

Clinical Paper

Clinical Experience with Intracranial Brain Needle Biopsy Using Frameless Surgical Navigation

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ABSTRACT Interactive, image-guided frameless systems are currently used in many centers for navigation during open craniotomies. We report our experience in 34 cases of brain needle biopsy performed with a frameless stereotactic system based on an optical digitizer. Preoperative images were acquired after adhesive skin markers were placed on the patient's head. Biopsy planning was done on the computer monitor using triplanar and 3-dimensional reformatted images. All biopsies were performed under local anesthesia through a twist drill craniostomy. The biopsy guide consisted of a rigid canula stabilized by a self-retaining retractor arm attached to the reference arc placed around the patient's head in the operating room. The position of the probe tip and its ideal continuation were displayed on real-time reformatted images and compared with the previously obtained trajectory plan. The position of the probe was adjusted as necessary to align it accurately with the surgical trajectory calculated by the computer in angles and displayed on the computer images. Diagnostic tissue was obtained in all cases; the mean and standard deviation of the maximum longitudinal diameter of the lesions was 3.5 ± 1.1 cm. All patients reported minimal discomfort during the procedure; there was no operative morbidity or mortality. Our experience suggests that interactive image-guided frameless stereotactic brain needle biopsy successfully provides diagnostic tissue. *Comp Aid Surg* 3:33–39 (1998). ©1998 Wiley-Liss, Inc.

Key words: frameless stereotaxy, brain needle biopsy, image-guided surgery

INTRODUCTION

Image-guided stereotactic biopsy is frequently used to obtain neuroanatomically defined intracranial tissue.^{1,2,5,10,13,14} However, traditional frame-based stereotaxy has several disadvantages. First, most rigid frames are fixed to the skull at four points with pins, which is uncomfortable for the patient. Second, stereotactic frames may limit the surgical approach or restrict the surgical field. Third, most frame-based stereotactic systems require immediate preoperative scanning. Fourth, placement of the rigid frame for biopsy of low-temporal or

posterior fossa lesions may not be straightforward using certain systems.⁶

To overcome some of the disadvantages of conventional stereotaxy, frameless stereotactic systems are being used with increasing frequency^{1,3,9,12,14} to provide accurate intraoperative localization during open craniotomies. Several digitizing technologies have been adapted to these systems, including articulated mechanical arms and sonic, electromagnetic, and optical digitizers.¹⁰ Recent indications for closed procedures

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with frameless stereotaxy include cyst aspiration, placement of difficult shunts, and brain biopsies.^{7,8,12} This report describes our experience with a frameless stereotactic system based on an optical digitizer for a needle biopsy of the brain performed through a twist drill craniostomy in awake patients.

CLINICAL MATERIALS AND METHODS

Between November 1995 and November 1997, 34 computer-assisted frameless brain needle biopsies were performed. All biopsies were performed by the same surgeon (I.M.G.).

Surgical Planning

All biopsies were performed with the NeuroStation frameless system (Sofamor Danek, Memphis, TN), which has been described in detail elsewhere.^{3,14} Briefly, this system is based on an optical digitizer and light-emitting diodes (LEDs). Preoperative images were obtained in all patients after 6–10 self-adhesive markers (Medical Products, Baltimore, MD) were applied to the patient's head in a noncollinear fashion. Images (field of view, 34; matrix, 256×256 ; thickness, 2 mm) were transferred on digital audio tape (DAT) to the NeuroStation and reformatted by the computer in triplanar and 3-dimensional (3-D) images. Surgical planning was then performed on the computer screen using axial, coronal, sagittal, 3-D, and two different trajectory images (Fig. 1). Trajectory images are images obtained in the coronal and sagittal plane of the probe, similar to those obtained with surgical ultrasound systems. An entry point and a target point were selected in each case. The computer automatically calculates the distance between the two points and displays it on the screen. The selected trajectory appears on the triplanar images as a yellow line and on the 3-D image as a hollow yellow probe.

Operative Technique

In the operating room, the patient was positioned in the supine position (for supratentorial lesions) or in the lateral decubitus (for posterior fossa lesions). After adequate intravenous neuroleptic analgesia was administered, the scalp was anesthetized with 1% lidocaine at three points for the Mayfield head clamp holder. The rigid reference arc with LEDs was then clamped to the Mayfield head holder (Fig. 2) and connected by cable to the digitizer. Triplanar images were used to register (calibrate) the NeuroStation system. The com-

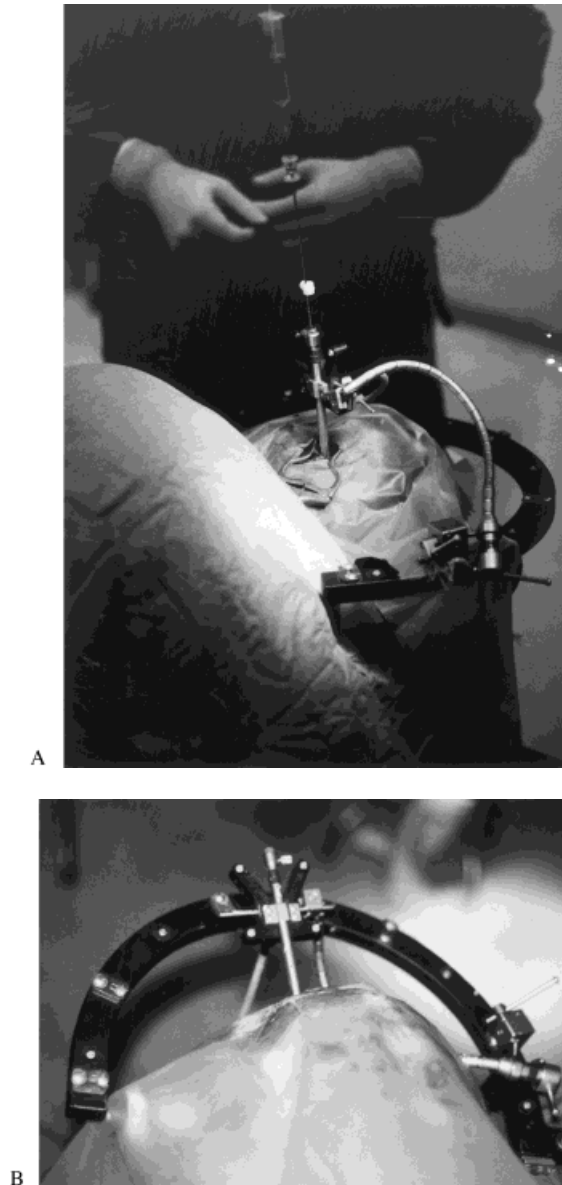


Fig. 1. A: Lateral decubitus position for a frameless stereotactic brain needle biopsy of the posterior fossa. After adequate neuroleptic analgesia was administered, the patient's head was fixed in a Mayfield head clamp holder. The rigid reference arc with light-emitting diodes was then clamped to the Mayfield head holder and connected by cable to the digitizer. The biopsy guide was stabilized with a self-retaining retractor arm attached to the reference arc. **B:** Close-up of the butterfly shaped biopsy guide and reference arc.

puter cursor was placed on the screen at the center of the first marker. The other markers were then selected in consecutive order on the screen. Each marker was then identified and touched with an LED probe connected by cable to the digitizer.

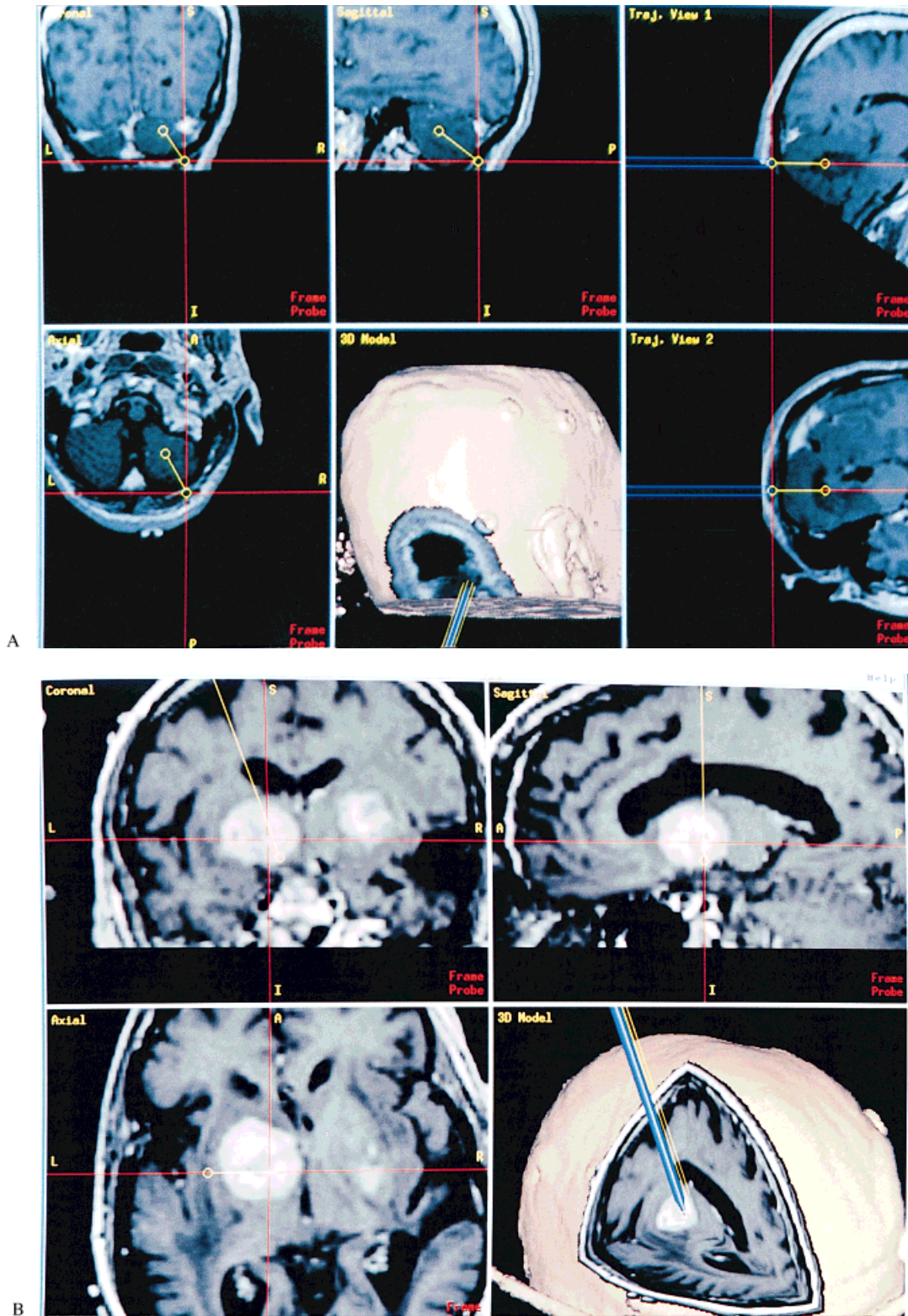


Fig. 2. A: Case 10. Photograph of the computer screen showing triplanar views, real-time, intraoperative images in six planes: axial, coronal, sagittal, 3-D, and two trajectory views (see text). The yellow cylinder is the selected trajectory to the lesion. The blue probe is the real-time image of the biopsy guide on the patient's head. This shows the planned trajectory for a posterior fossa lesion. B: Case 7. Photograph of the computer screen showing triplanar (coronal, sagittal axial) and 3-D images. The yellow cylinder is the planned trajectory for this supratentorial lesion. The blue pointer shows the actual real-time trajectory of the biopsy needle. The crossing of the red lines is the planned biopsy site.

A registration error of <2 mm was considered acceptable. After the registration was completed, the registration probe and the biopsy guide with LEDs were used as a wand on the patient's head and their position was seen in real time on the computer monitor. With the help of the intraoperative guidance provided by the frameless system, the same entry point previously selected in the surgical planning phase was then located on the patient's head with the probe.

The patient's head was then minimally shaved, prepared with betadine, and draped with a transparent drape to allow visualization of the skin markers at any given time. This allows reregistration in case the reference arc moves with respect to the patient's head.² The biopsy guide was then secured to the reference arc by a self-retaining flexible arm. The biopsy guide is a hollow, 120-mm tube with four LEDs mounted on two butterflylike wings on either side of the probe. The hollow shaft accommodates a Radionics biopsy guide restricted by a screw to 3.2 mm to accept the drill bit and to 2.0 mm to accept the biopsy needle (Fig. 1).

The position of the probe in space can be adjusted to align it accurately with the planned surgical pathway. Each time that the probe is moved, the computer displays the distances between the probe tip and the previously selected entry and target points. It also displays the degrees of deviation from the planned pathway. When the biopsy guide was satisfactorily aligned, a craniotomy was performed with a hand-held twist drill. An accuracy check was then accomplished by placing the probe in one of the skin markers previously used for registration. The position of the probe within the marker is seen in real time on the computer; furthermore, the computer calculates the difference in millimeters between the current location of the probe and that obtained at the time of registration. This difference should be <1 mm. A Nashold biopsy needle was then used to perform the biopsy. The length of the needle was calculated by adding the length of the biopsy guide (120 mm), the height of the restriction screw (5 mm), and the distance to the target displayed on the screen (variable in each case).

At the end of the procedure, error due to motion of the head with respect to the frameless system was determined by touching two of the registration markers with the probe. The computer then calculated the distance between the

Table 1. Location and Histology of 34 Biopsied Lesions

	No. cases	Percentage
Location		
Frontal	19	56
Cerebellum	7	20
Temporal	2	6
Parietal	1	
Occipital	2	
Basal ganglia	3	
Histology		
Glioblastoma	13	38
PCNS Lymphoma	7	21
Gliomas	7	21
PML	4	
Metastasis	2	
Other	1	

PCNS, primary central nervous system; PML, progressive multifocal encephalopathy.

preoperative and postoperative positions of the markers to determine the "motion error."

System Accuracy and Statistics

Although determination of the accuracy of this system was not the aim of this study, we used the imaging and operative techniques described above to perform five mock biopsies on a plastic head phantom. In each case, the biopsy needle was lowered to the target according to the measurements calculated by the computer and displayed on the screen. The distance between the tip of the needle and the phantom target was measured with a ruler.

Data are reported as mean \pm standard deviation (SD). Power analysis of this data set to determine delta (δ) as the difference in millimeters between the center of the lesion and the actual achieved result was calculated for a p value of 0.05, a $z\alpha$ of 1.96, a $z\beta$ of 1.282, and a power of 90%: $6 = \delta = \sqrt{2} (z\alpha + z\beta)\sigma^2/2N$.

RESULTS

There were 19 men and 15 women with a mean age of 52 ± 16 years (range, 5–88 years). The location and histology of the biopsied lesions is reported in Table 1; 22 biopsies were performed on the left side. The maximum longitudinal diameter of the lesions biopsied was 3.5 ± 1.1 cm (range, 1.5–6.3 cm).

Diagnostic tissue was obtained in all cases. Postoperative imaging showed that the biopsy was taken from the expected area based on intraoperative real-time images.

The accuracy of the system on the phantom

was 0.1 cm. Intraoperative motion error was 0.2 ± 0.2 cm (range, 1–8 mm). Power analysis of our data showed that the smallest δ discernible by this data set is 1.3 cm.

Illustrative Cases

Case 2

This 37-year-old right-handed man presented with a 19-year history of migraine headaches. Recently, the headaches had increased in frequency and severity and family members had noted emotional lability and subtle personality changes over the preceding 3 months. Magnetic resonance (MR) images of the brain showed an area of increased uptake in the left frontal region after administration of contrast material. Differential diagnosis included astrocytoma and lymphoma. Neurologically, the patient had mild impairment of short-term memory but he was otherwise intact. His Karnofsky score at presentation was 90. A computer-assisted frameless stereotactic needle biopsy was performed. Histologic analysis of frozen sections of the biopsy specimen revealed glioblastoma multiforme. A craniotomy for tumor resection was therefore performed. Histologic analysis of the surgical specimen corroborated the diagnosis.

Case 6

This 48-year-old right-handed man presented with gait imbalance. Neurologic examination revealed gait ataxia and left upper extremity dysmetria. MR images showed a heterogeneously enhancing lesion in the left cerebellum. Thallium-201 single photon emission computed tomography (SPECT) showed uptake in the same location, suggesting a primary central nervous system (CNS) lymphoma (Fig. 3). A computer-assisted frameless stereotactic needle biopsy was performed. The histologic findings were consistent with primary CNS lymphoma.

DISCUSSION

Conventional stereotactic brain needle biopsy has been proven to be a safe and accurate method to access the cranial vault.^{2,5} The accuracy of frameless stereotactic systems is still under investigation. Most systems have an accuracy of approximately 2 mm when used on a phantom.^{4,11} The accuracy of the NeuroStation frameless system during needle biopsies on a phantom was similar to that of other systems. During surgery, however, further error can occur. Motion error

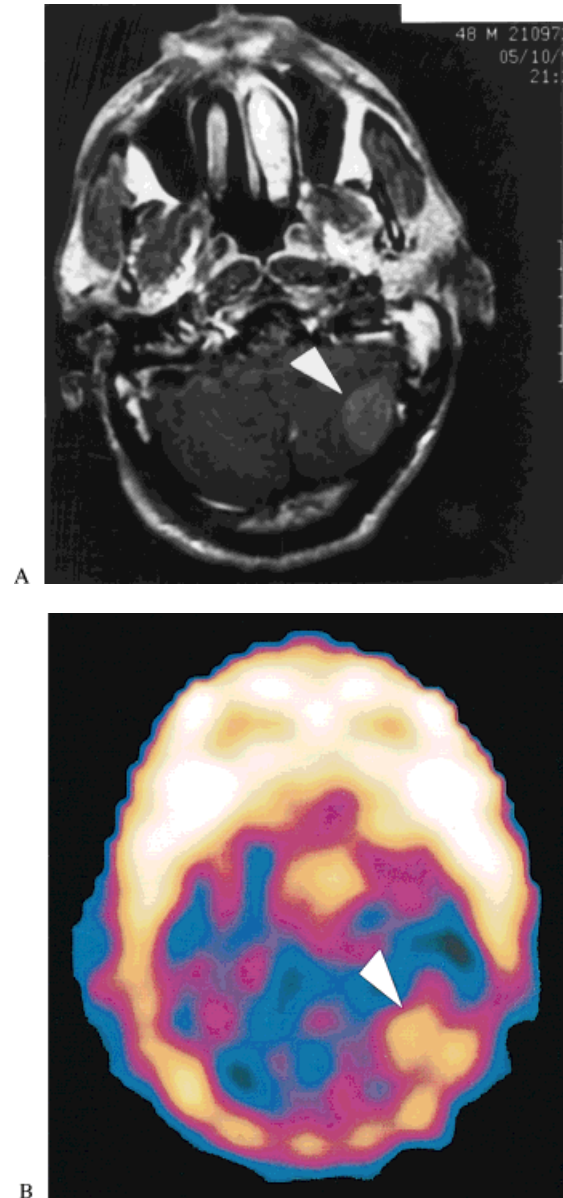


Fig. 3. Case 6. **A:** Axial magnetic resonance image of the brain showing a heterogeneously enhancing lesion in the left cerebellum (arrow head, 2-cm maximum longitudinal diameter). **B:** Thallium-201 SPECT showing increased uptake in the same area (arrow head). A frameless stereotactic brain needle biopsy confirmed the presence of a primary CNS lymphoma.

can be due to a combination of factors: head motion with respect to the frameless system, drift of the biopsy guide relative to the reference arc, or skin movement near the skin markers by insertion of the Mayfield holder.³ If head motion is detected, reregistration is possible at each given time to correct for this error. Furthermore, we

recommend that an accuracy check be performed prior to insertion of the biopsy needle as suggested earlier. Our phantom study showed a smaller error than our clinical experience. Thus, another source of error could reside in the self-adhesive skin markers. These could move on the patient's skin between the MR image acquisition and the intraoperative registration. Movement of the skin markers due to placement of the Mayfield holder can be minimized by placing the pins at least 2 cm distant from the markers. Alternatively, screw markers can be used. However, these are as invasive as the screws used to place a rigid frame. Thus, we do not use them in our clinical practice. Further movement error can be secondary to the hardware used in this study. Movement due to instability of the self-retaining flexible retractor arm used to stabilize the biopsy guide can add further error to the system. This type of retractor offers no resistance to extension due to the direction of the tension of the inner cable holding the retractor together. Therefore, the stability of this retractor cannot achieve the type of stability achieved by a rigid system. On the other hand, drilling the twist drill craniostomy with the biopsy guide activated in real time allows the surgeon to see it on the computer monitor overlapped to the previous surgical plan and to correct for possible movement. The degree of movement observed in our experience with the current system suggests that a rigid frame system should be used when considering biopsies in the diencephalon or brain stem.

The diagnostic yield of brain needle biopsies is greater than 90% in most series.^{2,5,10} In our series, all 34 biopsies were diagnostic. Our preliminary experience suggests that the diagnostic yield obtained with the optical digitizer for frameless brain needle biopsy is similar to that of conventional stereotactic techniques. However, the size of the lesion to be biopsied undoubtedly affects accuracy. Given a system accuracy of 2–3 mm, and a motion error that ranged from 1 to 8 mm, small lesions can be missed. The smallest lesion in our series had a maximal diameter of 1.5 cm. Power analysis of our data showed that the smallest δ discernible by this data set is 1.2 cm. Therefore, further advances need to be made before this system can be used in lesions < 1.5 cm in maximum diameter.

The concept of frameless biopsy is not novel. Laborde et al.⁸ used a computer-assisted mechanical arm to drain cerebral abscesses in two patients. Sandeman and colleagues performed

five biopsies using a different mechanical arm.¹² To our knowledge, this series of 34 consecutive cases is the first report of brain needle biopsy performed with the optical digitizer through a twist drill craniostomy in awake patients. The advantages of using a frameless system to perform brain needle biopsies include less discomfort for the patient and more flexibility for the surgeon in selecting the surgical approach. In our experience, application of the rigid frame after local anesthesia and intravenous sedation causes significant discomfort for most patients. The application of the Mayfield holder in the operating room under neuroleptic short-lasting analgesia was found to be comfortable by all patients in this series. Furthermore, application of the rigid frame for posterior fossa and low temporal lesion biopsy requires expertise that may not be familiar to neurosurgeons who have not performed many stereotactic biopsies. The frameless system offers the advantage that there is no limitation of the surgical space because the reference arc is not attached to the patient head.

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