Intraoperative Ultrasound-Guidance in Neurosurgery

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Since the first recorded use of the “ultrasonoscope” for localizing subcortical intracerebral neoplasms in postmortem specimens in 1950 (4), technological advances in ultrasound have seen a transformation from poor-quality, A-mode wave forms to superb-quality, real-time images in 2 (2D) and 3 (3D) dimensions. As a result, intraoperative ultrasonography (IOUS) has undergone remarkable development, particularly in the last 2 decades.

The brain’s viscoelastic properties make it a superb medium for ultrasound wave propagation, resulting in high-quality image capability (12). The quality of ultrasonographic imaging, however, is directly proportional to the frequency of the probe being used. Higher-frequency probes are better able to differentiate 2 targets as separate objects and hence provide better image resolution, but this comes at the cost of a lower tissue penetration. Most modern-day probes can be electronically tuned for a range of frequencies, greatly enhancing the image quality that they provide at a variety of depths (18). Although 2D ultrasound has gained wide acceptance, spurred on largely by the benefit of real-time feedback, a major limitation has been the need for extra space within the surgical field, mostly dependent on the size of the ultrasound probe (17). The range of probes available for neurosurgery has increased significantly, with a mixture of linear and phased array probes of varying size, with frequencies generally ranging between 3 and 12 MHz. The emergence of 3D ultrasonographic imaging, by acquiring and registering 100–200 2D images, has gone a long way to address this shortcoming and has also proven to be a very useful surgical adjunct in its own right, especially when integrated with preoperatively acquired magnetic resonance images (16, 18).

As all neurosurgeons are aware, the greatest obstacle to adequate ultrasound-based visualization of the brain is the bony skull or spinal canal, and the subsequent need for a craniectomy/ laminectomy or larger exposure to accommodate the ultrasound probe. The natural sonographic window provided by the open fontanelle in infants, allows widespread use of this modality in pediatric neuroimaging.

Despite these limitations, ultrasonography does have some very appealing features including real-time feedback, versatility, relative cost-effectiveness, and the absence of radiation. Real-time image acquisition has distinct advantages over conventional neuronavigation based on preoperatively acquired static images. Compensation for tissue and fluid shift after dural opening and the detection of untoward intraoperative events prior to bone flap replacement, such as hematoma formation or hydrocephalus, are perhaps the most notable of these advantages (7, 14). There are also certain limitations associated with the use of IOUS, which include an initial learning curve, operator dependence, and orientation difficulties (13), although the latter has been somewhat improved by 3D ultrasound (18).

In contemporary practice, IOUS has a well-established role as a guidance tool for lesion localization and resection and for ventricular catheter placement in hydrocephalus. Other described

Key words
- Cerebrospinal fluid
- Hydrocephalus
- Image guidance
- Intracranial pressure
- Neuronavigation
- Ultrasound
- Ventricular catheter
- Ventriculostomy

Abbreviations and Acronyms
- IOUS: Intraoperative ultrasonography
- 2D: 2-Dimensional
- 3D: 3-Dimensional
uses include assessment of the adequacy of posterior fossa bony decompression for Chiari I malformation (13), guidance for aspiration of central nervous system—infected collections, and Doppler flow studies for delineating vascular malformations (7).

**LESION LOCALIZATION AND RESECTION**

IOUS provides valuable information about the location, size, vascular relationships and structures adjacent to a targeted lesion (5, 20). It is most useful in guiding the resection margins during surgery, and for confirming the degree of resection at the end of surgery, and when combined with magnetic resonance imaging—based neuronavigation systems, has demonstrated significant additional benefit (7). The advantages of ultrasonography as a surgical adjunct have been described in adult patients with malignant astrocytoma, low-grade glioma, inflammatory lesions, and metastatic tumors (5, 15, 20), as well as pediatric patients in a variety of supratentorial and posterior fossa tumors (14).

**VENTRICULAR CATHETER INSERTION IN HYDROCEPHALUS**

In the treatment of hydrocephalus, misplaced shunt catheters account for a significant proportion of proximal shunt failure (1); hence a number of studies have addressed different methods of ventricular catheter placement such as freehand placement, frame-based stereotactic guidance, electromagnetic guidance, ultrasonographic guidance, and endoscopic assistance (6, 9, 21). Surprisingly, however, it remains unclear whether improved accuracy of ventricular catheter placement changes the overall incidence of shunt failure (6, 9). Ultrasonography as a guidance tool for safer ventricular catheter placement, particularly in children with an open fontanelle, appears quite useful. The natural window provided by the patent anterior fontanelle in neonates adds to its appeal in this particular population group. Possibly the greatest benefit of ultrasonography in hydrocephalus is the real-time feedback it provides, which allows the surgeon to plan, and where necessary to adjust, the entry point and trajectory of the ventricular catheter. The benefit of confirming the final resting place of the catheter at the end of the procedure, prior to skin closure, is useful, as the catheter position can shift during connection to the distal end of the shunt. The 2D images obtained with IOUS, that is, sagittal and coronal, do require some adjustment initially, but the benefit gained from the real-time feedback certainly justifies the effort involved.

The current paper by Jakola et al. addresses the very important issue of improving the accuracy and optimizing ventricular catheter placement in the treatment of hydrocephalus. The neurosurgical unit at St. Olav’s Hospital has pioneered the use of 3D ultrasound-based navigation for over a decade. Tumor resection guidance has been the major indication for the use of this technology and the current paper presents data on ventricular catheter placement in adult patients with hydrocephalus using a novel, purpose-built “burr-hole probe.” Although the number of patients in this study is small, it highlights the issue of image guidance when placing ventricular catheters, given the adverse sequelae of misplaced catheters. The burr-hole ultrasound probe described in this article is an attractive tool, as it eliminates the need for enlarging the access portal used to insert the ventricular catheter, and appears quite user-friendly. The ultrasound-based technique described in this article for guiding ventricular catheter insertion is certainly elegant and would also be quite an appealing option in children, where limiting the exposure of the developing brain to unnecessary radiation is always a desirable goal. Although the Kakarla grading is useful for assessing the placement of freehand catheters, it is probably not refined enough to assess the precision of catheter placement using an image guidance system such as the one described. Further evaluation of this technique in larger studies involving both adult and pediatric populations would be helpful in further defining its role as a guidance tool.

The influence of ultrasonography on neurosurgery is dynamic and has transcended its traditional role as a purely diagnostic tool. Although the application of acoustic energy as a therapeutic modality is not a new concept, it has enjoyed a resurgence. Recent advances in imaging modalities and improved methods of delivering the ultrasound wave have bolstered efforts to improve the degree of precision and minimize any adverse effects associated with the technique. Several innovative applications of this modality as a diagnostic and therapeutic entity have been investigated. These include 1) 3D ultrasound, integrated with magnetic resonance imaging—based navigation systems, which has demonstrated significant advantages in delineating the solid component in certain tumors (18, 19), 2) improved intraoperative tumor visualization using microbubbles as a contrast agent (2), and 3) functional ultrasonographic imaging to detect transient changes in regional cerebral blood flow (11).

Therapeutic applications of high-intensity focused ultrasound have been described for a myriad of neurosurgical conditions, most notably, for the treatment of medication-resistant essential tremor (10), ablation of certain brain tumors (9), and focal disruption of the blood—brain barrier to enhance the targeted delivery of certain molecular therapeutic agents (3).

If future trends echo recent history, the role of ultrasound in the neurosurgeon’s armamentarium, both as a multidimensional diagnostic tool and an evolving therapeutic modality, certainly appears poised for a boom.

**REFERENCES**


