Intraoperative Sonography for Neurosurgery

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Objective. The purpose of this study was to review the technical aspects and the clinical applications of intraoperative sonography of the central nervous system (CNS) as well as the characteristic appearances of brain and spine diseases. Methods. A pictorial review of cases is presented on the basis of the performance and interpretation of intraoperative sonography of the CNS from January 1998 to December 2004 at a single academic institution. Results. This technique is most commonly used for the localization and characterization of intracranial and spinal masses. Indications for intraoperative sonography of the CNS are biopsy guidance, tumor resection, and drainage or removal of inflammatory masses. It provides important additional information to the surgeon at the time of the operation and contributes to intraoperative decision making and surgical planning. This article reviews the advantages and limitations of intraoperative sonography of the CNS and highlights the typical appearance of CNS diseases. Conclusions. Intraoperative sonography of the CNS is an interactive technique and helps the neurosurgeon in decision making and surgical planning. Key words: brain; central nervous system; intraoperative sonography; sonography; spine.

Intraoperative imaging technology continues to develop, driven by the need for accurate and real-time neuronavigation based on data from preoperative magnetic resonance imaging (MRI) or computed tomography (CT). Whereas intraoperative MRI and CT are generally accepted methods to achieve this goal, they are available only in highly specialized centers, are expensive, and require a special infrastructure.

Intraoperative sonography has been used over many years and is an efficient imaging adjunct to neurosurgery. Image resolution as well as the size and engineering of probes have improved considerably since 1978, when Reid\(^4\) first described the use of sonography for neurosurgical guidance. Three-dimensional sonography with navigation software, which has been introduced recently, solves the orientation problem experienced previously with 2-dimensional sonography in neurosurgery.\(^5\)

Sonography is truly real time. The ability to depict real-time anatomic data during a surgical procedure is a valuable surgical adjunct and affects surgical decision making.\(^1,6-9\) Intraoperative sonography is a rapid and effective way to localize and characterize diseases of the brain, osseous spine, and adjacent spinal cord, providing accu-

Abbreviations
CNS, central nervous system; CSF, cerebrospinal fluid; CT, computed tomography; MRI, magnetic resonance imaging
rate localization of anatomy and reducing the risk of injury to the spinal cord or surrounding brain parenchyma.

The purpose of this study was to review the technical aspects and applications of intraoperative sonography of the central nervous system (CNS) as well as the characteristic appearance of brain and spine diseases based on experience gathered over a 7-year period at a single academic institution.

**Technical Requirements**

When preparing to perform intraoperative sonography of the CNS, communication with the surgeon to establish goals and strategies is critical. Preoperative CT, MRI, and angiographic studies should be reviewed to maximize intraoperative interpretation. Intraoperative sonography is best performed with routine mobile sonographic equipment with dedicated transducers. The radiologist must be aware that patients are often awake during neurosurgical procedures, and any communication within the operating room should be modified appropriately.

For procedures performed in the brain with burr hole access, a small end-fire or endocavitary transducer is used. A larger end-fire transducer provides a wider field of view during craniotomy. The transducer should be set at the highest possible frequency (7–15 MHz) and deepest penetration to identify reliable anatomic landmarks. Transducers must have pulsed Doppler and color flow capability to delineate tumor vascularity and surrounding vasculature. Because the head is draped for surgery and only a small opening is visible, transducer orientation must be established preoperatively. Liberal use of degassed saline before application or insertion of the probe improves acoustic coupling. The probe should be wrapped in a sterile sheath and applied directly to intact dura or exposed brain. It is important to apply the least possible external pressure to the surgical field at all times. Care must also be taken not to tear the sterile sheath on sharp bone fragments lining the burr hole.

Intraoperative sonography of the spine is most commonly performed with the patient in the prone position. After removal of the posterior vertebral body components, the dura overlying the spinal cord is exposed. Initial imaging is typically performed to localize lesions within the exposed surgical bed. Spinal cord imaging commonly uses a 7.5- to 15-MHz linear side-fire or an end-fire transducer. Direct application of the transducer onto the cord is seldom warranted because of the delicate nature of the spinal cord. Therefore, sterile degassed saline is commonly infused into the surgical bed to establish an acoustic bath. The ensheathed transducer is then gently placed onto the dura overlying the cord. Less saline is usually required when spinal imaging is performed in a sagittal plane because the transducer can be placed closer to the cord. If transverse images of the cord are required, the presence of sharp vertebral body elements will frequently prevent transducer placement directly on the dural surface. In this case, additional saline will allow the transducer to be positioned more superficially to provide high-resolution images of the subjacent cord.

**Intraoperative Sonographic Imaging of the Brain**

**The Normal Brain**

In the normal brain, surface sulci appear echogenic, whereas the underlying parenchyma is homogeneously hypoechoic. Blood vessels within the parenchyma and intravessel blood flow can be visualized with color Doppler sonography. The unique appearance of cystic and solid tumors can be distinguished against this background.

**Mass Lesions**

Intraoperative sonography of the brain is most commonly used for localization and characterization of intracranial masses. Tumors such as meningiomas, gliomas, lymphomas, and metastases are typically hyperechoic relative to normal brain parenchyma and surrounding vasogenic edema (Figures 1 and 2). Anechoic cysts may be present in patients with cystic astrocytomas and other cystic tumors, and cystic degeneration of benign or malignant solid lesions is common (Figure 3).

Localization and characterization of solid tumors become more difficult in the presence of chronic peritumoral edema, which causes increased echogenicity and may obscure the margins between the mass lesion and adjacent normal brain. Whereas acute edema is typically less echogenic than tumors, the appearance of chronic edema or previously radiated tissue is less predictable and may be isoechoic or hyperechoic relative to the tumor.
Infiltrative and more aggressive tumors vary in their echogenicity and composition. Low-grade astrocytomas are often heterogeneous, with indistinct margins (Figure 4). However, even a distinct tumor margin on sonography may be deceptive and may not correlate with margins seen on CT or MRI. Intracranial lymphoma is similarly facile, appearing either hypoechoic or isoechoic to surrounding parenchyma (Figure 5). Despite their infiltrative nature, these lesions tend to displace blood vessels. Color flow Doppler sonography may be a valuable tool in delineating tumor margins in cases in which vessels have been displaced.

Inflammatory and Infectious Disorders
The sonographic appearance of inflammatory masses varies according to lesion maturity. Inflammatory lesions such as abscesses can easily be distinguished from adjacent normal sulci (Figure 6). Abscesses characteristically have a sharply circumscribed echogenic wall. Their internal echogenicity depends on the amount of debris and the extent of necrosis. Although tumor margins tend to be obscured by surrounding vasogenic edema, the thick abscess margin remains conspicuous (Figure 6). Alternatively, chronic inflammatory, infectious, and demyelinating processes may have a less distinct appearance than abscesses. In these conditions, involved parenchyma is only mildly echogenic and may be quite difficult to distinguish from normal brain tissue (Figures 7 and 8).

Sonographically Guided Procedures in the Brain
Intraoperative sonography can be used to closely monitor the progression of cyst or abscess drainage in both supratentorial and infratentorial regions. Guidance is also required during drainage or insertion of ventricular catheters (Figure 9).

Figure 1. Metastatic esophageal carcinoma of the brain in a 61-year-old man. Intraoperative sonography of a frontal brain lesion shows a hyperechoic mass against the less echogenic surrounding parenchyma.

Figure 2. B-cell lymphoma in a 65-year-old woman. Intraoperative sonography, performed with an endocavitary probe, shows an echogenic parietal brain lesion. Note the well-defined margins of the tumor and the absence of any echogenic surrounding edema.

Figure 3. Metastatic adenocarcinoma of the lung in a 54-year-old patient. Intraoperative sonography shows a necrotic mass with solid portions that are hyperechoic.
Dynamic 2-dimensional sonography, with a biopsy guide mounted on the transducer, can direct a needle into the image plane along a predictable path. When a needle is inserted through the guiding device, its tip is continuously monitored as it approaches and enters the lesion. Visualization of the biopsy needle throughout its length is crucial to avoid complications and damage to crucial adjacent structures (Figure 8B). After the needle is advanced, biopsies can be obtained and sent for frozen sections or full pathologic evaluation.

The best site for biopsy of solid lesions is the viable portion of a tumor. This is usually represented by the echogenic margin at the periphery of the mass. As with any solid structure, tumors should be imaged in 2 planes. This is especially important in the brain because images of a gyrus surface may resemble a rounded mass on sonography (Figure 10).

During craniotomy, intraoperative sonographic guidance can be highly advantageous. Opening the dura widely, with associated loss of cerebrospinal fluid (CSF) and cortical swelling, may result in intraoperative displacement of brain tissue. Surgical retraction, creation of the resection cavity, and placement of catheters or biopsy needles will also result in brain shift, alteration of the surgical anatomy of the lesion and surrounding structures as defined on preoperative CT and MRI images.14

Brain shift is easily visualized on real-time sonographic imaging. Sonographic scans are inherently stereotactic in that the frame of reference is the transducer itself. As a result, intraoperative sonography improves localization.

Figure 4. Central nervous system glioma in a 44-year-old man. A, Intraoperative sonography of the brain performed with an endo
cavitary probe shows a poorly circumscribed, mildly hyperechoic mass with minimal surrounding edema (arrows). B, Color Doppler
sonography was used to define adjacent blood vessels surrounding the tumor and those located in the echogenic sulci (arrow). Note
the adjacent, normal-appearing, hypoechoic parenchyma and echogenic sulci.

Figure 5. Brain tumor in a 50-year-old woman. Intraoperative
sonography of the brain shows a poorly defined, poorly
marginated hypoechoic mass (arrows) with surrounding vague-
ly defined hyperechoic chronic brain edema. Biopsy performed
with sonographic guidance revealed a primary high-grade B-cell
lymphoma.
Intraoperative Sonographic Imaging of the Spine

The Normal Spine

The surface dura appears as an echogenic ring with surrounding anechoic CSF. Within the dural layer, the spinal cord shows homogeneous low-level echoes, demarcated from the surrounding CSF by a bright echogenic line on the surface of the cord (Figure 11). In the center of the spinal cord, the central canal is identified as an echogenic structure (Figure 11). The location of the central canal serves as a useful indicator of cord disease because it can be obliterated or displaced by intramedullary disease. The size and shape of the spinal cord and central canal vary predictably according to the vertebral level. The surrounding nerve routes are echogenic (Figure 11) and become particularly prominent at the level of the conus medullaris, appearing as bright linear echoes in the longitudinal axis.

Mass Lesions

The sonographic appearance of spinal cord lesions can vary with location; however, certain patterns have been well established. Intramedullary masses are often complex, containing both solid and cystic components (Figure 12). Cysts and syringomyelia appear as anechoic lesions that frequently contain fibrous

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septa. They can occur at any level of the cord, assume any shape, and be solitary or multiple, simple or multiseptated (Figure 13). Intraoperative sonographic guidance may be required during cyst puncture and aspiration. Intra-medullary neoplasms, when solid, appear as areas of increased and sometimes inhomogeneous echogenicity of the cord. Gliomas, metastases, and even focal myelitis commonly appear hyperechoic (Figures 14 and 15). Ependymomas, astrocytomas, and dermoids may contain areas of calcification, which enhance their echogenicity. Tumors may be identified at all levels of the cord, including the cauda equina (Figure 16). Imaging of mass lesions within the cauda equina may present an additional challenge because of rostral migration of these tumors from preoperative planning to surgical exploration.

As in the brain, gliomas are characteristically difficult to visualize because of their infiltrative nature. Intraoperative sonography may be required for their identification. The presence of septa within a cystic lesion can aid in distinguishing a neoplastic from a reactive mass. The presence of calcification within a lesion can also be detected sonographically.

Figure 8. Right frontal lobe mass in a 25-year-old woman. A, Intraoperative sonography of the brain shows a homogeneous and mildly hyperechoic region approximately 3.5 cm deep to the brain surface. The needle guide is used to gauge depth and plan the biopsy. B, The hyperechoic line represents the trajectory of the biopsy needle and its tip as it traverses the lesion (arrows). Biopsy of the mass confirmed the presence of lymphoplasmacytic encephalitis.

Figure 9. Lung carcinoma and a cerebellar cyst in a 70-year-old patient. Predrainage (A) and postdrainage (B) images of the lesion show complete aspiration of the cyst. Cytologic evaluation confirmed benign cyst contents.
properties and poor definition on sonography. Focal cord expansion and obliteration of the central canal provide valuable clues for intraoperative detection of spinal cord neoplasms.

Extramedullary lesions constitute a diverse group that includes neoplasms (such as meningiomas, neurofibromas, metastases, lipomas, and dermoids) and non-neoplastic lesions that produce a mass effect (such as bony fragments, herniated disks, hematomas, cysts, and abscesses). Extramedullary lesions are generally hyperechoic relative to the adjacent spinal cord and often displace or compress adjacent structures, including nerve roots (Figures 17–19).

Figure 10. Lymphoma in a 57-year-old man. These images show a pitfall of intraoperative brain sonography. A, When an end-fire transducer is placed directly on top of a gyrus, the resulting image resembles a solid hypoechoic mass (arrows). When the transducer is turned, the gyrus appears similar to those located on the deep brain surface. B, The poorly defined echogenic lymphoma is shown in the deep brain tissue, permitting a biopsy to be performed (arrows).

Figure 11. Sonography of the spinal cord performed through an intact dura in a 20-year-old man. A, In the transverse plane, the spinal cord is surrounded by an echogenic line that demarcates it from the surrounding anechoic CSF (long white arrows). The central canal appears as an echogenic focus in the center of the spinal cord (arrowhead). The transverse ligaments can be visualized as echogenic lines that extend from the dura to the adjacent vertebral bodies (black arrows). The dura appears as a thick outer echogenic structure (short white arrows). B, Note the central canal in the sagittal plane (arrows).
Figure 12. von Hippel-Lindau disease and hemangioblastoma of the cervical spine in a 45-year-old woman. A, Sagittal T1-weighted MRI obtained after administration of intravenous gadolinium shows the peripherally enhancing mass to be at the level of C5 to C7 (arrow). B, On intraoperative sonography, this sagittal image shows a complex solid and cystic mass expanding the cord (arrows).

Figure 13. Multiseptated syrinx in the thoracic cord in a 57-year-old man. Intraoperative sonography was required to localize this lesion. A, Note the echogenic dura overlying the cord (arrows). B, Before needle insertion, the dura was removed, allowing the overlying arachnoid to be identified (arrows).
Sonographically Guided Procedures in the Spine
For syringohydromyelia, preoperative MRI is used to delineate the rostrocaudal extent of the lesion, the presence and location of septa, and the presence of associated disease. During surgery, sonography is used to limit unnecessary exploration, guide syrinx drainage via catheter placement, and assist in proper fenestration and drainage of loculated cysts (Figure 20).

During tumor biopsy, sonography guides the biopsy needle to the most suitable diagnostic site for tissue sampling. It also assists the surgeon in avoiding blood vessel penetration and in identifying optimal sites for myelotomy or tumor resection. After resection, sonography is often

Figure 14. Metastatic papillary adenocarcinoma of the thyroid in a 47-year-old woman. A, Panoramic intraoperative sonography of the thoracic spine shows a fusiform focal expansion of the cord with obliteration of the central canal. B, The mass is isoechoic, poorly defined, and solid in consistency, with no cystic components, but does contain several punctate echoes suspected to be calcifications (arrows).

Figure 15. Transverse myelitis in a 31-year-old man. The patient had a 3-week history of tingling and numbness of the right hand and foot. Magnetic resonance imaging showed a spinal cord mass suggestive of a tumor. Transverse intraoperative sonography of a well-circumscribed lesion in the cervical cord shows the masseslike appearance of myelitis (arrowheads). The appearance is indistinguishable from that of a neoplasm. This inflammatory lesion appears as an echogenic intramedullary mass with an associated mass effect on the central canal and expansion of the cord. Sonography was required for lesion localization and to guide biopsy.

Figure 16. Suspected pulmonary metastases to the spine in a 48-year-old man, causing cauda equina syndrome manifested by difficulty urinating and urinary incontinence. The patient received steroids, received 2 doses of radiation for metastasis to L3, and also had vertebroplasty. Surgery was performed for urgent lumbar laminectomy and fusion. Transverse sonography below the level of the lumbar cord area shows echogenic nerve roots lying in a dependent position within the spinal canal. Nerve root prominence is probably caused by metastases. Note a blood level layered at the posterior dural surface (arrowheads).
useful in determining the adequacy of resection margins before closing. After spinal surgery, intraoperative sonography of the spine can be used to ensure alignment of vertebrae before the incision is closed and to check for the presence of swelling or inadequate decompression.

**Limitations**

The technique requires knowledge of neuroradiologic abnormalities that are not routinely evaluated by sonography. Routine implementation of this technique may be limited by difficulties distinguishing a tumor from normal tissue and lesion obscuration by chronic edema. Its role may be also diminished by the widespread use of CT stereotaxis and real-time MRI fusion images. Additionally, assisting with intraoperative guidance is a large time commitment and requires complete removal of the radiologist from other clinical duties.

**Figure 17.** Schwannoma in a 50-year-old man. Parasagittal intraoperative sonography shows an extramedullary mass (calipers) adjacent to and displacing the spinal cord. When small, these tumors are typically solid.

**Figure 18.** Schwannoma of the lumbar spine in a 16-year-old female patient. Transverse (A) and sagittal (B) images of the lumbar spinal cord show a complex solid and cystic extradural mass that has displaced the spinal cord. Sonography was required for localization and biopsy guidance.
Conclusions

Intraoperative sonography in neurosurgery is used to facilitate surgery for benign and malignant diseases. The advantages include reduced exploration and surgical time and, presumably, decreased cost. It is a safe and noninvasive technique, which may be easily adapted to the neurosurgical field.

References


