Brain biopsy sampling by using prospective stereotaxis and a trajectory guide

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Object. The authors describe their initial results obtained using a skull-mounted trajectory guide for intraoperative magnetic resonance (MR) imaging–guided brain biopsy sampling. The device was used in conjunction with a new methodology known as prospective stereotaxis for surgical trajectory alignment.

Methods. Between January 1999 and March 2000, 38 patients underwent 40 brain biopsy procedures in which prospective stereotaxis was performed with the trajectory guide in a short-bore 1.5-tesla MR imager. In most cases, orthogonal T₂-weighted half-Fourier acquisition single-shot turbo spin–echo (HASTE) images were used to determine the desired trajectory and align the device. The surgical trajectory was defined as a line connecting three points: the target, pivot, and alignment stem points. In all cases, surgical specimens were submitted for frozen section and pathological examination. Postoperative turbofluid-attenuated inversion-recovery and gradient-echo images were obtained to exclude the presence of hemorrhage. Trajectory determination and alignment was simple and efficient, requiring less than 5 minutes. Confirmatory HASTE images were obtained along the biopsy needle as it was being advanced or after reaching the target. All biopsy procedures yielded diagnostic tissue. One patient with a lesion near the motor strip experienced a transient hemiparesis of the hand related to passage of the biopsy needle, and another sustained a fatal postoperative myocardial infarction. No patient suffered a clinically significant or radiologically visible hemorrhage.

Conclusions. In combination with prospective stereotaxis, the trajectory guide provided a safe and accurate way to perform brain biopsy procedures.

KEY WORDS • biopsy • brain neoplasm • interventional magnetic resonance imaging • stereotactic biopsy

Brain biopsy procedures have evolved over the last three decades in conjunction with the ability to image the brain directly. Beginning in the mid-1970s, biopsy sampling of lesions in the brain was performed in a freehand fashion by using CT scanning. In the early 1980s, CT scanning was incorporated into stereotactic procedures because it allowed both the precise translation of a three-dimensional database into the three-dimensional coordinate system of a stereotactic frame and the direct visualization of lesions in the brain without inferring their positions based on shift of the ventricles as seen on pneumoencephalography or ventriculography. Later in that decade, MR imaging became an important aid to neurosurgeons because of its ability to show the brain in multiple projections and its exquisite anatomical detail. This modality was immediately incorporated into stereotaxis for both brain biopsy procedures and volumetric tumor resections.

Frameless stereotactic systems have been under development and implementation since the mid-1980s. These systems require preoperative imaging that is oriented to a constant set of fiducial markers and is performed either several days or immediately before the planned operative procedure. Optical, ultrasound, or electromagnetic sensors are used to detect the movement of surgical instruments during the operative procedure. Disadvantages associated with frameless navigational systems include fiducial registration inaccuracy and the potential for brain shift with subsequent displacement of the mass that is undergoing either biopsy sampling or resection.

Most recently, MR imaging has been adapted for use in the operating room for interventional purposes. Lesions of the brain can be sampled in an interactive fashion without fear of displacing the target, which can happen with both frame-based and frameless stereotaxis. The position of the biopsy needle directly within the target can be confirmed during the procedure, which should increase the diagnostic yield compared with conventional stereotaxis. Initially, interventional MR imaging–guided brain biopsy procedures were performed in a freehand fashion without the ability to direct the passage of the biopsy needle through the brain and with no means to stabilize the needle during scanning or when tissue samples were being
obtained. We describe our initial results obtained using a skull-mounted trajectory guide to perform brain biopsy procedures with intraoperative MR imaging guidance.

Clinical Material and Methods

Patient Demographics and Lesion Characteristics

The age range for the 38 patients was 9 to 84 years, with a median age of 47 years and a mean age of 47 years. There were 28 male (74%) and 10 female (26%) patients who underwent biopsy procedures. Twenty-two lesions (55%) were located in the left hemisphere, and 18 lesions (45%) were located in the right hemisphere. Left hemispheric lesions were located in the thalamus (two cases), and frontal (17 cases), temporal (two cases), and parietal (one case) lobes. Right hemispheric lesions were in the frontal (nine cases), temporal (two cases), parietal (five cases), and occipital (two cases) lobes.

Intraoperative Configuration of the MR Imaging Suite

A fully detailed description of the intraoperative MR imaging suite at the University of Minnesota has been published previously.6,8

Brain Biopsy Procedure Guided by MR Imaging

The specific details associated with performing brain biopsy sampling in a high-field MR imaging environment by using a 1.5-tesla short-bore interventional MR imager (model ACS-NT; Philips Medical Systems, Inc., Best, The Netherlands) have been previously reported. Briefly, a general anesthetic agent was used in most patients because of the uncertain length of the procedure and the concern that patients might move their heads during intraoperative imaging while the biopsy needle was in the brain. Before imaging, two surface coils were placed on the patient’s head and the biopsy procedure was often performed through the aperture of the coil that was draped into the operative field. A marker grid was placed on the patient’s scalp during preoperative imaging to determine the optimal location for cranial penetration. After shaving and preparing the scalp, the skin was incised and the skull penetrated with a cranial perforator. The dura mater was opened, and the base of the trajectory guide was secured to the skull with three self-tapping titanium screws. A variable-diameter guide tube known as the ball stem was snapped into the base and secured in place with a thread-ed locking nut. The alignment stem was filled with saline and inserted into the guide tube to perform prospective stereotaxis in multiple MR imaging planes. After the appropriate trajectory for the biopsy needle was determined, the locking nut was tightened and the alignment stem was removed. An MR imaging-compatible titanium biopsy needle (Elekta, Decatur, GA) with a blunt tip and side-cutting opening was advanced to the target in a stepwise fashion, with periodic imaging updates. During the procedure, interactive $T_2$-weighted half-Fourier acquisition single-shot turbo spin-echo imaging in two orthogonal planes was used to demonstrate the full length of the biopsy needle within the target. Frozen section analysis was performed to confirm the presence of diagnostic tissue before leaving the operating room. While the pathologist was examining the tissue, the needle was withdrawn and the biopsy site was evaluated with turbofluid-attenuated inversion-recovery and gradient-echo imaging to exclude the presence of a clinically significant or radiographically visible hemorrhage. Once diagnostic tissue was identified, the trajectory guide was removed and the scalp was closed. Between January 1997 and December 1998, 54 brain biopsy procedures were performed using intraoperative MR imaging in a freehand manner without the use of the trajectory guide.

Trajectory Guide

A description of the trajectory guide (Navigus; Image-Guided Neurologics, Inc., Melbourne, FL) has been published.7 This device is approved by the Food and Drug Administration for brain biopsy procedures, placement of...
Brain biopsy sampling using a trajectory guide

Prospective Stereotaxis

Prospective stereotaxis is a novel method for trajectory alignment that starts at the target and then works outward toward a point on the alignment stem. This new methodology, which is adaptable to both CT and MR modalities, has recently been described in more detail.13 Once the target point is chosen, two other points in space are determined to align the trajectory guide with the desired target. The second point, known as the pivot point, is located on the ball stem at the most proximal point of the trajectory guide. The third point is located in space and corresponds to the desired position of the distal end of the alignment stem. After inserting the alignment stem into the trajectory guide, the ball joint can be freely rotated in space until all three points are colinear. Once all three points are aligned, which generally takes less than 5 minutes, CT or MR imaging can be performed along the entire length of the alignment stem to verify that the trajectory guide is indeed directed toward the target (Fig. 2). In phantom experiments, the accuracy of the device is approximately 2 mm when a lesion 7 cm away from the distal end of the alignment stem is targeted (H Liu, personal communication).

Results

Efficacy and Safety of Prospective Stereotaxis With the Trajectory Guide

All 40 biopsy procedures in these 38 patients yielded diagnostic tissue. The ability to visualize the biopsy needle within the target and the use of intraoperative frozen section analysis are greatly responsible for this diagnostic yield rate. The pathological diagnoses obtained from brain biopsy specimens included 15 cases of GBM (37%), six cases of anaplastic astrocytoma (15%), five cases of radiation necrosis (12%), four cases of oligodendroglioma (10%), three cases of anaplastic oligodendroglioma (7%), two cases of astrocytoma (5%), and one case each (3%) of ganglioglioma, lymphoma, germinoma, vasculitis, and demyelinating disease (Table 1).

After the biopsy procedure, images were obtained that excluded the presence of a radiographically visible or clinically significant hemorrhage in every case. One patient, with a lesion near the motor strip that was found to be lymphoma, experienced a transient hemiparesis of the
hand, which occurred the day after surgery and was thought to be caused by cerebral swelling from passage of the biopsy needle. Another elderly patient with a left temporal GBM suffered a fatal myocardial infarction despite preoperative clearance by a cardiologist. The overall morbidity rate based on the number of biopsy procedures was 3% and the mortality rate was 3% based on the entire patient cohort.

Discussion

Brain biopsy sampling in which CT scanning was used was performed in a freehand manner before the development of stereotactic head frames. In four series in which 344 patients underwent CT-guided freehand biopsy procedures, the diagnostic yield was 90% (range 79–97%), the mortality rate was 2.5% (range 0.5–4.7%), and the morbidity rate was 7.8% (range 2–14%). After the development of stereotaxis, it was coupled with CT scanning during brain biopsy sampling. In 17 of the largest stereotactic biopsy series, which included nearly 7500 patients, the diagnostic yield was 91% (range 80–99%), the mortality rate was 0.7% (range 0.5–2.6%), and the morbidity rate was 3.5% (range 0–13%). Reasons for diagnostic failure in stereotactic brain biopsy procedures included small sample size, inaccurate tissue targeting resulting in sampling error, target choice in areas of high signal on T2-weighted MR imaging, small target size, inability to penetrate a firm tumor with the biopsy needle, and lesion location adjacent to the ventricular system. Neurological deficits after biopsy procedures can result from either hemorrhage or increased cerebral edema, both of which have occurred with gliomas and lymphomas because of their abnormal blood vessel structure and neovascularization. The complication rates for stereotactic biopsy sampling in glioma, lymphoma, and metastasis were 6.4%, 6.3%, and 2.8%, respectively, in one series.

The introduction of MR imaging into the operating room now allows for near–real time imaging during brain biopsy procedures. In 35 such procedures performed using 1.5-tesla MR imaging, the diagnostic yield was 100% and the neurological morbidity was 3%. One patient with a brainstem anaplastic astrocytoma sustained a transient hemiparesis following the biopsy procedure and another patient developed a scalp cellulitis several weeks thereafter that was successfully treated with antibiotic medications. No patient experienced a clinically significant or radiographically visible hemorrhage during the biopsy procedure. Nevertheless, one should be cautious when comparing the results of interventional MR imaging–guided brain biopsy with stereotactic brain biopsy procedures because of the small number of patients who have undergone MR imaging–guided biopsy sampling to date.

An early issue that was recognized with interventional MR imaging–guided brain biopsy procedures was the need to guide and stabilize the biopsy needle during the procedure. To address these concerns, some institutions used an MR imaging–compatible optical triangulation system that was combined with frameless stereotaxis to plan the burr hole placement and surgical trajectory and guide the biopsy needle or other instrument in a minimally invasive manner. This combination system was found to be accurate, with a mean error of 1.5 mm. The authors of that study concluded that the positional accuracy of the system was comparable with that of conventional stereotactic systems.

Prospective stereotaxis and conventional frame-based or frameless stereotaxis require base imaging to define the target and plan the procedure. Once the entry site and target have been defined, the two techniques differ substantially. Frameless stereotaxis requires registration between physical space and image space and then orients the displayed or newly acquired image, based on the orientation of an external device. This external device is adjusted until the desired target is in view. The latter stage involves substantial computing power or the ability to control the MR imager directly with the external device.

In the case of prospective stereotaxis, manual coregistration of image space and physical space becomes unnecessary because real-time imaging demonstrates the geometry. In prospective stereotaxis intraoperative imaging is used to align the trajectory. Once aligned, orthogonal planes along the trajectory are monitored until the biopsy needle encounters the target. The two approaches are diametrically opposed. Whereas frameless stereotaxis locks the display to the orientation of an external device, prospective stereotaxis locks the display to the desired trajectory. Much like a joystick, the alignment stem brings the ball stem, through which the biopsy needle is passed, into alignment with the intended surgical trajectory. Neither additional computing power nor sophisticated scanner control is necessary with prospective stereotaxis. Moreover, because intraoperative imaging is at the core of the procedure, concerns about brain shift are greatly reduced.

The trajectory guide can be used in an intraoperative MR imaging suite by using near–real time imaging or in a standard operating room by using frameless stereotaxis with images that were previously acquired. In the first 40 brain biopsy procedures in which prospective stereotaxis and a trajectory guide were used, the alignment method was rapid and the diagnostic accuracy was 100%. The single case of neurological morbidity was believed to be more related to the tumor histological findings (that is, lymphoma) and subsequent cerebral edema than to the use of the trajectory guide. No clinically significant hemorrhages occurred during the biopsy procedure in any patient.

Conclusions

The combination of prospective stereotaxis and the trajectory guide in the era of intraoperative MR imaging represents a natural evolution in the method by which neurosurgeons perform brain biopsy procedures.

Disclosure

Drs. Hall, Maxwell, Liu, and Truwit each have a financial interest in Image-Guided Neurologics, Inc.

References

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