Modern stereotaxic surgery is dependent upon compatible advanced imaging tools, including computerized tomography (CT) scanning and magnetic resonance (MR) imaging. The authors describe three cases in which the patients underwent stereotaxic surgery for mass lesions identified by both MR imaging and CT scans. Identical target coordinates were defined by both techniques, and accuracy was confirmed by intraoperative CT. In comparison to stereotaxic CT, MR provided superior contrast resolution, allowed direct multiplanar imaging and target determination, and permitted accurate correlation of the image with histological features. The operative set-up and technique are described. Stereotaxic surgery with MR imaging may permit more accurate histopathological definition of tumor margins and ultimately lead to better dosimetry for therapeutic procedures such as interstitial brachytherapy.

**Key Words** • stereotaxic surgery • computerized tomography • magnetic resonance imaging • radiographic technique

STEREOTAXIC techniques assisted by computerized tomography (CT) have sparked a resurgent interest in the application of guiding devices to intracranial surgery. Magnetic resonance (MR) imaging has recently been integrated with modified stereotaxic systems to define stereotaxic targets and lesions. In order to define the merits of this latter combination, we operated on three patients with brain lesions identified by both stereotaxic CT and MR imaging. This permitted us to directly compare the imaging attributes of CT and MR, as well as the results of precise histological sampling of the lesions depicted by these imaging techniques.

**Materials and Methods**

**Stereotaxic Coordinate Device**

The Leksell stereotaxic coordinate frame* was used in this investigation. This device has been modified to make it both CT- and MR-compatible. The aluminum coordinate frame has been magnetically isolated to reduce magnetic field artifacts. After the patient was suitably premedicated, the coordinate frame was applied to the head under local anesthesia in the operating room at Presbyterian-University Hospital, Pittsburgh. Skull fixation was achieved by fiberglass pins attached to the frame by plastic and aluminum chuck holders. The device is lightweight and permitted transportation of the patient without discomfort. Target determination was performed by both CT and MR techniques. During MR imaging, bilateral coordinate indicator plates with fiducial markers for coronal and axial images permitted determination of the target referable to the center of the stereotaxic device; an additional vertex coordinate plate provided fiducial markers for sagittal localization. The coordinate indicators for MR consisted of plastic tubes filled with a dilute copper sulfate-water solution (Fig. 1 left). For CT, the coordinate indicator plates are plastic with aluminum fiducial markers (Fig. 1 right).

**Stereotaxic Magnetic Resonance Imaging**

With the coordinate frame attached, patients were transported by ambulance to the Pittsburgh Nuclear Magnetic Resonance (NMR) Institute, located three blocks from the hospital. Magnetic resonance imaging was performed using a GE Signa 1.5-Tesla supercon-
MR- and CT-compatible stereotaxic system

![Image](https://via.placeholder.com/150)

**FIG. 1.**  **Left:** Photograph of the Leksell stereotaxic coordinate frame designed for magnetic resonance (MR) imaging. The target coordinates are obtained by imaging fiducial markers on the coordinate indicator plates (tubes filled with a dilute copper sulfate-water solution). Coronal and axial coordinates are determined using the indicators on the side of the frame. Sagittal MR requires a vertex coordinate plate to determine coordinates.  **Right:** The same stereotaxic device is compatible for computerized tomography scanning by substituting the MR coordinate indicator plates for plates with aluminum fiducial markers.

ducting magnet system.† The patient and stereotaxic frame were placed in the head radiofrequency coil. The MR imaging was performed perpendicular or parallel to the coordinate frame base. The frame was attached by plastic feet to a specially constructed plastic MR adaptor that rests within the head coil. A rapid T₁ (spin-lattice)-weighted spin-echo image was obtained in either axial or coronal planes to locate the target. Additional T₂ (spin-spin)-weighted images were then obtained in multiple planes with 5-mm scan thickness. Stereotaxic coordinates of the target were obtained using the standard computer software of the MR scanner. With the Leksell system, the target location was determined referable to the frame center; these measurements were obtained using “deposit cursor” and “measure distance” functions on the computer console. After completion of the MR imaging, the patient was returned by ambulance to the stereotaxic operating room at Presbyterian-University Hospital.

**Stereotaxic Computerized Tomography Imaging**

Computerized tomography scanning was performed with a dedicated GE 8800 CT/T scanner‡ in our operating room. The plastic footplates on the coordinate frame were replaced by steel footplates that anchored the frame to a magnetic adaptor for CT imaging. Serial axial 5-mm thick CT images were obtained after intravenous infusion of contrast material. Target coordinates were obtained as reported elsewhere. The CT target coordinates initially were checked by comparing these results to the coordinates derived from a specially constructed computer software program using the Leksell system coupled with a GE 8800 CT/T scanner (LD Lunsford, et al., in preparation, 1986).

**Surgical Procedure**

With the patient on the CT operating room table, twist drill trephination of the skull was completed under local anesthesia. Biopsy and/or aspiration of the lesion identified by MR imaging and CT scanning were performed. Serial biopsy samples were taken along a predetermined trajectory of 30 to 40 mm using a 10-mm corkscrew spiral. Repeat CT imaging was performed immediately to verify target accuracy and to assess operative results. The tissue samples were fixed in 10% buffered formaldehyde for embedding in paraffin. The samples were stained with hematoxylin and eosin or any other special stain if indicated and reviewed by light microscopy the day after surgery. The tissue samples were correlated serially with the site of the biopsies depicted on MR images and CT scans.

**Results**

No complications of either imaging or surgery occurred. The lightweight coordinate frame was well tolerated by the patients during transportation between the imaging centers and the operating room. Multiplanar MR imaging lasted approximately 1 hour, and CT imaging required approximately 15 minutes. Target coordinates determined by axial CT and axial MR were

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† GE Signa magnet system manufactured by General Electric Medical Systems, Milwaukee, Wisconsin.
‡ GE 8800 CT/T scanner manufactured by General Electric Medical System, Milwaukee, Wisconsin.
virtually identical, varying by millimeters only in the choice of the actual target site selected by each technique (Table 1). Targets were determined easily using coronal MR images. Coordinates could be obtained from the sagittal MR image by knowing the distance of the vertex fiducial indicators from the center of the frame (100 mm).

Stereotaxic MR images were virtually artifact-free. The frame itself, the skeletal fixation pins, and the pin holders have no NMR signal and therefore were not visualized on the images. The coordinate indicators (fiducial markers) were visualized best on T2 spin-echo images, but were seen satisfactorily with T1 images as well. With the GE 1.5-Tesla MR unit, a 24-cm reconstruction field was necessary to visualize the coordinate indicators. Proper positioning of the patient within the radiofrequency head coil was mandatory to permit visualization of the entire brain and to prevent "wrap-around" artifacts.

A histological diagnosis was obtained in all three patients we studied. Serial sampling of the lesion allowed direct comparison of CT scans and MR images with the histological features. The three cases are reported briefly to contrast the differences between CT scans and MR stereotaxic images as well as the result of stereotaxic biopsy.

**Case Reports**

**Case 1**

This 38-year-old right-handed white woman presented after she had suffered two major motor seizures 6 months apart. No neurological deficit was detected. Computerized tomography disclosed a non-enhancing mass with low attenuation in the right frontoparietal area (Fig. 2 left). Stereotaxic MR imaging (Fig. 2 right) defined a much larger area of increased signal on a T2-weighted image. Target coordinates of the lesion varied less than 2 mm in all dimensions between the CT and MR images. Serial 10-mm biopsy specimens were obtained via a parietal parasagittal approach to the target through the entire lesion depicted by CT (Fig. 3 left). A well-differentiated astrocytoma was present in every specimen (Fig. 3 right).
MR- and CT-compatible stereotaxic system

Fig. 3. Case 1. Left: Reformatted coronal stereotaxic computerized tomography scan of a right parietal mass demonstrating the probe trajectory and sites of 10-mm histological biopsies (a–c). Right: Photomicrographs (A–C) corresponding to biopsy sites (a–c) shown at left show a well-differentiated astrocytoma in all specimens. No evidence of anaplasia was found. H & E, × 125.

Case 2

This 67-year-old right-handed man was evaluated for a progressive left hemiparesis and right cortical sensory loss. Computerized tomography disclosed a densely contrast-enhancing mass in the right parietal region, surrounded by an area of reduced attenuation. Angiography revealed a very vascular mass, early-draining veins, and extensive neovascularity. Reformatted stereotaxic CT images were compared to direct sagittal MR scans (Fig. 4). Axial CT scans and MR images were used to compare the sites of histological sampling, which was performed via a right parietal stereotaxic approach (Fig. 5). Histopathological features of the specimen disclosed a well-differentiated astrocytoma in the area of low attenuation seen on the CT scans and a reduced signal on the MR images. Glioblastoma multiforme corresponded to the high T2 signal with MR and to the contrast-enhancing portion noted on the CT image.

Case 3

This 49-year-old right-handed woman presented with a 2-week history of left-sided weakness of rapid onset. Initially she had a left foot-drop, followed within 5 days by subtle left arm weakness and cortical sensory loss. A CT scan disclosed a highly attenuated right parietal parasagittal mass that changed minimally with contrast enhancement and was surrounded by an area of reduced attenuation (Fig. 6 left). Angiography demonstrated an intra-axial avascular mass. Stereotaxic MR imaging suggested a primary intracerebral hematoma (Fig. 6 center). The presence of multiple areas with different MR signals suggested a “layering” effect within the lesion and either surrounding edema or neoplasm (Fig. 6 right). Nine milliliters of blood was evacuated by stereotaxic technique. More recent hemorrhage was noted in the superior aspect of the lesion, whereas the inferior portion of the lesion proved to be dark altered blood. Biopsy of the high-signal area on MR disclosed edematous brain.

Histopathological Correlation

Serial sampling of the area of low attenuation seen on CT scans in Case 1, which corresponded to an area of greatly increased MR signal, disclosed a well-differentiated astrocytoma in all biopsy specimens; no areas of abnormal central nervous system tissue or reactive astrocytosis were detected in this lesion, which extended to the cortical surface of the parietal region. A low-attenuation area on CT, corresponding with an area of
FIG. 4. Case 2. Left: Reformatted parasagittal stereotaxic computerized tomography scan obtained after contrast infusion demonstrating a deep right parietal mass. Right: Direct sagittal spin-echo stereotaxic magnetic resonance (MR) scan (TR = 2000, TE = 40) showing dramatic definition of the mass and neoplastic vessels within the tumor. The most inferior aspect of the biopsy trajectory is demonstrated by the cross. An area of abnormal MR signal can be seen posterior and inferior to the lesion. The trajectory can be varied to avoid large tumor vessels demonstrated by MR.

### TABLE 2

**Comparison of MR and CT for stereotaxic imaging***

<table>
<thead>
<tr>
<th>Stereotaxic MR</th>
<th>Stereotaxic CT</th>
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<tbody>
<tr>
<td>superior contrast resolution</td>
<td>superior spatial resolution (0.8 mm)</td>
</tr>
<tr>
<td>direct multiplanar imaging and target determination</td>
<td>direct axial imaging; multiplanar reformatted imaging</td>
</tr>
<tr>
<td>artifact-free (modified coordinate frame has no MR signal)</td>
<td>artifact created by skull fixation pins and any metal in image</td>
</tr>
<tr>
<td>lesion depiction by varying $T_1$ and $T_2$ relaxation times in spin-echo sequence</td>
<td>lesion enhancement by intravenous contrast infusion</td>
</tr>
<tr>
<td>imaging time of approximately 1 hour</td>
<td>imaging time of less than 20 min</td>
</tr>
<tr>
<td>impractical for intraoperative imaging at present (1.5-Tesla magnetic field strength)</td>
<td>excellent tool for intraoperative imaging</td>
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<tr>
<td>no ionizing radiation</td>
<td>ionizing radiation</td>
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*MR = magnetic resonance; CT = computerized tomography.

...nners has greatly expanded the use of stereotaxic surgery both for morphological brain lesions such as tumors, abscesses, and hematomas and for functional neurosurgical intervention for pain, epilepsy, and movement disorders. For example, diagnostic brain biopsy with the CT stereotaxic technique has reduced mortality to less than 1% in recent series and achieved a diagnostic accuracy rate as high as 96%. Magnetic resonance offers the possibility of superior brain imaging for a variety of structural and anatomical targets in the brain. Image acquisition by MR is significantly more complex than with CT and is related to the MR signal of specific nuclei, the strength of the external magnetic fields, and the $T_1$ and $T_2$ relaxation times of the tissues being imaged. The use of a 1.5-Tesla MR imaging unit, as was available for this study, has been suggested as a means to greatly improve the signal-to-noise ratio relative to magnets of lesser field strength.

The development of MR stereotaxic surgery has awaited modification of stereotaxic coordinate frames to make them suitable for strong magnetic fields. The Leksell stereotaxic device used in this study was designed for both CT and MR. The coordinate frame was isolated magnetically to reduce eddy currents. The aluminum coordinate indicator plates used for target determination during CT scanning were replaced for MR imaging by plastic plates containing tubes filled with a dilute copper sulfate-water solution. These fiducial markers are seen well on both $T_1$- and $T_2$-weighted images. Addition of a vertex indicator plate to the coordinate indicator frame permitted target determination from sagittal MR images. Direct comparison of MR- and CT-derived coordinates then became possible.

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This preliminary study confirmed that, in comparison to CT scanning, stereotaxic MR imaging had significant advantages and relatively few disadvantages (Table 2). The MR multiplanar images were greatly superior to CT scans and provided much better morphological detail. The MR images were virtually artifact-free, and tissue differentiation could be augmented by changing the T1 and T2 image weighting during a spin-echo sequence. Stereotaxic MR imaging, especially with T2-weighted images in multiple planes, took considerably longer to perform than did stereotaxic CT scanning, even when multiplanar reformatted CT imaging was added to the imaging sequence. Because of the strong magnetic fields and the expense of the MR equipment in comparison to CT scanners and the lack of compatible surgical instruments, intraoperative stereotaxic MR imaging is as yet impractical as an alternative to CT.

The ability to use the Leksell stereotaxic device in both CT and MR scanners permitted assessment of comparable imaging sequences. It was possible to compare directly the size of lesions as determined by both techniques and to evaluate the importance of various T1 and T2 weightings in defining tumor margins. With this precise operative technique, the actual histological nature of reduced-attenuation areas on CT scans could be determined and related to the specific MR appearance. Histological studies of biopsy specimens obtained from specific areas seen on both CT and MR images were possible. The data from these preliminary cases indicate that, despite differences in signals for various components of the lesion, differentiation of edema from tumor itself is as yet very unreliable with both CT and MR.

It is now possible to perform MR- and CT-assisted surgery on the same patient using a standard stereotaxic device adapted to both systems. Despite the promise of MR to provide more specific information regarding tumor morphology and biology, as yet a direct comparison between CT and MR imaging followed by histological confirmation obtained by stereotaxic surgery has not been accomplished in a large series of
FIG. 6. Case 3. Left: Stereotaxic axial computerized tomography scan disclosing a right parietal mass with increased attenuation and surrounding low density and minimal intravenous contrast enhancement. Center: Stereotaxic axial magnetic resonance (MR) scan (T2-weighted image; TR = 2500, TE = 30) showing a graphic MR signal. The frame center is identified and the distance from frame center to the target is displayed (the X coordinate). Right: Stereotaxic coronal MR image (T1-weighted image; TR = 600, TE = 25) precisely depicting the lesion and suggesting a hematoma with “layering” in the lesion.

patients. Such a study is now under way at our institution.

It is likely that stereotaxic MR also will prove superior to CT for many therapeutic stereotaxic procedures such as interstitial brachytherapy, where CT-derived dosimetry probably provides insufficient depiction of actual tumor boundaries. As seen in the present study, multiple morphological lesions, including those not visualized at all by CT, can be biopsied using MR-assisted stereotaxic techniques. We believe that, despite major advances in brain imaging, histological investigation of tissue samples remains mandatory to reach an accurate diagnosis, to confirm tumor boundaries, and to study tumor biology.

Acknowledgments

The authors thank Dr. G. Rao for providing useful suggestions, Phyllis Shoemaker for assistance in preparing the manuscript, and Jean Stalmac, Frank Taormina, and the staff of the NMR Institute for help with the imaging and surgical procedures.

References


Manuscript received July 19, 1985.
Accepted in final form December 2, 1985.
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