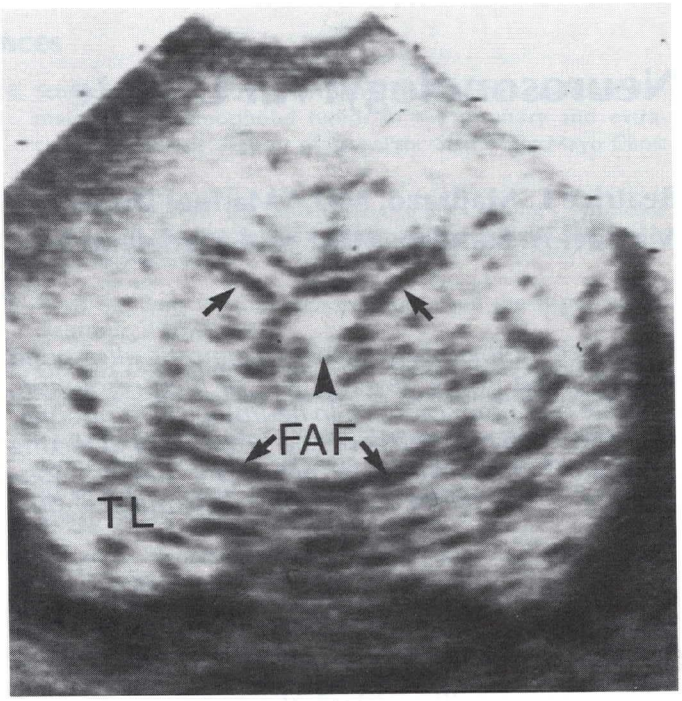

Fig. 1

Transfontanelle coronal sonogram of a neonate obtained at the level of the frontal horns, which are seen as slit-like structures to each side of midline (arrows). Cavum septum pellucidum is seen between the frontal horns (arrowhead). TL: temporal lobe; FAF: floor of anterior cranial fossa.

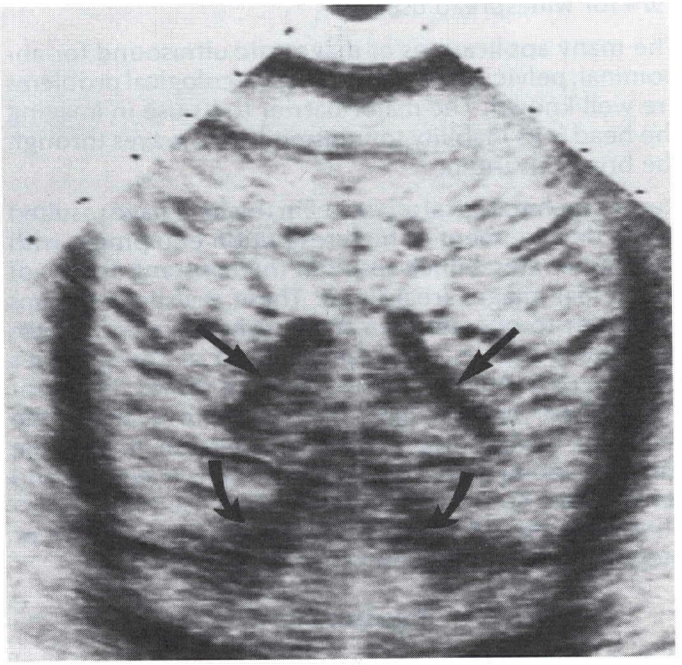

Fig. 2

Coronal scan through the bodies of the lateral ventricles demonstrating the characteristic echogenic appearance of the choroid plexuses (arrows). Tentorium cerebelli, also echogenic, is seen inferior to the lateral ventricles (curved arrows).

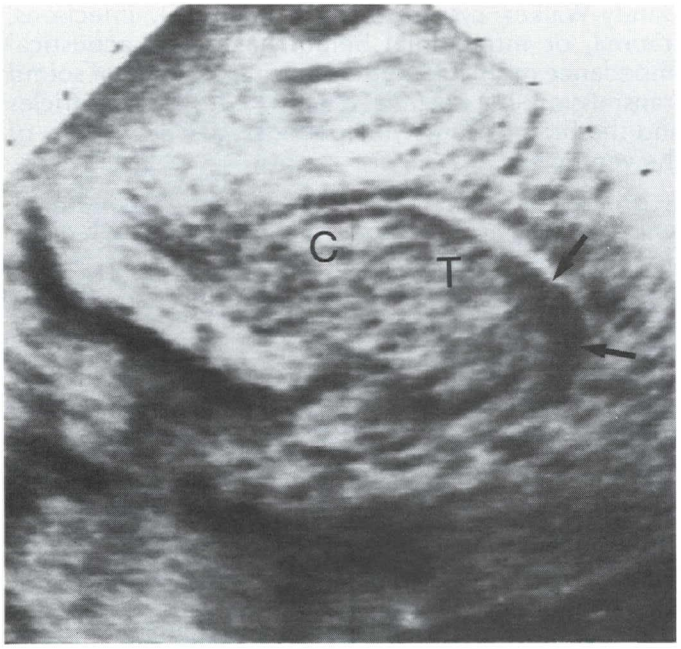

Fig. 3
Sagittal sonogram demonstrating normal curvilinear, fluid-filled lateral ventricles that contain the echogenic choroid plexus within the atria (arrows). Caudate nucleus (C) and thalami (T) are situated inferior to the lateral ventricles. Scan was obtained with transducer angled 30° laterally relative to base of the nose.

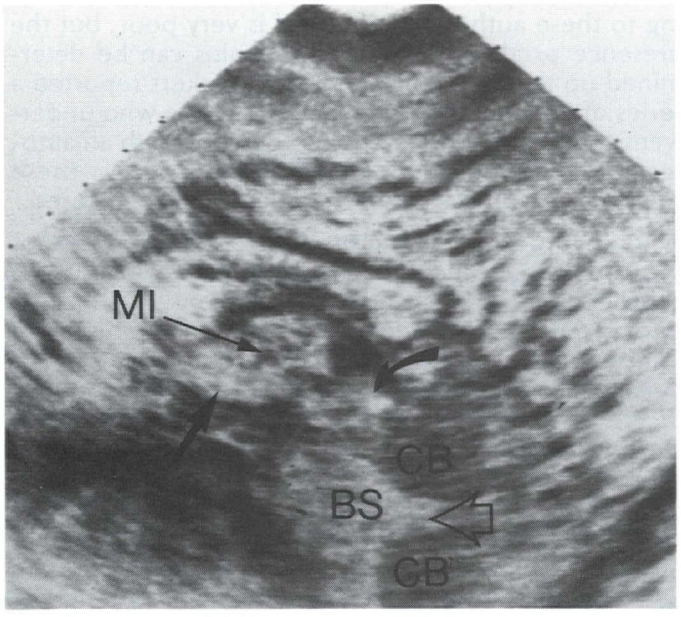

Fig. 4
Midline sagittal sonogram demonstrating the third ventricle (arrow). Massa intermedia generates a prominent echo (MI) and aids in identifying the third ventricle. Fourth ventricle is seen (open arrow) bordered by the moderately echogenic brain stem (BS) anteriorly and the very echogenic cerebellum posteriorly (CB). The quadrigeminal plate cistern is also seen cephalad to the fourth ventricle (curved arrow).

Intracranial Hemorrhage

Intracranial hemorrhage in the newborn mainly affects premature infants and has an incidence of approximately 40-60% (7). Hemorrhage can occur in many different locations, such as subependymal-intraventricular, subdural, subarachnoid, or intracerebellar, but germinal matrix hemorrhage is by far the most common in premature infants. The following neonatal conditions have been associated with germinal matrix hemorrhage: maternal ingestion of aspirin, hypoxia, acidosis, pulmonary disease, and excessive administration of $NaHCO_3$ (6).

In infants of less than 32 weeks gestational age, the germinal matrix is composed of sheaths of primitive cells, connective tissue, and thin-walled vessels. It lies above the caudate nucleus and may extend along the floor of the lateral ventricle. Most commonly, it is situated in the undersurface of the frontal horns. Acute germinal matrix hemorrhage is seen as a highly echogenic focus situated inferior to the frontal horns. The hemorrhage usually extends along the subependymal surface and results in increased echogenicity along the undersurface of the entirety of the lateral ventricles. Because a fresh hemorrhage is intensely echogenic, it becomes difficult to separate the choroid plexus, which is also very echogenic, from the adjacent hemorrhage. Extension of the hemorrhage into the ventricle, also quite common, results in ventricular dilatation. The ependymal lining is very thin and not recognizable on sonograms. Because it becomes impossible to discriminate subependymal from intraventricular hemorrhage, the condition (Figs. 5,6) is referred to as subependymal-intraventricular hemorrhage (6).

Premature infants of less than 32 weeks gestation or with a body weight of under 1,500 grams should be screened for subependymal-intraventricular hemorrhage between the fifth to seventh day of life. Once hemorrhage occurs, progress studies are indicated to detect complications such as ventricular dilatation or parenchymal extension. Findings secondary to hemorrhage may persist for approximately 35 to 45 days after the hemorrhagic episode has occurred (8).

Sonography may fail to detect subdural or epidural hematomas and subarachnoid hemorrhage. The peripheral location of these collections along the brain convexities and their proximity to the bony calvarium make it difficult to display them by sonography. Computed tomography should be performed if such collections are suspected.

Hydrocephalus

Hydrocephalus can be isolated or associated with other brain processes such as malformations (eg, Arnold-Chiari,

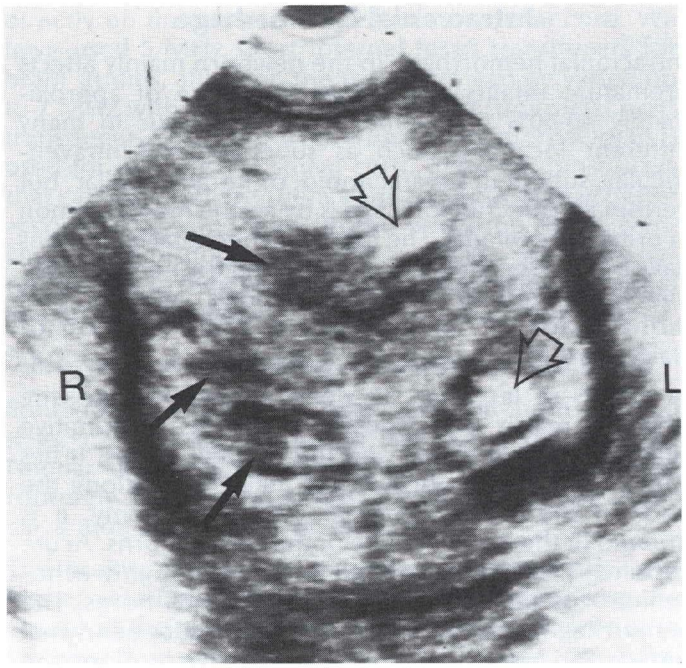

Fig. 5
Coronal sonogram demonstrating hemorrhage within the lateral ventricles extending from frontal horns into the temporal horns (arrows). Ventricular system is dilated on the left side (open arrows).

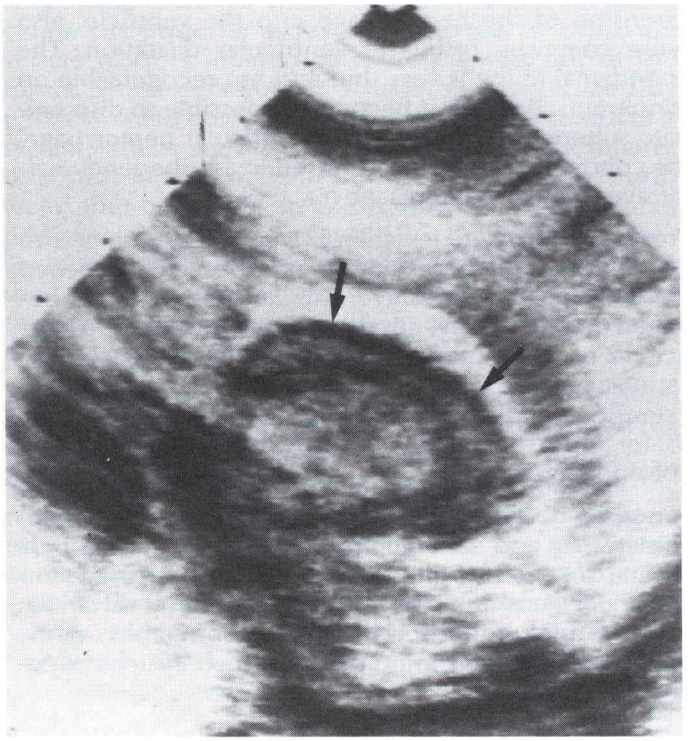

Fig. 6
Sagittal sonogram demonstrating subependymal-intraventricular hemorrhage (arrows). Note loss of definition of the choroid plexus and associated ventricular dilatation.

Dandy-Walker cyst, aqueductal stenosis), infections, trauma, or intracranial hemorrhage. The acoustical impedance mismatch (difference in the speed of sound transmission) between the dilated, fluid-filled ventricles and the brain parenchyma permits excellent display of the ventricles.

Hydrocephalus can be related to a variety of conditions which must be evaluated once hydrocephalus is demonstrated. Often the cause of hydrocephalus is readily apparent on sonograms. If not, computed tomography and/or ventriculography are indicated before therapy is undertaken.

High-resolution, real-time scanners permit recognition of in utero hydrocephalus as early as the 20th week. The developing fetal brain differs from that of the adult in that the ventricles occupy as much as 50% or more of the head volume before 20 weeks of gestation. Johnson and co-workers have developed tables to assess the normal lateral ventricular hemispheric width ratio during pregnancy (7).

Neonates and infants can be screened for hydrocephalus by transfontanelle sonography until 12 to 18 months of life when closure of the cranial sutures precludes sonographic scanning. Rumack and Johnson suggest scanning in the axial plane (horizontal) just above the external auditory meatus, transmitting sound through the squamous portion of the temporal bones (8). According to these authors, brain detail is very poor, but the presence or absence of hydrocephalus can be determined up to age 4. Garrett and co-workers reported a series of 830 children up to 12 years of age who underwent sonographic evaluation of the brain with an automated, water-delayed scanner (9). However, these sophisticated ultrasonic machines are not widely used.

When hydrocephalus is present, the lateral borders of the frontal horns become rounded, and the dilated third ventricle can be seen on coronal sections. The normal third ventricle is not seen on coronal scanning due to its thin width as well as the parallelism of the ultrasonic beam relative to its walls. Dilatation of the body and atria of the ventricles results in a wider separation of the choroid plexus from the ventricular walls. Thus, the normal choroid plexuses adhere to the medial walls of the ventricles, but when hydrocephalus is present, the plexuses can be seen in a lateral position. The temporal horns, which frequently contain very little cerebrospinal fluid, become prominent when ventriculomegaly exists.

Figures 7 and 8 are of a neonate with ventricular dilatation.

Congenital Malformations of the Brain

Congenital malformations of the brain both in utero and

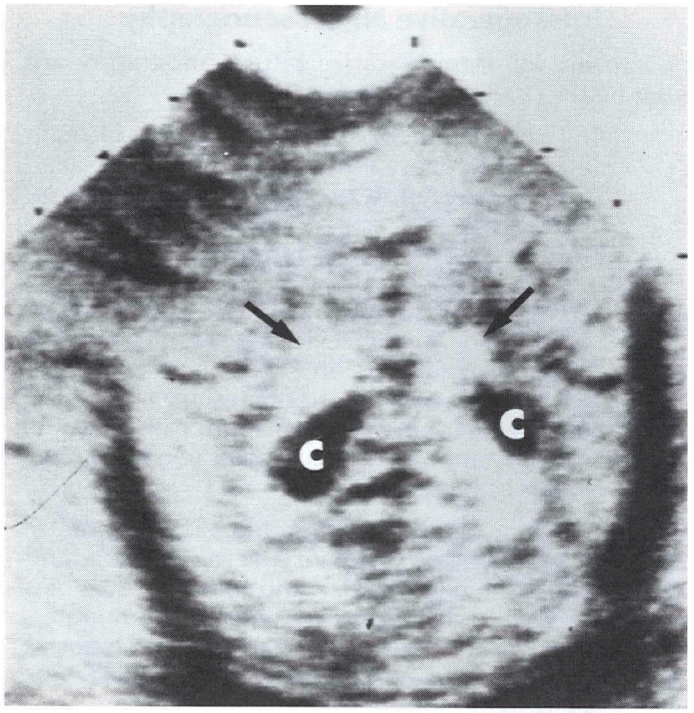

Fig. 7
Transfontanelle coronal scan through the atria of the lateral ventricles demonstrating mildly dilated ventricles (arrows). Note the echogenic choroid plexus (C) within the ventricles.

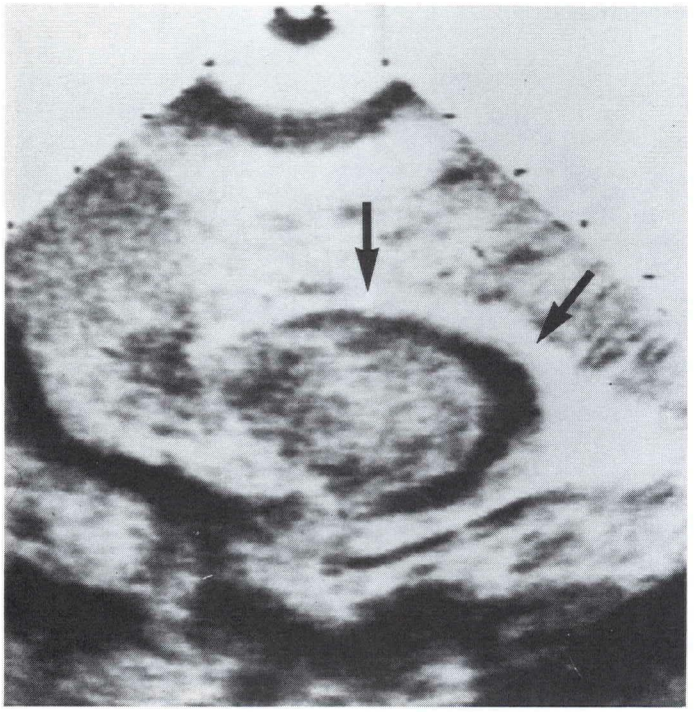

Fig. 8
Transfontanelle sagittal scan demonstrating mild dilatation of lateral ventricles (arrows).

during the neonatal period have been detected by sonography (6,7).

In our recent practice, a newborn who presented with congestive heart failure also had a vein of Galen aneurysm demonstrated by ultrasonography (Figs. 9-11). A transfontanelle sonogram revealed a 3 x 3.5 cm midline cystic mass with divergence of the body and atria of the lateral ventricles. Ventriculomegaly was present. On sagittal scans, the mass was noted to extend posteriorly to the occipital region, a finding consistent with drainage of the aneurysm into the torcula and straight sinus. Computed tomography with dynamic capability revealed a hypervascular midline mass displacing the third ventricle anteriorly and continuing into the torcula.

Because aneurysms of the vein of Galen frequently thrombose, their sonographic appearance is quite variable. Our case had no internal echoes, and both computed tomography and angiography revealed no evidence of thrombosis. Babcock and Han described a partially echogenic, thrombosed, vein of Galen aneurysm with a large anechoic peripheral zone which corresponded to a venous aneurysm (6).

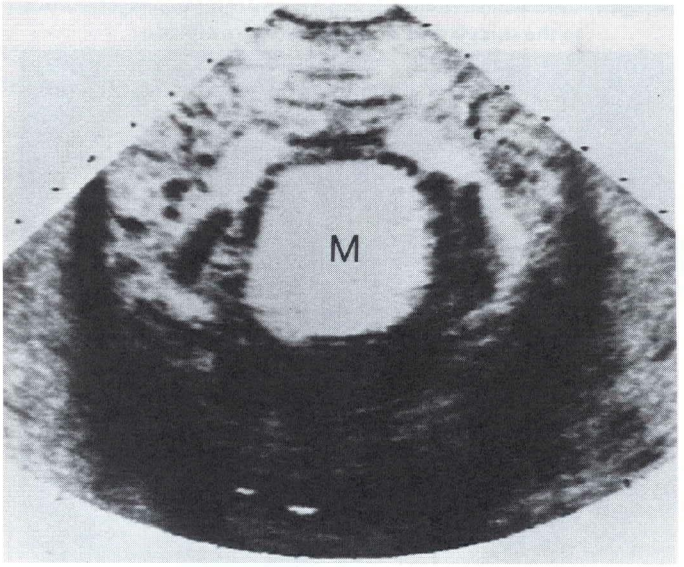

Fig. 9
Transfontanelle coronal scanning revealing 3 x 3.5 cm midline posterior cystic mass (M), supratentorial in location. Mass causes divergence of the lateral ventricles which drape around its superior and lateral aspects. Associated ventricular dilatation is seen.

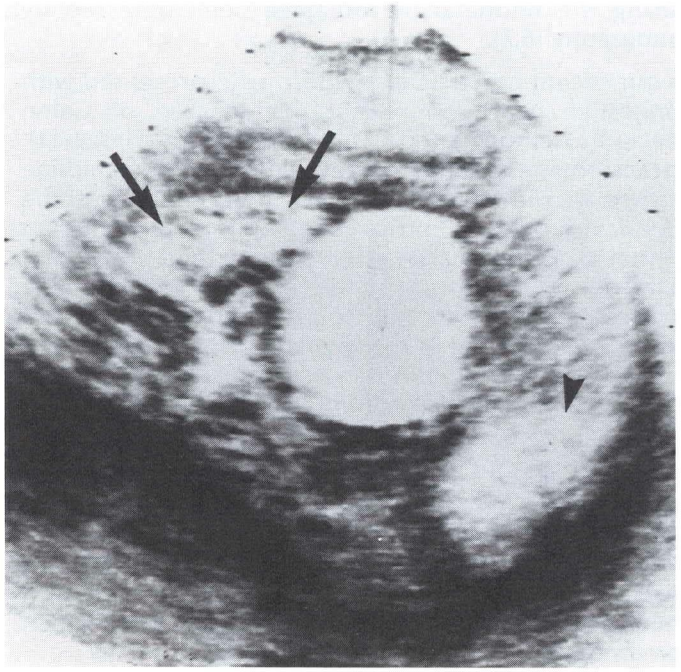

Fig. 10
A sagittal transfontanelle sonogram revealing the midline mass displacing the third ventricle anteriorly (arrows). Mass drains posteriorly to the torcula and straight sinus (arrowhead).

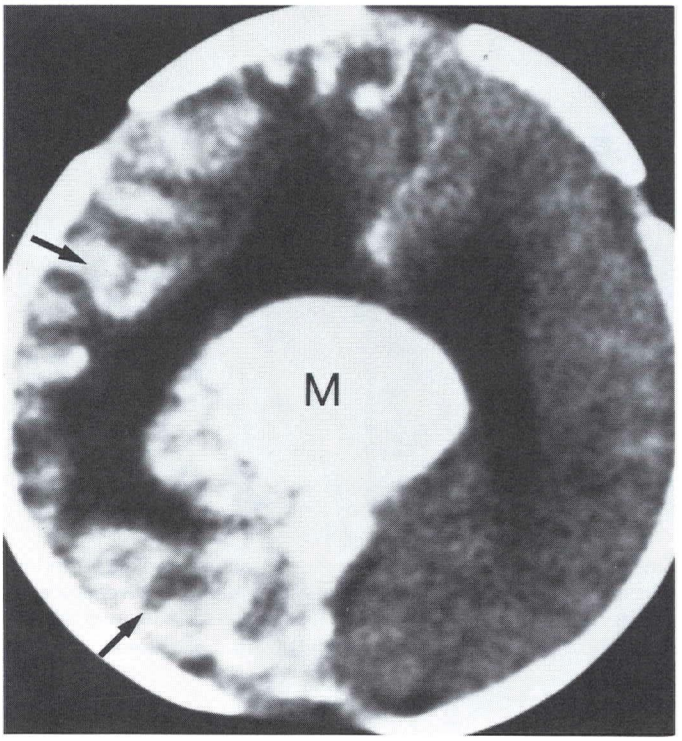

Fig. 11
Computerized tomographic scan with dynamic scanning reveals a hypervascular mass (M) splaying the body and atria of the lateral ventricles. Drainage into the straight sinus and torcula is seen. Luxury perfusion of the right cerebral hemisphere is also present (arrow).

Intraoperative Neurosonography

Indications for intraoperative neurosonography are listed below (10-13):

1. Two-dimensional rapid localization of brain and spinal cord lesions
2. Characterization of the lesion (cyst, tumor, abscess)
3. Depth of the lesion (no magnification exists in ultrasound)
4. Passage of a brain needle or probe under ultrasonic guidance to serve as a guide for excision of the lesion
5. Aspiration and biopsies of lesions
6. Placement of ventricular shunt catheters
7. Localization of foreign bodies (eg, bony fragments, bullets)

As we acquire more experience in the operating room, we need less time to prepare the equipment and perform the examination. Brain and spinal cord studies to locate masses can be performed in 15-20 minutes, while longer periods aree needed to perform biopsies and place shunt catheters. Figures 12 to 15 illustrate our experience with intraoperative neurosonography.

Acknowledgment

We wish to thank Ms. Marsha Strong and Mrs. Maurine Tolbert for secretarial and research assistance, respectively.

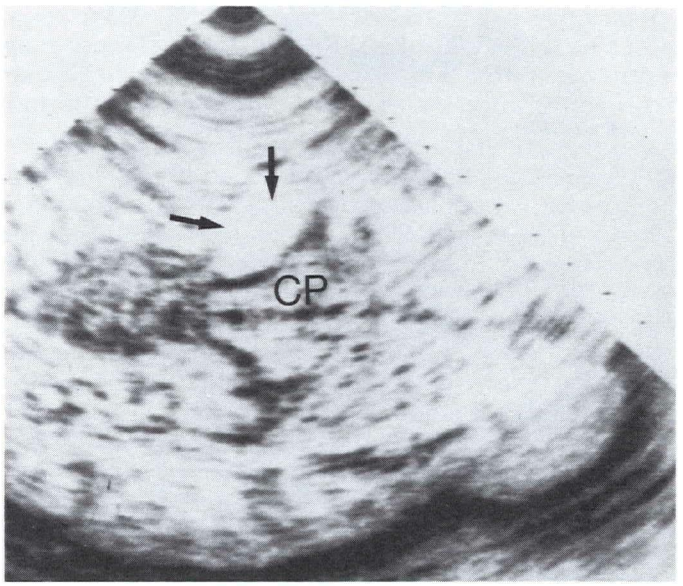

Fig. 12
Axial scan performed through a craniotomy opening demonstrating 2 cm, sharply circumscribed, echo-free mass (arrows), adjacent to cerebral peduncles (CP). Its sonographic appearance is consistent with that of a cyst. Final diagnosis: congenital arachnoid cyst.

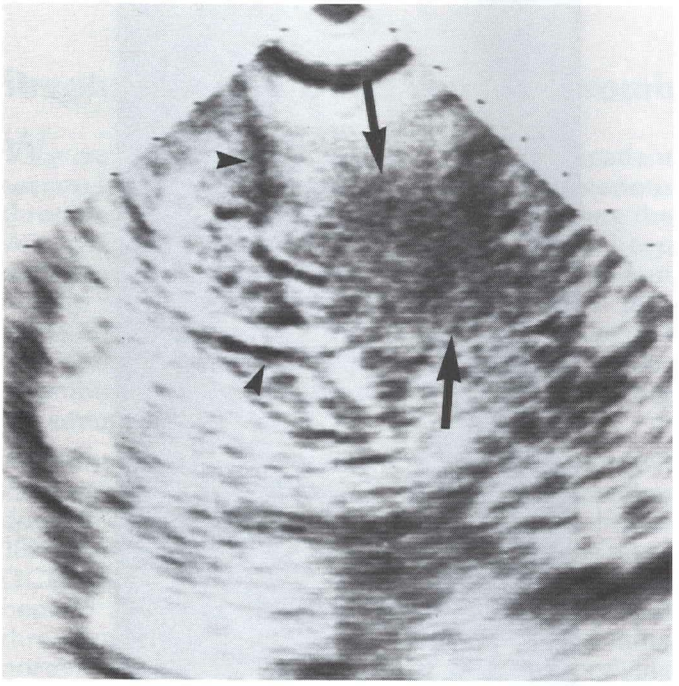

Fig. 13A
Coronal scan through left frontoparietal craniotomy revealing 4 cm, poorly circumscribed mass (arrows) displacing the falx and frontal horns of the lateral ventricles (arrowheads).

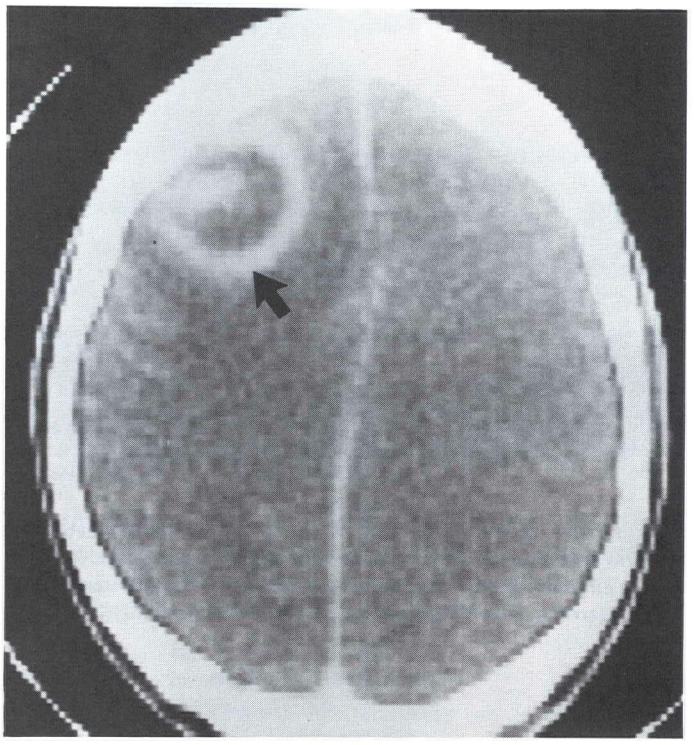

Fig. 13B
Computed tomography after intravenous infusion of contrast revealing low density mass with a peripheral rim of enhancement (arrow). An abscess was drained at surgery.

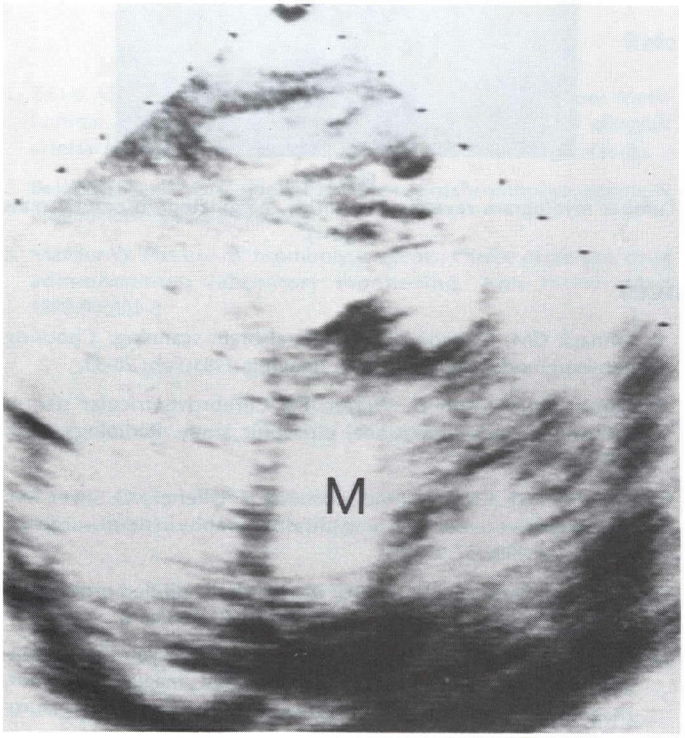

Fig. 14A
Coronal scanning during surgery revealing advanced hydrocephalus secondary to an arachnoid cyste that extends from the posterior fossa into the middle cranial fossa and is seen at midline (M).

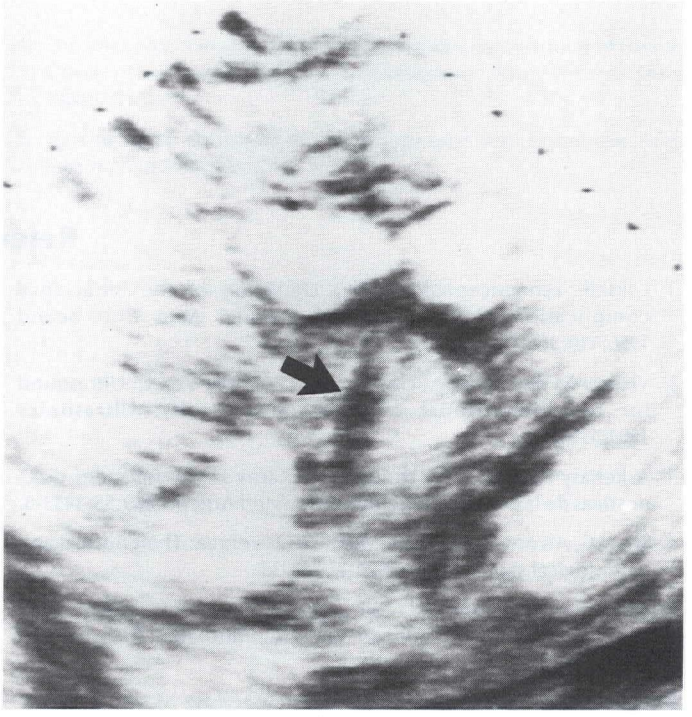

Fig. 14B
Under sonographic guidance, a shunt catheter was placed within this midline arachnoid cyst (arrow).

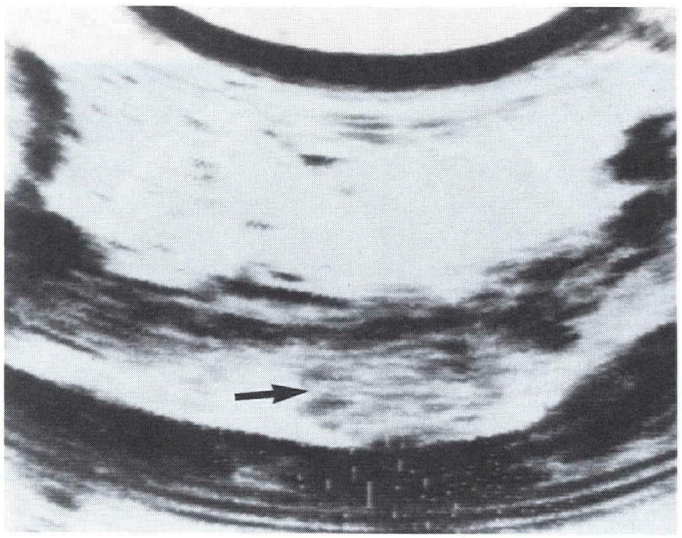

Fig. 15A
Intraoperative scanning through a laminectomy defect reveals a fusiform dilatation involving a nerve root of the cauda equina. A 2 cm, sharply circumscribed, echogenic mass is noted within this nerve root (arrow). Final diagnosis: nerve root schwannoma.

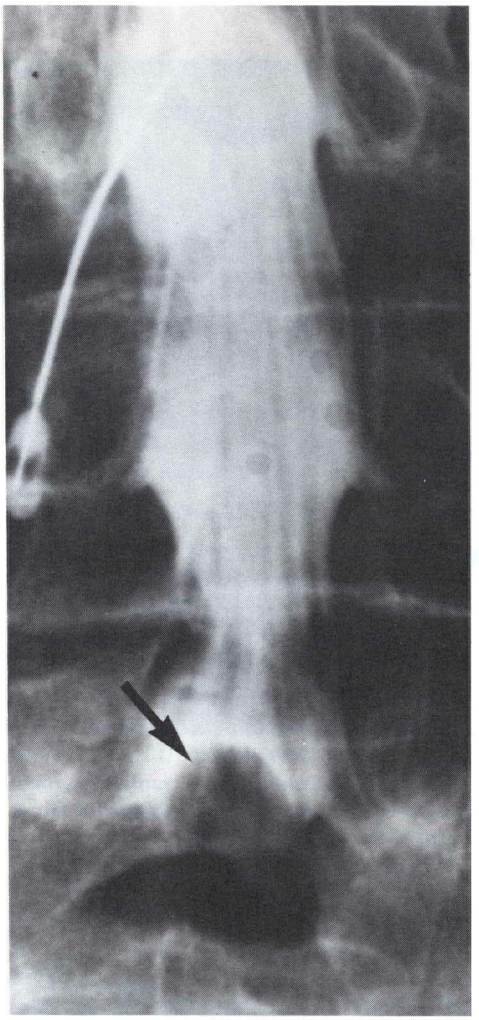

Fig. 15B
Lumbar myelogram revealing smoothly marginated, intradural mass (arrow).

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