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Intraoperative Sonography for Brain Tumor Localization and Ventricular Shunt Placement

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Intraoperative sonography using portable real-time equipment at the dural or brain surface in 16 patients provided accurate localization of a variety of brain lesions for direct dissectional or needle aspiration biopsies as well as for decompression of cysts. The technique has proven to be reliable and rapid, reducing brain exploration in the search for small or poorly accessible lesions and eliminating complex stereotactic procedures. Ventricular shunt catheter placement was also monitored intraoperatively in two infants.

Cranial sonography has proven to be highly successful in imaging the infant brain, but the more mature skull is still a formidable barrier to sonographic evaluation. Nevertheless, some remarkably good B-scans of tumors and other lesions obtained through the intact skull appeared more than 15 years ago [1]. There have been sporadic reports of imaging normal and morbid anatomy through the scalp over preexisting craniotomy defects [2–4], but this technique has limited application due to the small number of appropriate patients and the much greater information obtainable by computed tomography (CT).

A more useful extension of sonography for imaging the brain is the direct intraoperative application of the sonographic transducer for preexcisional localization of brain tumors. Two reports of such attempts have recently appeared [5, 6]. Another intraoperative application suggests itself, namely the guidance and/or confirmation of ventricular shunt catheter placement. The portability and instant feedback of current real-time sector scanning equipment makes sonography uniquely superior to CT. This report summarizes our experience with intraoperative cerebral sonography during a 12 month period.

Materials and Methods

The instrument used was a real-time sector scanner (Advanced Technology Labs., Bellevue, Wash.) with an integrated 22.9 cm television monitor, videocharacter generator, videotape interface, and a second small monitor for hard-copy Polaroid prints. This assembly has been used extensively for imaging the neonatal brain through the anterior fontanelle. To assure its capability for imaging adult brain, it was first applied to the intact scalp over craniotomy defects in five patients, and the sonograms and CT images were compared (fig. 1).

In anticipation of the need to guide both ventricular shunt catheters and aspiration needles in selected cases, a stainless steel guide unit was designed and constructed for easy attachment to, and removal from, the hand-held transducer (fig. 2). The guide accommodates the 3.1-mm-outside diameter of the standard Holter shunt catheter, and its angle can be adjusted to parallel the central beam of the transducer or to intercept the central beam at varying depths.

Cadaver liver and brain specimens were used to confirm that a needle probe or shunt catheter passing through the guide path maintained continuous visibility within the sonographic image display (fig. 3).

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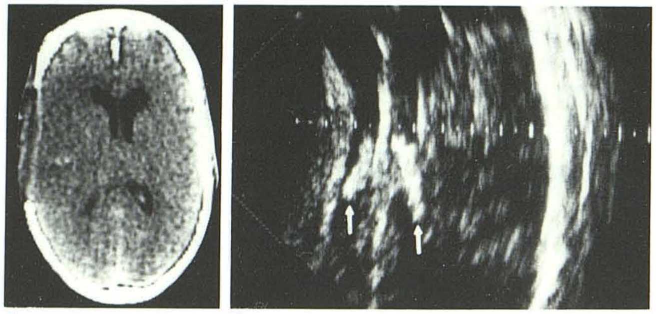

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Fig. 1.—**A**, Axial CT through midventricular level. Large right frontoparietal skull defect from old infected craniotomy bone flap. **B**, Axial sonogram through scalp over bone defect shows same ventricular anatomy. Marker intervals are 5 mm. Hyperechoic choroid plexus (*arrows*).

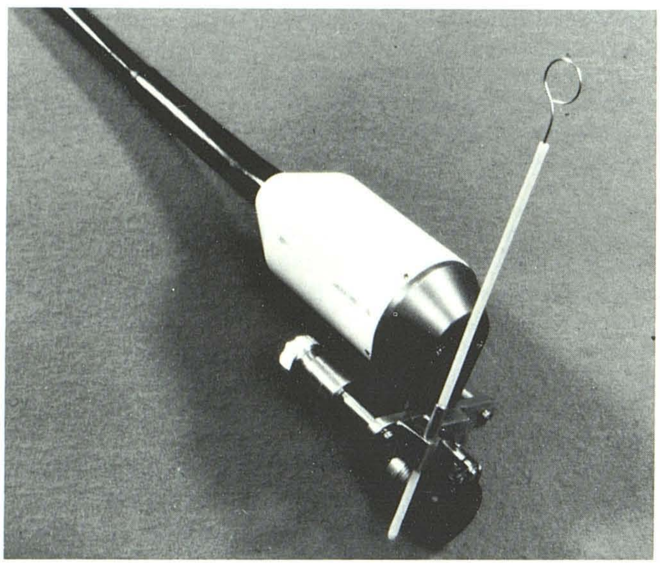

Fig. 2.—Stainless steel guide unit attached to 5 MHz transducer. White 3.1 mm Holter ventricular catheter with wire guide is held in guide channel. For operative use, transducer would first be covered with sterile glove and stockinette.

For use in the operative field, the transducer is first inserted into a sterile rubber glove partly filled with a thick coupling gel. The transducer and its cable are then covered with a sterile stockinette, and the transducer face is allowed to protrude through a small incision in the stockinette. It is useful to secure these coverings with sterile string ties or rubber bands. Care must be taken to remove all air bubbles from the transducer/glove interface. When needed, the steam-sterilized needle guide unit can be attached to the glove-covered transducer without disturbing the glove.

The transducer is applied gently to the intact dura or to the exposed brain surface. In the search for relatively small brain lesions, sonography is usually done first through the intact dura, since accurate localization will minimize the size of the dural incision. An attempt is made to visualize the lesion in two planes (e.g., coronal and parasagittal or coronal and axial), and the dura is marked over the center of the lesion. After opening the dura, repeat sonography at the brain surface reconfirms the position of the lesion. Depth and size of the lesion are indicated by centimeter markings within the central beam of the displayed image, and these markings change appropriately with changes in focal depth setting of the variable-focus transducer. Both 3 and 5 MHz transducers have been used, the choice depending primarily upon the depth of the lesion. A needle probe can be passed into the lesion, or it can be approached by direct dissection at the point of localization.

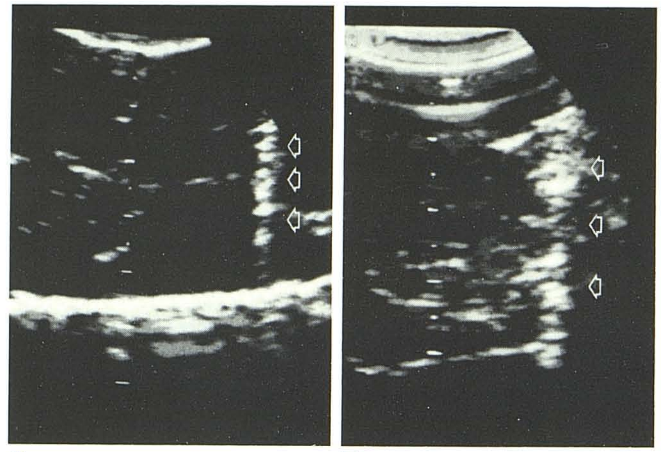

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Fig. 3.—Testing visibility of needle or catheter within sonographic image of cadaver brain specimen. An 18 gauge needle (**A**) and 3.1 mm Holter ventricular catheter (**B**) were passed through guide channel. Each is seen as a continuous vertical line of dense white echoes (*arrows*) to the right of the vertical marker scale.

Intraoperative sonographic brain lesion localization was performed in 16 cases. In addition, transfontanelle sonography was done intraoperatively for monitoring ventricular catheter placement in two infants with moderate hydrocephalus.

Results

The 16 cerebral masses localized by intraoperative sonography included ganglioglioma (one case); grades I and II astrocytoma (five cases); endodermal sinus tumor (one case); arteriovenous malformation (one case); metastases of lung, breast, and renal carcinoma (six cases); undifferentiated small cell metastasis (one case); and "unclassifiable malignant glial neoplasm" (one case). Ten of the masses were smaller than 2.5 cm in greatest dimension, five were 2.5–4.0 cm, and the largest was a 4 × 6 cm cystic metastasis.

Only three lesions had detectable calcification. Half of the lesions had produced mild to moderate reactive brain edema, and half showed negligible edema. Although both calcification and edema could be identified during sonography, neither feature proved necessary for lesion localization. Each of the neoplasms was at least mildly hyperechoic in relation to the surrounding brain, and the one arteriovenous malformation examined had a markedly echogenic border with mixed internal echoes. Cystic parts of neoplasms were easily identified, as expected. In no case was there any doubt about proper identification of the lesion during the real-time sonographic examination.

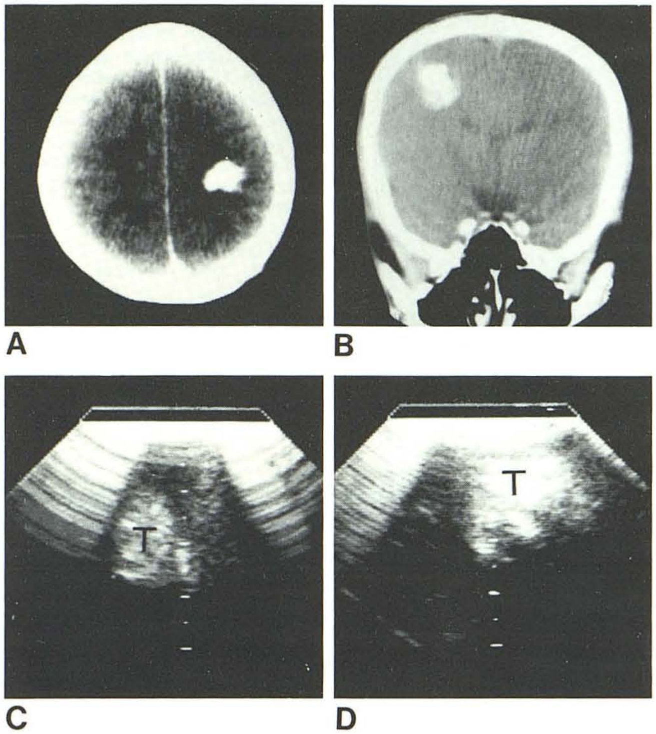

Fig. 4.—Case 1, ganglioglioma. Axial (**A**) and coronal (**B**) CT. Right parietal tumor is partly calcified, exerts no regional mass effect, and does not reach brain surface. **C** and **D**, Intraoperative transdural sonograms at shallow focal-depth setting (scale markers are at 5 mm intervals). Tumor (T) is markedly hyperechoic relative to adjacent white matter and attenuates sound transmission. Transducer face was rotated 90° to produce coronal (**C**) and semisagittal (**D**) images. Dense white bands at both sides of images are artifacts due to poor contact of transducer margins.

Examination times ranged from 10 to over 45 min, depending on whether a single lesion was merely localized for dissectional approach or whether guided cyst aspirations and multiple needle biopsies were undertaken. Three patients had transient postoperative fever, but none developed cerebral infection, and there were no known complications directly attributable to the sonographic procedure.

In the cases of ventricular shunt placement, the position of the strongly echogenic ventricular catheters was verified without difficulty.

Representative Case Reports

Case 1

A 20-year-old man developed twitching of the left arm and face 7 months before admission, and later had two grand mal seizures. Cranial CT (figs. 4A and 4B) revealed a 2.5 cm partly calcified right parietal mass. At surgery, sonography easily localized the lesion beneath the intact, normal-appearing dura (figs. 4C and 4D), and it was biopsied through a small dural incision. Although the frozen section was reported as only gliosis and hypervascularity, the sonograms helped provide confidence that the appropriate area had been biopsied, and the incision was closed. Permanent histologic sections revealed ganglioglioma, and the residual tumor was excised 1 week later.

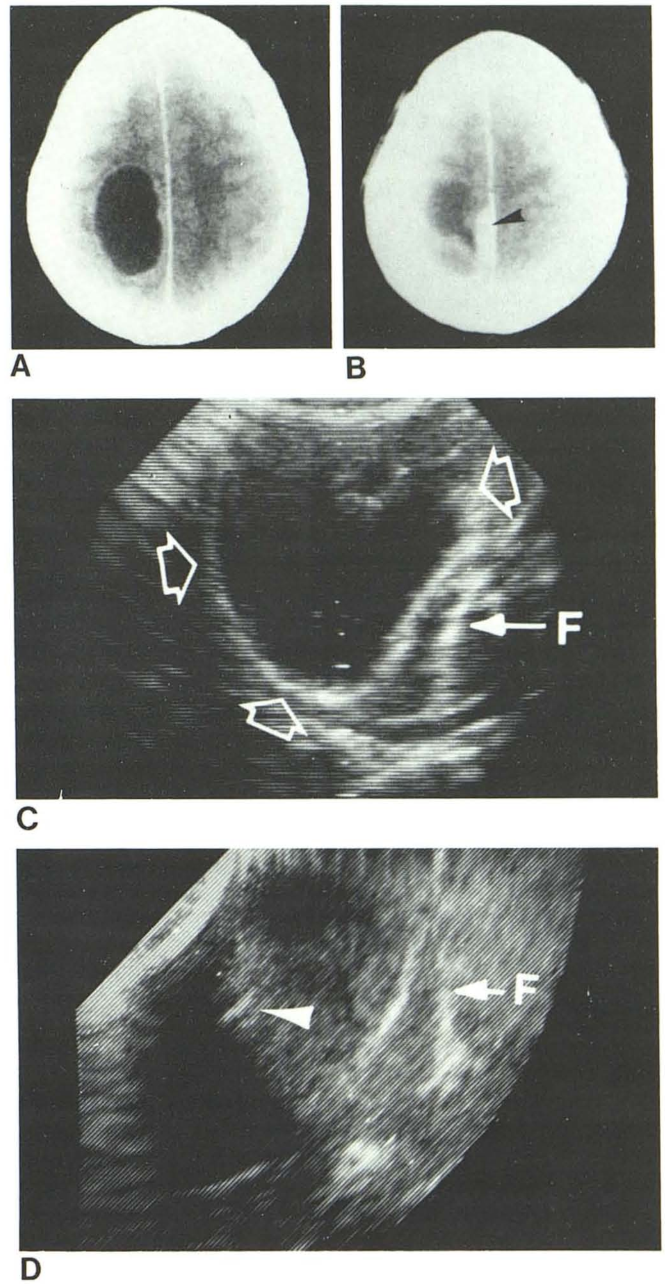

Fig. 5.—Case 2, cystic metastatic breast carcinoma. **A** and **B**, Contrast-enhanced axial CT at high parietal level. Tumor is largely cystic. Small enhancing solid-tissue nodule (*arrowhead*) adjacent to falx. **C**, Intraoperative transdural sonogram, coronal plane. Anechoic cystic tumor with strongly echogenic capsule (*open arrows*) shown at high magnification adjacent to falx cerebri (F). **D**, During cyst aspiration, needle tip (*arrowhead*) causes artifactual reverberations (gray area surrounding arrowhead) within residual cyst. Straight-edged bands of gray at left and upper image margins are artifacts due to poor contact at periphery of transducer.

Case 2

A 47-year-old woman who had undergone mastectomy for adenocarcinoma of the breast 3 years earlier developed right leg tremors, and cranial CT elsewhere reportedly showed a "left parietal lesion." The tremors ceased after phenobarbital therapy was started. She had bilateral papilledema and mild right body and face

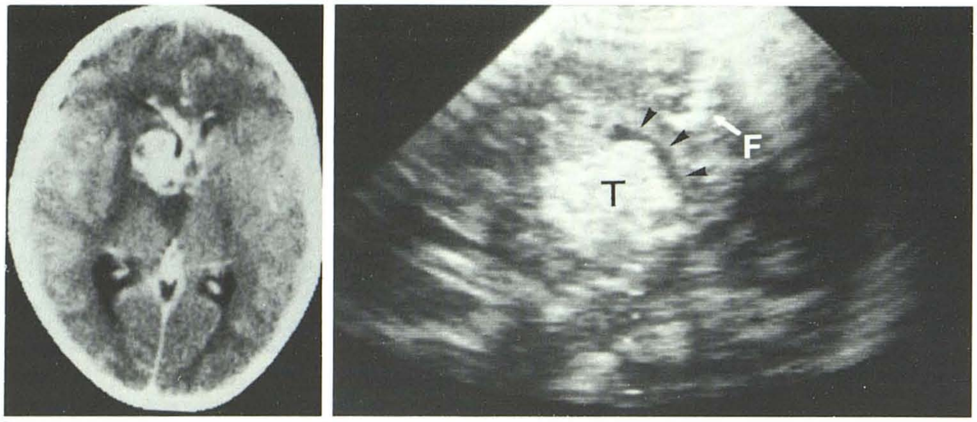

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Fig. 6.—Case 3, endodermal sinus tumor. **A**, Axial CT. Pathologic contrast enhancement surrounds compressed frontal horn of right lateral ventricle, most massively in caudate region, with moderate edema and midline shift. **B**, Intraoperative coronal sonogram. Part of right ventricle (*arrowheads*) overlies upper tumor (T) surface. Falx (F).

weakness 6 months later. CT showed a large, mostly cystic left parietal parasagittal mass (figs. 5A and 5B). Intraoperative sonography both before and after dural incision showed the cystic part of the tumor in relation to the falx (fig. 5C) and allowed identification of a smaller solid tumor nodule, which was excised after frozen section biopsy revealed adenocarcinoma. A brain cannula was guided into the cyst cavity, and it was decompressed during sonographic observation (fig. 5D). Postoperatively, the patient had a mild right arm drift and persistent mild papilledema and received radiation therapy.

Case 3

A 17-year-old girl with growth arrest at a height of 132 cm and no menarche but with normal neurologic and intellectual development began to experience headaches 8 months before admission. Cranial CT 2 and 3 months later showed an area of subependymal enhancement in the region of the right foramen of Monro that was suspiciously more prominent than normal subependymal veins, but no other definite abnormality. After 6 months without clinical change, follow-up CT showed a large enhancing mass at the same location (fig. 6A). Transdural sonography through a high frontoparietal craniotomy revealed densely echogenic tumor and its relationship to the right lateral ventricle, which partially overlay the upper tumor surface (fig. 6B). A direct dissection approach was guided to biopsy the upper lateral tumor substance and avoid the lateral ventricle. Frozen section indicated tumor of indeterminate type. Final section indicated endodermal sinus tumor for which radiation therapy was given.

Case 4

An 11-year-old girl who complained of headache and a weak, tremulous right arm was found to have papilledema. Cranial CT showed a partially cystic mass of the left caudate/thalamic region with questionable contrast enhancement (fig. 7A). Intraoperative sonography in the coronal plane (fig. 7B) identified the cystic and solid tumor areas in relation to the partially overlying left lateral ventricle. A brain cannula was guided to the accessible superolateral tumor surface, avoiding the ventricle, and two suction biopsies were taken. The frozen sections were reported as brain tissue, but sonographic visualization provided confidence that the tissue had been taken from the appropriate area. The brain cannula was then guided into the cystic portion, where slightly turbid yellow fluid was aspirated. The permanent histologic sections as well as cytologic examination of cells spun from the cyst fluid all demonstrated grade I astrocytoma. The child recovered uneventfully from surgery.

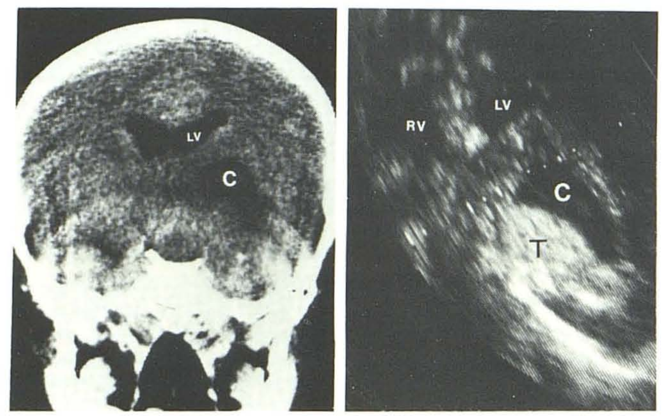

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Fig. 7.—Case 4, grade I astrocytoma. **A**, Coronal CT. Image degraded by slight motion. Cystic part of tumor (C) best shown beneath elevated and mildly dilated left lateral ventricle (LV). Tissue deep to cyst showed only questionable contrast enhancement. **B**, Intraoperative sonogram, coronal plane, shows solid tumor (T) deep to cyst. Aspiration biopsy of this tissue was ultimately diagnostic (see text). RV = right ventricle.

Discussion

Several years experience with transfontanelle sonography of the infant brain in our own and many other centers provided expectation that direct sonography of the brain during surgical procedures would be similarly successful. From this experience, it was presumed that calcified lesions such as some gangliogliomas, low-grade astrocytomas, and meningiomas would be sufficiently echogenic to be recognizable. It has been most encouraging to learn that noncalcified noncystic tumors such as moderate-grade astrocytomas and metastases can also be differentiated from the surrounding brain.

Because all of the solid masses examined have appeared rather similarly echogenic, and because these lesions have all been evaluated with standard neuroradiologic examinations before surgery, the sonographic technique has not added measurably to the differential diagnostic process. Its great value lies instead in its ability to accurately guide the surgeon to small lesions or lesions of limited accessibility, especially in the dominant cerebral hemisphere. Our cases were specifically selected to challenge the sonographic

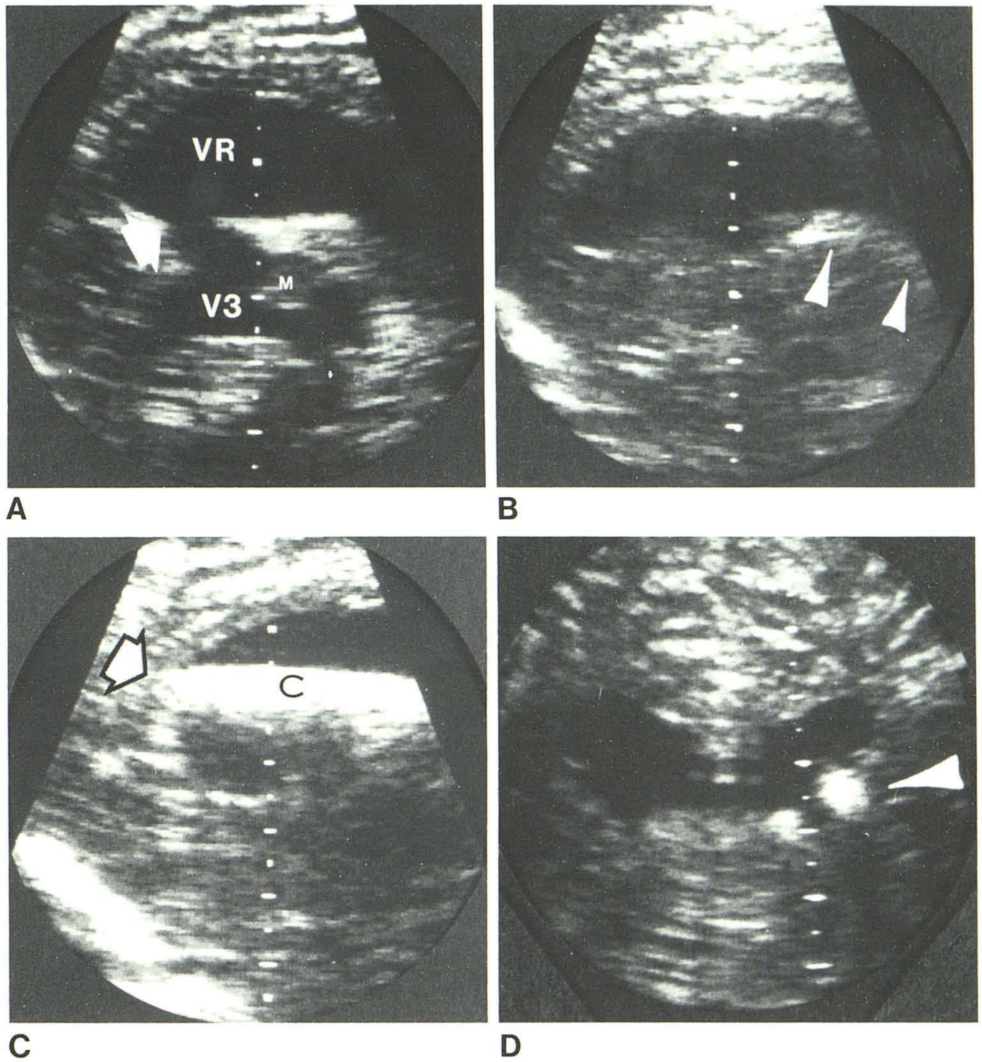

Fig. 8.—Monitoring ventricular shunt catheter placement by transfontanelle sonography. **A**, Sagittal-oblique plane before catheter insertion. Foramen of Monro (*arrow*). VR = right lateral ventricle; V3 = third ventricle; M = massa intermedia. **B**, Advancing catheter (*arrowheads*) (more distinct when in motion during real-time sonography). **C**, Catheter tip (*arrow*) indenting ependyma at anterior margin of right frontal horn. Catheter (C) size exaggerated by reverberations within ventricle. **D**, Rotating transducer 90° for coronal view. Cross-section of catheter (*arrowhead*) within frontal horn. Small echogenic area medial to catheter is choroid plexus.

technique. For example, very large or easily accessible masses such as bulky meningiomas or widespread infiltrative gliomas were excluded, since sonography of such lesions is not needed for precise localization, nor would it alter the surgeon's approach.

In ventricular catheter placement (fig. 8), the currently available transducers cannot be used at the catheter insertion site due to insufficient contact area through the usual small single burr hole. Although accurate paraxial guidance of the catheter insertion should certainly be possible, based on the experience gained with cadaver brain specimens, such a technique would require a larger burr hole with a notch at the side to allow the catheter to pass adjacent to the transducer face. Transfontanelle sonography during shunt placement does not then actually "guide" the catheter along its path, but it does monitor the advancement of the catheter in real-time, instantly assures proper catheter position within the ventricle, and thereby eliminates the need for radiography or fluoroscopy in the operating room during shunting procedures.

The range of intracranial conditions for which intraoperative sonography may be useful requires still further evaluation, but the following advantages of the procedure are already apparent: (1) It provides accurate identification and localization of brain masses of widely varying types, with definite though unquantifiable reduction in degree of brain exploration and size of dural incisions and, thereby, presumably in surgical morbidity. In two of our cases, the operation was confidently concluded after sonographically guided biopsy, even though frozen section reports indicated the tumor may have been missed. In each case, final histologic sections confirmed the accuracy of the biopsy. (2) It offers instantaneously visible and accurate guidance of brain probes or aspiration cannulas without the need for complex stereotaxic CT procedures. (3) It eliminates the need for intraoperative radiography or fluoroscopy during ventricular catheter placement. (4) It features portability, low cost, lack of ionizing radiation, and the use of equipment already available in many centers. The sonographic techniques described in this report are now almost routinely called upon in our institution when the size or limited accessibility of a lesion indicates their use.

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