Intraoperative use of Doppler ultrasound and endoscopic monitoring in the stereotactic biopsy of malignant brain tumors

Technical note

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An intraoperative monitoring tool is described that prevents mechanical injury to intracerebral vessels during stereotactic surgery. The method, which combines pulse Doppler ultrasonography and fiberendoscopy, allowed stereotactic biopsy to be performed without serious intracranial bleeding in 25 patients with hypervascular malignant brain tumors, 13 with glioblastoma multiforme, five with anaplastic astrocytoma, five with metastatic tumor, and two with malignant lymphoma. The ultrasound apparatus has a built-in fast-Fourier transformation system analyzer and an improved filtering system that provide real-time measurement of blood flow velocity. The source of flow (arterial or venous) could be identified by both real-time sonography and acoustic signal frequencies. It was possible to measure the size and distance of a vessel by adjusting the Doppler signal gain dial from initially waxing to waning sounds, because the acoustic signal was adjusted to the axial flow of each vessel in 0.1-mm steps. Each of three Doppler probes (1 mm, 2 mm, and 3 mm in diameter) fit through the outer cannula of the biopsy needle. Vessels located within 7 mm from the tip of these probes could be detected easily and rapidly, so the biopsy needle could be advanced safely to the desired target in 7-mm steps. If sonograms revealed blood flow, indicating the presence of larger vessels in the intended stereotactic trajectory, the angle of the needle was changed slightly to avoid vascular injury. Because the fiberendoscope was connected to a video processor, the vessel could be visualized at a higher magnification on the video display, unless there was active bleeding. This technically simple and reliable system enhances operative safety while maintaining accuracy.

Key Words: stereotaxy • ultrasound • endoscopy • brain neoplasm • intraoperative monitoring • hemorrhage

In the procedures described, stereotactic surgery was guided by computerized tomography (CT) or magnetic resonance (MR) imaging, and performed with a Leksell microstereotactic system.* Three biopsy needle kits are available: a spiral-shaped device, cup forceps, and a “sedan” type. The sedan type of biopsy kit has a vacuum and side-cutting cannula. All kits are designed specifically for use with the Leksell instruments as well as with Doppler ultrasonography and fiberendoscope imaging systems.

Intraoperative Ultrasonogram Recording

Doppler Ultrasonic Apparatus

A Doppler ultrasound device† was used to detect flow in intracerebral vessels not only at biopsy sites but also along stereotactic trajectories to predetermined targets. The instrumentation and techniques have been described elsewhere.1,3 Briefly, the ultrasound signal was detected acoustically and its mean frequency displayed in real time in both analog and digital formats.

* Stereotactic system manufactured by AB Elekta Instruments, Stockholm, Sweden.

† Ultrasound device, Model MF20, manufactured by Eden Medizinische Elektronik GmbH, Ueberlingen, Germany.
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The use of a 20-MHz high-resolution system made it possible to explore microvessels as small as 0.1 mm in diameter. The incident angle of the microvascular probe was adjusted by referring to Doppler sounds both acoustically and under direct vision, so that the signal provided maximum output. A second transcranial Doppler ultrasound device was used in combination with the first; it provides information on flow patterns by superimposing a real-time display of the sound spectrogram associated with flow direction on the pulsatility index described below. Mean ultrasound signal frequency is converted into mean blood flow velocity (mm/sec) by the built-in computer. Real-time ultrasoundograms can be recorded in wave form by connecting these two Doppler devices. Furthermore, flow toward the transducer is displayed above the fiducial line while flow away from the transducer is shown below. The Doppler ultrasonic systems are compatible with the video processor, and thus all recordings can be stored and displayed at any time.

When ultrasonography is performed intraoperatively, the signal gain dial is first turned to maximum to detect vessels. Once signals are detected acoustically or on the sonographic display, the signal gain is decreased until the static background noise disappears from the sonogram, then the sonogram is recorded. Whether the blood flow is venous or arterial in origin can be determined by analyzing the spectrograms. In addition, both flow direction and pulsatility index (systolic velocity minus diastolic velocity divided by the mean-time value), which can be calculated from the spectral envelope, are displayed on the video terminal and are useful in further characterizing vessels.

Three autoclavable Doppler ultrasound microprobes (1 mm, 2 mm, and 3 mm in diameter) are available for intraoperative use. They are all adapted to the outer cannula of the biopsy needle and have adequate stability. The gate of the Doppler signal was adjusted to the axial flow of each vessel in 0.1-mm steps. The depth of the gate (axial resolution) was selected within a 7-mm range. Thus, intraoperative application of this system makes it easy to detect intracerebral vessels crossing the stereotactic trajectory before introduction of the needle and to insert the biopsy needle safely into any desired point in 7-mm steps, thereby making it possible to perform biopsies with safety and accuracy.

Microscopic Fiberimaging

A fiberimaging system was used with a thin, flexible fiberendoscope (0.9 mm in diameter) fixed to the outer cannula of the stereotactic biopsy needle. This sterilizable catheter contains 3000 optical fibers for fine imaging and bright illumination. The fiberendoscope is compatible with both the video processor and the camera system.

When a vessel crossing the stereotactic trajectory to the predetermined target or biopsy site is detected by Doppler acoustic signal or real-time sonography, the microvascular probe is removed and the fiberendoscope is placed in the cannula. Because the fiberendoscope is connected to the video processor, the vessel can be visualized at a higher magnification on the video display, unless there is active bleeding. The diameter of the vessel can thus be measured, and all recording can be stored and displayed at any time. Even if a vessel cannot be observed because of bleeding, its distance, size, and type can be evaluated by Doppler acoustic signal or sonography as described later. Because of the technical simplicity of the procedure and flexibility of the fiberendoscopic catheter, mechanical injury to brain tissue can be minimized.

Guided Stereotactic Biopsy Procedure

After the lesion is located by MR imaging or CT, the patient is moved to the operating room with headframe in place. Under local anesthesia and strict blood pressure control, a burr hole is made and the dura mater is opened. The stereotactic frame and arc are adjusted to the chosen coordinates, and the cannula with stylet is placed on the brain surface as a conduit. The stylet is then removed and replaced with the adjustable microvascular probe, which is capable of exploring for vessels, as described below. If there are no vessels, the stylet with the cannula in position is moved down to the cannula stopper (which is set 7 mm below the brain surface) and is secured in this position. If a large vessel is identified in the path by sonography, the insertion angle is changed slightly; this same procedure is repeated until the tip of the stylet with the cannula reaches a point 10 to 15 mm from the desired target point. The biopsy needle is then replaced and stereotactically advanced to the point where the tissue sample is taken. Successive serial samplings are carried out on the same trajectory at 5-mm intervals until the desired end point of the target is reached. This intraoperative monitoring method permits serial histological examinations to be carried out safely and accurately. Furthermore, biopsy specimens may be obtained along other chosen trajectories for further histological studies. This simple, noninvasive monitoring is performed at every step of needle insertion.

Vascular Ultrasonographic Features

We have conducted a preliminary study to determine how to identify the ultrasonographic features (flow pattern and flow direction on spectrograms) of various types of vessels. The real-time Doppler sonograms revealed a characteristic pattern for individual vessels, including the internal carotid artery, middle cerebral artery, sylvian vein, and jugular vein. (Fig. 1). Both characteristic flow patterns and Doppler acoustic signals were useful in intraoperatively differentiating vessels of venous or arterial origin. The pulsatility index was also of value in discriminating between intracerebral vessels of arterial and venous origin, for instance when the vessel was too small to be clearly displayed.

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‡ Ultrasound device, Model TC2-64, manufactured by Eden Medizinische Elektronik GmbH, Ueberringen, Germany.
§ Fiberingaging system, Model FV-3000, and fiberendoscope, Model AS-003, No. 63B-0293, manufactured by Mizuku, Tokyo, Japan.
on the video terminal or when sonograms were not clearly defined despite the audible Doppler sounds. In the case of arterial vessels, pulsatility index values ranged from 0.68 to 1.30 (median 0.92); on the other hand, they were higher for vessels identified as venous from intraoperative fiberendoscopic observations. Thus, when a vessel was detected acoustically but the sonogram was not clear, as shown in Fig. 2B, a venous origin was likely if the pulsatility index value was high. If the pulsatility index was about 0.9, however, the vessel was usually of arterial origin. It was often possible to measure the size of a vessel by turning the Doppler signal gain dial from initially waxing to waning sounds, because the Doppler acoustic signal was adjusted to the axial flow of each vessel in 0.1-mm steps.

As long as there was no active bleeding, fiberendoscopy played a significant role in identifying vessels detected by sonographic studies. Because the system is connected to a video processor equipped with high magnification, the size or diameter of even microvessels could be measured from the magnified display with a high level of accuracy. Furthermore, the venous or arterial origin of detected vessels could be determined, and a decision whether to advance the biopsy needle further could be made.

Considering these findings as a whole, it was concluded that ultrasonography is highly reliable, while fiberendoscopy may not be useful when there is active bleeding. Even in the presence of hemorrhaging, however, stereotactic surgery could continue because Doppler acoustic signals, real-time sonograms, and pulsatility index are all of use in evaluating vessels.

Conventional real-time ultrasonograms indicated the presence of vessels (Fig. 2). The initial flow pattern was obtained from a small vessel on the brain surface prior to needle insertion for biopsy of a garland-shaped contrast-enhanced tumor (Fig. 2A). The recording yielded a clear sonogram with flow direction toward the probe. Mean velocity was 20 mm/sec and the pulsatility index was 1.19, and the vessel was believed to be an artery. After the real-time sonograms were recorded, the microvascular probe was removed and replaced with the fiberendoscope; this device easily identified the vessel as an artery by magnifying it on the video display. As a result, the entry point on the brain surface was changed slightly to avoid vascular injury. The second vessel flow pattern detected by Doppler acoustic signal was displayed at a depth of 6 mm (Fig. 2B). The waveform was unclear, however, even after the Doppler signal gain was increased to the highest level. Mean velocity was 6 mm/sec, and the pulsatility index was 9.99. The flow appeared to be of venous origin based on both the Doppler acoustic signal and the pulsatility index. The microvascular probe was then removed and replaced with the fiberendoscope to observe the vessel on the highly magnified video image. The fiberendoscope showed a microvessel (Fig. 3), which appeared to be venous in origin, when there was

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**Fig. 1.** Doppler spectrographic sonograms demonstrating characteristic flow patterns. PI = pulsatility index; "mean" denotes mean velocity in mm/sec. Upper: Tracings from an internal carotid artery (ICA) and a middle cerebral artery (MCA), with mean velocity and flow direction toward the probes. Lower: Tracings from a sylvian vein and a jugular vein, with mean velocity and flow direction toward the probes.
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Fig. 2. Intraoperative findings of envelope signals and real-time sonograms indicating the flow pattern, mean velocity ("mean" in mm/sec), and pulsatility index (PI) of a vessel on the brain surface (A) and at depths of 6 mm (B) and 36 mm (C) from the surface. cal = calibration.

Fig. 3. Intraoperative fiberendoscopic appearance of an intracerebral microvessel crossing the stereotactic trajectory. Both Doppler acoustic signals and pulsatility index (PI) suggested a venous origin, as shown in Fig. 2B. The vessel appears to be as small as 20 μm when highly magnified on the video terminal. Calibration bar = 100 μm.

no active bleeding. Subsequently, the needle was advanced and no significant hemorrhage occurred. The third flow pattern at a depth of 36 mm was depicted as a clear sonogram with flow direction toward the probe (Fig. 2C). Mean velocity was 18 mm/sec, and the pulsatility index was 0.76. The Doppler acoustic signal, real-time sonograms, and pulsatility index all suggested arterial origin, and the fiberendoscope revealed a microvessel. The cannula was then replaced with a styllet, and the needle was withdrawn slightly and its angle of insertion was changed for safety. The same monitoring procedure was repeated at each step, and injury to the microvessel was avoided. Thus, biopsy samples were obtained safely and accurately. The operation time from headframe mounting to discharge of the patient into the recovery room was approximately 3 hours, not much longer than the time required for biopsy without the intraoperative monitoring method.

Discussion

Magnetic resonance imaging-guided stereotaxy has been widely used to define anatomical relationships between intracranial lesions and surrounding brain tissues. Despite advances in technology, however, mechanical injury to intracerebral vessels along the trajectory may occur during insertion of the needle, resulting in severe intracerebral hemorrhage. To enhance the safety of stereotactic surgery, this complication must be eliminated, because it may be followed by serious neurological deficits or fatal outcome, particularly during stereotactic biopsy of hypervascular malignant brain neoplasms. Complication rates of stereotactic biopsy of high-grade gliomas, such as glioblastoma multiforme and anaplastic astrocytoma, have been reported to be as high as 12%, in contrast to less than 2% in low-grade gliomas. Even emergency surgery cannot spare the brain such irreversible damage. It would thus be a great advantage to be able to detect vessels that, if injured, might cause life-threatening bleeding. We know of no previous noninvasive method that can identify the presence of a vessel intraoperatively.
Our intraoperative monitoring method, in particular the ultrasonic technique, is of value in preventing mechanical injury to intracerebral vessels during insertion of the needle along the stereotactic trajectory to the predetermined target and biopsy sites. Biopsy procedures in a patient with a hypervascular tumor located near a ventricle demand great caution because intracerebral bleeding may develop and penetrate the ventricle, with a fatal outcome. Although our experience is not large enough to determine if there is a statistical difference between the safety of biopsy with and without intraoperative monitoring, we have demonstrated the successful use of this technique in 25 patients with highly vascular malignant brain neoplasms, 13 with glioblastoma multiforme, five with anaplastic astrocytoma, five with metastatic tumor, and two with malignant lymphoma. We know that there is no specific evidence that the method we devised is effective; however, Doppler acoustic signals, real-time sonograms, pulsatility index, and fiberendoscopic findings can help to determine the characteristics of a specific vessel including its arterial or venous pattern, distance, and size. Doppler ultrasonography was used not only to evaluate the presence of vessels crossing the stereotactic trajectory to the predetermined targets or biopsy sites but also to determine whether the vessel was of venous or arterial origin by identifying the sonographic flow pattern and pulsatility index. In fact, real-time sonograms can detect the flow of vessels as small as 50 μm in diameter. Unless there was active bleeding, the vessel was readily identified with the aid of fiberendoscopy and its diameter could be measured. Even when fiberendoscopy was of no use because of active bleeding, the size of a detected vessel could be measured by turning the Doppler signal gain dial from initially waxing to waning sounds, because the Doppler acoustic signal was adjusted to the axial flow of each vessel in 0.1-mm steps. All recordings can be stored and displayed on the video terminal. Of course, in order to prevent life-threatening intracerebral hemorrhage, other factors such as intraoperative systemic blood pressure and clotting parameters must be identified and controlled.

The main advantages of our intraoperative monitoring method are as follows: First, enhanced operative safety can be obtained while maintaining stereotactic accuracy; thus, even a less experienced neurosurgeon can complete stereotactic biopsy of highly vascular malignant brain tumors without serious intracerebral bleeding. Second, the stereotactic frame does not need to be realigned and the microvascular Doppler probes may be withdrawn and inserted repeatedly with each change of position since they are compatible with the outer cannula of the biopsy needle. Third, intraoperative monitoring does not add much time to the procedure. Accordingly, the indications for this intraoperative monitoring method may include a large number of stereotactic neurosurgical procedures, such as tissue biopsy, positioning of a catheter in a cystic cavity for aspiration or instillation of biologically active compounds, placement of tissue grafts or electrodes for chronic electrical stimulation for functional stereotaxy to treat pain or involuntary movement and other functional neurosurgical disorders, implantation of radioactive isotopes for interstitial irradiation of malignant tumors, endoscopy-guided removal of cysts, tumors, or hematomas, and image-directed laser surgery for deep-seated intracranial lesions. This intraoperative monitoring method integrates current image-guided stereotaxis using CT or MR imaging to further enhance the safety, flexibility, reliability, and reproducibility of this neurosurgical technique.

References


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