Intraoperative use of real-time ultrasonography in neurosurgery

WILLIAM F. CHANDLER, M.D., JAMES E. KNake, M.D., JOHN E. McGILLCUDDY, M.D., KEVIN O. LILLEHEI, M.D., AND TERRY M. SILVER, M.D.

Department of Surgery (Section of Neurosurgery) and Department of Radiology, University of Michigan Medical Center, Ann Arbor, Michigan

The authors' experience with the intraoperative use of real-time ultrasonography during 21 neurosurgical procedures is reported. These procedures include neoplasm surgery in 18 cases, treatment of an arteriovenous malformation in one case, and ventricular catheter placement for hydrocephalus in two cases. In each of the neoplasm cases, the tumors were imaged just as well through the intact dura as on the brain surface itself. There were no cases in which the pathology could not easily be identified. The use of portable intraoperative ultrasonography in sterile coverings has proven to be extremely useful in localizing small subcortical neoplasms, as well as locating the solid and cystic portions of deep lesions. It has assisted in guiding needles for both biopsy and aspiration. It has also accurately identified and guided Silastic catheters during their placement in the ventricular system in cases of hydrocephalus. The authors have found real-time ultrasonography to be an important new tool in the operating room and will continue to rely on its imaging ability during selected procedures in the future.

KEY WORDS • real-time ultrasonography • brain tumor • hydrocephalus • arteriovenous malformation • neurosurgical technique

Recent technological advances in ultrasound instrumentation have resulted in equipment that will image in “real-time” slices of the human brain similar in quality to computerized tomography (CT). The term “real-time” implies that the image on the television monitor at any given point in time is precisely the image which is produced by the ultrasound unit at that instant. Thus, any movement of structures being imaged can easily be seen. Sonography of the brain continues to be limited, however, by the inability of the ultrasound beam to penetrate the human skull.11,22 Recently, real-time ultrasonography has proven to be extremely useful in detecting intracerebral or intraventricular hemorrhage, hydrocephalus, and porencephaly in premature or other infants.3-5 In those cases, advantage is taken of the open fontanel to image the brain in multiple directions with this simple and safe technique.

We have taken advantage of a similar circumstance in the operating room where a portion of the skull has been removed, often in pursuit of relatively small and deep mass lesions. Although attempts at intraoperative localization during neurosurgical procedures have been made in the past with older modes of ultrasonography, the availability of real-time imaging has renewed interest in this technique.6,8,10,13-17,19,21,24,25 We have investigated the imaging capabilities of real-time ultrasonography during a wide variety of neurosurgical procedures, and have found this technique to be extremely helpful and easy to perform.

Materials and Methods

Equipment

All ultrasound imaging was performed with an ATL real-time sector scanner.* This is a self-contained portable unit with a 9-in. television monitor on which is viewed in real-time the image produced by the transducer. The slice of brain imaged is several millimeters thick and in the shape of an inverted V. The depth of the brain imaged may be as shallow as from the surface to just 3 cm deep or from the surface to the opposite side of the brain. This depth of image

TABLE 1
Neurosurgical procedures using intraoperative real-time ultrasonography

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Pathology</th>
<th>Location</th>
<th>Size (cm)</th>
<th>Calcification*</th>
<th>Reactive Edema*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20, M</td>
<td>ganglioglioma</td>
<td>rt parietal</td>
<td>2.5</td>
<td>+++</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>17, F</td>
<td>endodermal sinus tumor</td>
<td>rt foramen of Monro region</td>
<td>3.0</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11, F</td>
<td>Grade I astrocytoma</td>
<td>lt caudate/thalamus</td>
<td>3.5</td>
<td>0</td>
<td>0</td>
<td></td>
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<tr>
<td>4</td>
<td>31, M</td>
<td>Grade I astrocytoma</td>
<td>lt frontoparietal</td>
<td>2.0</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>55, F</td>
<td>Grade II astrocytoma</td>
<td>lt parietal operculum</td>
<td>3.0</td>
<td>+</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>58, F</td>
<td>Grade II astrocytoma</td>
<td>lt deep temporal</td>
<td>3.0</td>
<td>0</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>77, F</td>
<td>unclassified malignant glial neoplasm</td>
<td>lt midtemporal</td>
<td>2.0</td>
<td>0</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>11, F</td>
<td>malignant primitive neural tumor</td>
<td>anterior corpus callosum</td>
<td>6.5</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>66, M</td>
<td>glioblastoma multiforme</td>
<td>lt parietal</td>
<td>5.0</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>50, M</td>
<td>metastatic lung carcinoma</td>
<td>lt parietal</td>
<td>2.0</td>
<td>0</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>61, M</td>
<td>undifferentiated small-cell metastasis</td>
<td>lt parieto-occipital</td>
<td>2.5</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>48, F</td>
<td>metastatic hypernephroma</td>
<td>lt parietal</td>
<td>1.5</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>48, F</td>
<td>metastatic lung carcinoma</td>
<td>rt cerebellar hemisphere</td>
<td>2.0</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>66, M</td>
<td>metastatic lung carcinoma</td>
<td>rt parieto-occipital</td>
<td>2.5</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>41, F</td>
<td>metastatic breast carcinoma</td>
<td>lt parieto-occipital</td>
<td>2.5</td>
<td>0</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>59, M</td>
<td>metastatic adenocarcinoma, unknown primary</td>
<td>rt parietal parasagittal</td>
<td>3.0</td>
<td>0</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>47, F</td>
<td>cystic metastatic breast carcinoma</td>
<td>lt parietal parasagittal</td>
<td>4 x 6</td>
<td>0</td>
<td>+/0</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>57, M</td>
<td>cystic metastatic lung carcinoma</td>
<td>lt midtemporal</td>
<td>2 x 4.5</td>
<td>0</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>32, F</td>
<td>arteriovenous malformation</td>
<td>rt posterior temporal</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>63, M</td>
<td>hydrocephalus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>63, F</td>
<td>hydrocephalus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 0 = none, +++ = severe.

is determined with a selector switch on the instrument. Every image is continuously labeled with centimeter depth markers as it is displayed on the television monitor. The system also includes a video recorder to store the television image, and a Polaroid camera for permanently recording images of interest. All illustrations appearing in this report are Polaroid photographs of the video images. It should be stressed that this equipment is so compact that it readily fits on a portable cart, and is generally available in most large hospitals.

Preliminary Non-Operative Experience

In addition to the 21⁄2-year experience with portable real-time ultrasonography gained in our neonatal unit, we initially used this imaging technique on five adult neurosurgical patients with existing cranial defects, but without intracranial pathology. Through the intact scalp, there was no problem identifying such brain structures as the ventricular system and the choroid plexus. These images compared favorably to the corresponding CT scans.

To determine the ability of this technique to image brain cannulas and catheters, a variety of such items in differing sizes and materials were passed into cadaver brains and imaged with ultrasound. Metal cannulas and silicone catheters were easily visible with ultrasonography, with the metal producing more acoustical distortion on the image.7

Intraoperative Technique

To assure sterile conditions in the operative field, the ultrasound transducer is carefully placed in a sterile rubber glove partially filled with a coupling gel. The transducer and the cable that connects it to the imaging unit are then covered with a sterile stockinette. The rubber-covered transducer head protrudes through a small opening in the stockinette.

The transducer head, which is approximately 2 × 2 cm in size, may then be placed either on the dura or directly on the exposed brain surface moistened with saline. We have found no difference in the quality of images with the dura intact or open. It has been our custom to image first over the intact dura, which helps determine the optimum site for opening the dura. The transducer is then rotated so that the object of interest is imaged in a variety of planes. Lesions are usually confirmed in two planes, such as the coronal and sagittal, or coronal and axial. It is important to reemphasize that the image on the television monitor is precisely what is beneath the transducer head, with no time delay. Structures such as the middle cerebral artery or an arteriovenous malformation (AVM) can be seen to pulsate on the screen.

Summary of Cases

Over the past 13 months we have used intraoperative ultrasonography during 21 neurosurgical procedures. The cases were not consecutive since we selected only those in which we thought the system would be helpful or particularly challenged by the uniqueness of the lesion. Obvious lesions such as meningiomas or large superficial gliomas were not studied. Our total experience to date includes 18 patients with cerebral neoplasms, one with an AVM, and two with ventricular catheter placement for hydrocephalus (Table 1). The cerebral neoplasms in-
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included seven subcortical solid metastatic lesions (1.5 to 3.0 cm in diameter), two subcortical cystic metastatic lesions, four low-grade gliomas, three high-grade gliomas, an endodermal sinus tumor, and a calcified ganglioglioma (2.5 cm in diameter). This report includes our total experience to date, with no cases omitted.

The most significant result of this investigation into the intraoperative use of real-time ultrasound imaging was that the pathology was clearly identified and localized in every case (Table 1). In addition, in the two cases of ventricular catheter placement, the Silastic catheters were easily identified and optimum placement was facilitated by the real-time ultrasonic imaging.

The seven solid subcortical metastatic neoplasms were readily identified as hyperechoic (more dense) masses. Five of these were not otherwise identifiable by gross inspection or palpation of the brain surface at the time of surgery. The calcified ganglioglioma was even more hyperechoic relative to brain, but calcification did not prove to be a prerequisite for tumor localization. The cysts that were part of the two cystic metastatic lesions and those associated with the AVM were easily identified as being less echogenic (less dense) than surrounding brain or solid tumor. Both the low- and high-grade gliomas were easily identified regardless of depth, and were all found to be somewhat hyperechoic. The rare endodermal sinus tumor was likewise hyperechoic. The AVM was very hyperechoic and pulsatile. The edema surrounding the various lesions (as confirmed by the CT scans) was easily demonstrated to be hypoechoic, but again the presence of edema was not necessary for the identification of the primary lesion.

The ventricular catheters could easily be visualized via an open anterior fontanel in the two cases in which this was attempted. When the plane of the ultrasound was held in the parasagittal direction, the catheter could actually be “seen” in real-time imaging as it was advanced from the parietal region into the ventricular system. The final position of the catheter was confirmed, including its relationship to the choroid plexus, obviating the need for intraoperative radiographs. In the three cases in which an aspiration or biopsy needle was placed within the solid or cystic portion of the neoplasm, the position of the needle within the lesion was confirmed easily with ultrasound. The needles could actually be followed in real-time as they entered the tumors. As is exemplified in two of the following illustrative cases, the system gives the surgeon considerable confidence that he is actually within the lesion in spite of equivocal frozen section reports.

Illustrative Cases

Case 1

This 66-year-old man presented with a grand mal seizure and a left homonymous hemianopsia. ACT scan demonstrated a right parieto-occipital lesion (Fig. 1 left). The brain surface appeared normal at surgery, but sonography localized this metastatic adenocarcinoma easily as a hyperechoic subcortical mass (Fig. 1 right).

Case 2

This 20-year-old man presented with two grand mal seizures and a normal neurological examination. A CT scan revealed a calcified subcortical lesion in the right parietal area (Fig. 2 left and center). At surgery, the cortex appeared normal, and the lesion was localized with ultrasonography (Fig. 2 right). Since the initial frozen section showed only “gliosis,” the procedure was terminated with confidence, based on the ultrasound localization, that the true lesion had been biopsied. The final pathological determination was a ganglioglioma, and the entire lesion was excised 1 week later.

Case 3

This 77-year-old woman presented with a mild right hemiparesis and was found on CT scanning to have a medial temporal lobe lesion (Fig. 3 left). At surgery this lesion, as well as the nearby ventricle and pineal gland, was imaged with ultrasonography (Fig. 3 right). Direct surgical biopsy revealed the diagnosis of a malignant glioma.
Case 4

This 11-year-old girl complained of headache and was found to have a right hemiparesis and papilledema. Her CT scan revealed a partially cystic mass in the left basal ganglia region (Fig. 4 left). Intraoperative ultrasound demonstrated this lesion well (Fig. 4 right) and assisted in both aspiration of the cystic portion and needle biopsy of the solid portion of the tumor. Again, the frozen sections were equivocal and the ultrasound imaging gave the surgeon the confidence that the biopsy needle was truly within the neoplasm. The pathology was reported as a Grade I astrocytoma.

Case 5

This 32-year-old woman presented with a history of a documented subarachnoid hemorrhage and a small intracerebral hematoma in the right temporal lobe 4 years previously. Cerebral angiography (Fig. 5 left) demonstrated a small arteriovenous malformation in the right posterior temporal lobe. At surgery, ultrasonography showed the pulsating AVM and two
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Fig. 5. Case 5.  
**Left:** Subtracted right vertebral angiogram, anterior view. The arteriovenous malformation (AVM, arrow) of the posterior right temporal region is seen to fill from the right posterior cerebral artery.  
**Right:** Intraoperative ultrasonography shows the AVM as a highly echogenic (white) mass in the inferior temporal lobe (large arrow). Two cysts (small arrows) are also noted, secondary to a previous intracerebral hemorrhage.

Case 6

This 4-month-old infant presented with an enlarging head circumference, and CT scanning revealed moderate hydrocephalus (Fig. 6 left). During placement of his ventricular catheter via a parieto-occipital trephine, the movement and position of the catheter were monitored with ultrasonography through the open anterior fontanel (Fig. 6 center and right). The catheter could be identified entering the ventricle and subsequently being advanced to the tip of the frontal horn.

Discussion

Less sophisticated ultrasound instruments of various types have been available for over 20 years. The older A-mode units did not actually image the brain,
but merely showed a depth-related echo on the oscilloscope tracing when an echogenic object was struck with the ultrasound wave. Several innovative attempts to use this relatively crude diagnostic mode for lesion localization in the operating room have been reported.14,17 The advent of real-time ultrasound scanning allows actual imaging of slices of the brain, and therefore provides great opportunity for its use as a localizing instrument during neurosurgical procedures. Several preliminary reports concerning real-time imaging have appeared in the literature since we began our investigations.3,13,18,20,23

Overall, we have found real-time ultrasonography to be extremely helpful for localization in a variety of neurosurgical procedures, and have so far been able to clearly identify every lesion in which ultrasound was attempted. This technique demonstrated the solid and cystic portions of tumors, as well as calcifications and surrounding edema. Both low-grade and high-grade gliomas were imaged clearly as hyperechoic tissue. This technique has demonstrated vascular lesions, as well as a variety of metal needles and Silastic catheters. The normal or distorted ventricular systems were, of course, also seen clearly. We have shown that these various lesions are imaged as well with the dura intact as with it open. The limitations of this technique in the operating room are primarily related to the size of the transducer head. If this could be miniaturized in the future, localization through a simple trephine might be possible for such procedures as needle biopsies and ventricular catheter placement, or even selected stereotactic procedures.1 An important point to emphasize about this technique is that the equipment required is fully portable and is generally available in most large hospitals.

Conclusions

The following advantages of intraoperative real-time ultrasonography during neurosurgical procedures have been identified.

1. It can provide critical assistance in precise localization of subcortical metastatic neoplasms, since in many instances the overlying surface of the brain provides no clue for localization. This technique clearly eliminates unnecessary open exploration or multiple passages of exploratory needles.

2. This technique is very useful for the identification of deep lesions, providing information about their solid and cystic components and about the shortest route of access to the tumor.

3. It provides precise information to help guide biopsy needles into deep lesions, and to confirm their presence within the lesion itself. This has proven in several cases to be critical in giving the surgeon the confidence to be satisfied with the biopsy specimen, even though the frozen sections were equivocal. In each of our cases the permanent sections confirmed the presence of pathological tissue.

4. The system is highly accurate in visualizing ventricular catheters during and after their placement. In young infants, this may be performed via the anterior fontanel, inside or outside the sterile field. The true usefulness of ultrasound in these cases remains to be seen, as it is not necessary in most situations of shunt placement for neonatal hydrocephalus. If the transducer could be miniaturized and the target ventricle visualized simultaneously with passage of the ventricular catheter through a common burr hole, then the system would be potentially useful in situations requiring ventricular catheters for normal-sized ventricles, such as in cases of trauma and chemotherapy administration.

5. The system is inherently safe for the patient and the operating room personnel since there is no radiation exposure.

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References


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Address reprint requests to: William F. Chandler, M.D., Section of Neurosurgery, University Hospital, Outpatient Building, C5068, 1405 East Ann Street, Ann Arbor, Michigan 48109.