Interactive magnetic resonance imaging–guided management of intracranial cystic lesions by using an open magnetic resonance imaging system

Spyros S. Kollias, M.D., and René L. Bernays, M.D.
Institute of Neuroradiology and Department of Neurosurgery, University Hospital of Zurich, Switzerland

Object. The authors present their experience with neurosurgical procedures requiring real-time imaging feedback such as aspiration of a cystic structure or abscess cavity, decompression of hydrocephalic ventricles, management of arachnoid cysts, and installation of permanent or temporary drainage conduits, in which interactive magnetic resonance (MR) imaging guidance was used to monitor structural alterations associated with the procedure.

Methods. Drainage of eight intraparenchymal brain abscesses in seven patients, decompression of space-occupying cysts or necrotic brain tumors in four patients, and endoscopic management of hydrocephalus associated with arachnoid cysts in three patients were performed using MR imaging–guided frameless stereotaxy in an open-configuration 0.5-tesla superconducting MR imaging system.

Intraoperative MR imaging guidance provided accurate information on the course of the surgical procedure and associated intraoperative changes in tissue position, such as the degree of cyst aspiration, the presence or absence of hemorrhage or induced swelling, and changes associated with decompression of adjacent brain parenchyma and the ventricular system. No clinically significant complications were encountered in any patient. There were no targeting errors, and procedural objectives were accomplished in all cases.

Conclusions. Drainage of brain abscesses, punctures of cystic or necrotic intracranial lesions with subsequent aspiration, and management of hydrocephalus can be performed safely and accurately by monitoring the procedure using real-time MR imaging to obtain immediate feedback on associated dynamic tissue changes.

Keywords • intraoperative magnetic resonance imaging • cystic tumor • frameless stereotaxy • brain abscess

During the past decade, the emergence of stereotactic concepts and the development of sophisticated frame-based and frameless devices for imaging-guided surgery have been coupled with major advances in neuroradiological imaging and computing technology. This has led to increased surgical precision and reduction of trauma to normal tissues, thus improving the results of neurosurgical procedures. Over the last 5 years, various types of open-configuration MR imaging systems have been developed, which allow direct surgical access to the patient during imaging and which have advanced the application of MR imaging technology to interactive imaging–guided neurosurgery. Feasibility studies based on the use of these systems have been reported by various groups, including ours, in connection with biopsy sampling, resection of malignant and benign brain tumors, transspheoidial surgery, interstitial hyperthermia, drainage of intracranial cysts and hemorrhage, and spinal surgery.

The temporal resolution requirements for intraoperative image updates depend on the procedure being performed. Whereas online images acquired at frequent intervals are sufficient for obtaining feedback on the progress of a volumetric procedure (for example, tumor resection), real-time image updating is necessary for guiding brain biopsy procedures and monitoring volume changes associated with aspiration of an intracranial cystic or necrotic lesion. In this context, we present our experience with neurosurgical procedures requiring real-time imaging feedback, which were performed in a selected group of patients harboring primarily cystic lesions. The procedure included aspiration of cystic or necrotic tumor or abscess, decompression of hydrocephalic ventricles, management of arachnoid cysts, and installation of permanent or temporary drainage conduits. Interactive MR imaging guidance was used to monitor structural alterations associated with each procedure. The experience we had previously gained from performing interactive MR imaging–guided biopsies of brain tumors formed the basis for our belief that aspiration procedures would be performed safely, fast, and effectively under MR imaging guidance and that real-time imaging would improve our understanding of structural changes associated with puncture and drainage of these lesions.

Abbreviations used in this paper: CSF = cerebrospinal fluid; CT = computed tomography; DTPA = diethylenetriamine pentaacetic acid; Gd = gadolinium; LED = light-emitting diode; MR = magnetic resonance; NEX = number of excitations; SPGR = spoiled gradient.
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Clinical Material and Methods

Patient Population

During a period of 3 years, 14 patients (11 male and three female patients aged 3 months–78 years) who harbored a cystic or necrotic space-occupying, intracranial lesion that was identified on CT or MR images and required neurosurgical treatment were enrolled in this study. The patients agreed to undergo MR imaging–guided, frameless, stereotactic tissue retrieval for histological and microbiological tissue assay, decompression and drainage, or installation of a permanent or temporary drainage conduit (Table 1). These patients were referred to the neurosurgical department of our hospital for further evaluation and treatment planning. Clinical and neuroradiological examinations revealed seven patients with intraparenchymal abscesses who were selected on the basis of the following criteria: 1) the abscess was located deep inside the brain and difficult to access by surgery; 2) the abscess enlarged after 2 weeks of antibiotic medication or failed to shrink after 3 to 4 weeks of this medical therapy; or 3) the abscess was located in a critical area of the brain or caused significant mass effect. In six of these patients MR imaging–guided aspiration was the only modality used. One patient underwent a craniotomy and drainage procedure; after fluid reaccumulated in the abscess, it was treated stereotactically in the open MR imaging system. In another patient two abscesses were treated during two different sessions. Four patients with intraparenchymal necrotic or cystic neoplastic lesions in whom aspiration biopsy sampling was performed for histological diagnosis and palliative decompression and three patients with intracranial arachnoid cysts were also included. Permission was obtained from our hospital’s human research committee before initiation of this prospective study.

Magnetic Resonance Imaging–Guided Procedure and Surgical Setup

Interventional MR Imaging System and Data Acquisition.

All procedures were performed using an open-configuration 0.5-tesla superconducting MR imaging system (Signa Advantage SP; General Electric Medical Systems, Milwaukee, WI), which was housed in a sterile procedure room with an MR-compatible respirator (Servo 9000 C; Siemens, Erlangen, Germany) and anesthesia monitoring equipment (Maglife LF ODA; Bruker, Wissembourg, France). Imaging is achieved by using either a standard

Table 1

Clinical characteristics of 14 patients who underwent the MR imaging–guided procedure*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Sex</th>
<th>Age (yrs)</th>
<th>Diagnosis</th>
<th>Lesion Location</th>
<th>Lesion Size (cm)</th>
<th>Symptoms</th>
<th>Procedure</th>
<th>Op Duration (hrs)</th>
<th>Postop Outcome/Follow Up (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>50</td>
<td>abscess, Streptococcus milleri</td>
<td>rt temporal</td>
<td>4x4x5</td>
<td>headache, dysarthria, seizures, lt hand weakness</td>
<td>evacuation, insertion of drainage catheter</td>
<td>1:30</td>
<td>no focal deficits/24 mos</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>70</td>
<td>abscess, Gram-negative</td>
<td>lt basal ganglia</td>
<td>4x2x5</td>
<td>headache, chronic sinusitis, motor aphasia</td>
<td>evacuation, insertion of drainage catheter</td>
<td>2:00</td>
<td>developed new abscess 2 days postop</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>40</td>
<td>abscess, S. constellatus species</td>
<td>lt occipital</td>
<td>5x3x3</td>
<td>headache, visual problems, rt leg weakness</td>
<td>evacuation, insertion of drainage catheter</td>
<td>1:40</td>
<td>neurologically normal/30 mos</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>73</td>
<td>abscess, Neococida</td>
<td>rt frontal</td>
<td>3x3x3</td>
<td>fever, headache, seizures</td>
<td>evacuation, insertion of drainage catheter</td>
<td>1:30</td>
<td>no focal deficits/17 mos</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>66</td>
<td>abscess, Gram-negative</td>
<td>rt frontal</td>
<td>3x2x3</td>
<td>lt hemiparesis</td>
<td>evacuation, insertion of drainage catheter</td>
<td>1:10</td>
<td>neurologically normal/14 mos</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>10</td>
<td>abscess, S. milleri</td>
<td>lt frontal</td>
<td>5x5x4</td>
<td>headache, sinuistis, odonto- genic granuloma, rt facial paresis</td>
<td>evacuation, insertion of drainage catheter</td>
<td>0:45</td>
<td>neurologically normal/6 mos</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>35</td>
<td>abscess, cysticercosis</td>
<td>rt frontoparietal</td>
<td>5x5x5</td>
<td>lt hemiparesis</td>
<td>aspiration &amp; biopsy</td>
<td>1:00</td>
<td>neurologically normal/10 mos</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>46</td>
<td>oligodendroglioma (WHO Grade III)</td>
<td>lt frontal</td>
<td>7x4x5</td>
<td>frontal syndrome, rt hemiparesis</td>
<td>aspiration of necrotic portion &amp; biopsy</td>
<td>3:30</td>
<td>clinical improvement, tumor excision/42 mos</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>40</td>
<td>astrocytoma (WHO Grade III)</td>
<td>rt frontal</td>
<td>3x2x2</td>
<td>lt hemiparesis, seizure</td>
<td>aspiration of necrotic portion &amp; biopsy</td>
<td>1:00</td>
<td>clinical improvement/16 mos</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>33</td>
<td>oligoastrocytoma (WHO Grade III)</td>
<td>lt fronto-temporal</td>
<td>7x8x5</td>
<td>rt hemiparesis</td>
<td>aspiration of cystic portion &amp; biopsy</td>
<td>1:00</td>
<td>clinical improvement, tumor excision/23 mos</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>78</td>
<td>ependymal cyst</td>
<td>lt precentral suprassellar</td>
<td>4x4x4</td>
<td>lt leg weakness</td>
<td>endoscopic aspiration &amp; ventricular fenestration &amp; insertion of cystoperitoneal shunt</td>
<td>0:45</td>
<td>neurologically normal/10 mos</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>60</td>
<td>arachnoid cyst</td>
<td>suprasellar</td>
<td>2x3x3</td>
<td>frontal syndrome</td>
<td>endoscopic aspiration &amp; ventricular fenestration &amp; insertion of cystoperitoneal shunt</td>
<td>3:50</td>
<td>neurologically normal/21 mos</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>40</td>
<td>arachnoid cyst</td>
<td>rt fronto-temporal</td>
<td>10x6x6</td>
<td>rt leg &amp; hand weakness</td>
<td>insertion of cystoperitoneal shunt</td>
<td>0:45</td>
<td>neurological improvement/10 mos</td>
</tr>
<tr>
<td>14</td>
<td>F</td>
<td>0.3</td>
<td>arachnoid cyst</td>
<td>infratentorial</td>
<td>8x8x5</td>
<td>hydrocephalus</td>
<td>endoscopic fenestration of septa &amp; insertion of ventricular catheter</td>
<td>2:25</td>
<td>neurological improvement/14 mos</td>
</tr>
</tbody>
</table>

* Two abscesses were evacuated in two different sessions in the patient in Case 2. Abbreviation: WHO = World Health Organization.
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mode, as with a conventional imager, or an interactive mode, in which case it is used as a frameless stereotactic device that allows interactive selection and control of the location and orientation of the imaging plane. \(^\text{3,8,16,25,30}\)

A flexible transmit–receive surface coil, wrapped in a sterile fashion, was applied around the patient’s head to encompass the operative site and to accommodate a modified Mayfield clamp (Ohio Medical Instruments, Cincinnati, OH), which was attached to the operating table. All but one patient received a general endotracheal anesthetic administered by an anesthesiology team trained to work in the interventional MR imaging suite. A local anesthetic was used in one patient.

Drainage of cystic lesions, similar to biopsy procedures, requires continuous monitoring; therefore, the highest possible spatial resolution and image quality should be adjusted to nearly real-time update frames of images during the interactive procedure. The intraprocedural imaging protocol used in this study was previously described by our group for MR imaging–guided biopsy sampling of brain tumors\(^\text{4,13}\) and included: 1) baseline, noninteractive imaging performed using a T1-weighted three-dimensional radiofrequency-fast SPGR sequence (TR 17 msec; TE 7.3 msec; flip angle 45°; slice thickness 3 mm; NEX 2; 28 slices covering the area of interest) and T2-weighted fast–spin echo sequence (TR 3500 msec; TE 114 msec; slice thickness 4 mm, 1-mm gap; NEX 2); 2) interactive imaging performed using a T1-weighted two-dimensional radiofrequency-SPGR sequence (TR 40 msec; TE 9.4 msec; flip angle 50°; slice thickness 5 mm; NEX 1), which provided image-update frames every 3 seconds; and 3) control T1- and T2-weighted images obtained at the end of the procedure by using the same protocol as that performed for baseline imaging.

Using this system, a temporal resolution of 1 second can be easily achieved. Spatial accuracy and image quality are of paramount importance in neurosurgical interventions, and we preferred to compromise the temporal resolution slightly to achieve a better signal that would permit execution of an accurate and safe procedure.

Neurosurgical Procedure. For aspiration of abscesses and cystic and necrotic tumors, we adapted a neuro biopsy needle probe (a three-point LED guide) without the attached needle to a custom-made, real-time trajectory-planning device (pathfinder) that simulates the 35° moving angle of the instrument guide and marks the skin for accurate burr-hole positioning. We determined the optimal entry point and trajectory to the lesion by showing a trajectory projecting into the lesion on three orthogonal planes. The process of trajectory planning was significantly accelerated by using the “fast needle graphics” option, which allows the scanner to acquire data continuously (<10 updates/second) and display them on a previously selected plane or on the last image that was acquired using the interactive sequence. After selecting the appropriate trajectory, the patient’s skin was marked and a 15-mm burr hole was made. The dura mater was opened and a previously described custom-made Snapper-Stereoguide was inserted and tightly affixed to the burr hole. The three-point LED probe was attached to the instrument guide, the previously planned trajectory was verified, and an artifact-free biopsy needle, which had been custom made from carbon fiber–reinforced polyether-etherketone, was advanced along the planned pathway with the aid of continuous imaging monitoring. Drainage was continued until outflow of purulent or necrotic material ceased. In patients harboring abscesses, after aspiration, the abscess cavity was rinsed with antibiotic solution and a temporary drainage catheter was inserted when considered necessary. The aspirate was sent to the laboratory for microbiological analysis and antibacterial sensitivity tests. In patients with cystic or necrotic tumors, biopsy specimens were obtained from the periphery of the lesion and sent for histological grading. In patients with arachnoid cysts, diluted (1:100) Gd-DTPA (Magnevist; Schering AG, Berlin, Germany) was injected into the cyst through an angiocatheter (Schneider; Boston Scientific Corp., Quincy, MA), which had a diameter of 2.2 mm, a shaft size diameter of 37 French, and a balloon of 2 × 20 mm, to outline its cavity and demonstrate the presence of septations. Through the same catheter an obturator was inserted, creating a fenestration between localized collections or between the cyst and the subarchnoid space and/or the ventricular system. In these last patients a rigid MR-compatible endoscope with 0° and 30° optics (Olympus; Winter and IBE, Hamburg, Germany) was inserted through the Snapper Stereoguide for visualization of the internal architecture of the cysts.

Before the patient was removed from the magnet, the system was switched back to standard imaging mode and control T1- and T2-weighted images were obtained to determine the presence or absence of hemorrhage, the alteration in the size of the intracranial mass, or other change. Unenhanced and contrast-enhanced CT monitoring was performed within 24 hours and, in the absence of clinical signs, again after 1, 2, and 6 weeks to evaluate changes and to detect possible lesion recurrence.

Results

The pathological diagnosis, presence of infectious agents identified in aspirates of abscess cavities, location and size of the lesions, clinical symptomatology, type and duration of the MR imaging–guided procedure, and postoperative outcomes are listed in Table 1.

Intraoperative MR imaging guidance allowed advancement of the aspiration needle to the chosen target on the first pass in each of the 12 consecutive aspiration procedures and successful navigation of the endoscope in the three cases of arachnoidal cysts. The T1-weighted sequence used for interactive imaging provided good visualization of the enhancing lesions and a clear distinction between the cystic or necrotic elements and solid components. The biopsy needle and the endoscope were identified clearly as linear signal voids with their actual diameter (4 mm). By selecting multiple viewing planes (at least two perpendicular planes) for a given probe position, the biopsy needle and endoscope were navigated intracranially with safety and certainty to the target lesion. The temporal resolution of the interactive sequence provided a nearly immediate image feedback (every 3 seconds) without disrupting or slowing down the interventional procedure. Associated intraoperative changes in tissue position,

\(^*\)
such as the degree of cyst aspiration, the presence or absence of hemorrhage or induced swelling, the accuracy of the biopsy site in cases of necrotic or cystic tumors, and changes associated with decompression of adjacent brain parenchyma and the ventricular system were clearly demonstrated. Significant degrees of tissue shift were observed in all patients with intraparenchymal abscesses. Deflection of the abscess wall caused by pressure from the needle before the wall’s actual perforation ranged from 8 to 17 mm (mean 1.1 mm) as measured on two-dimensional images along the needle trajectory (Fig. 1). Shifts of the ventricular system (manifesting as a reexpansion of the compressed ventricle adjacent to the abscess) ranged from 3 to 8 mm (mean 3.5 mm). Shifts of midline structures, which were measured immediately after the procedure, were less pronounced and ranged from none to 4 mm (mean 1.8 mm). The aspiration needle was guided to the center of the ring-enhancing lesion, and the abscesses were slowly and gently aspirated under continuous imaging monitoring to observe the progressive collapse of the abscess walls (Fig. 1). Complete evacuation of purulent material was achieved in all cases, as demonstrated interactively by MR imaging. In one patient, 2 days after evacuation of a deeply located temporal abscess, a new lesion...
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developed in an adjacent anterior location. The lesion, which had not been present at the time of the first procedure, was also treated successfully under MR imaging guidance. In three cases, a ventriculostomy catheter with added enlarged draining holes was inserted through the burr hole, at the end of the aspiration procedure, and was attached to a closed external drainage system placed beside the patient. Control T1- and T2-weighted images obtained in these cases demonstrated the accurate placement of the catheter in the drained residual abscess cavity (Fig. 1). It was left in place for 1, 4, and 6 days, respectively, and the decision to remove it was based on the amount of drainage and the appearance of the abscess on follow-up CT scans. After prolonged antimicrobial therapy (3–8 weeks), the results of clinical and CT evaluations confirmed abscess resolution, and all patients returned to their premorbid functional capacity.

In patients with necrotic or cystic tumors, biopsy material was obtained from the periphery of the lesion and was used to document the presence of glial tumors in three patients and an intraparenchymal ependymal cyst in the fourth patient. The cystic or necrotic components of these tumors were clearly identified as nonenhancing hypointense areas on real-time images (Fig. 2). The tumors were entered successfully in each case, and decompression was effected under continuous MR imaging monitoring. In contrast to the abscesses, the contrast-enhancing periphery of the tumors demonstrated much less resistance during perforation, and deflection under the pressure of the biopsy needle was only observed in two cases (3- and 4-mm deflections, respectively). A reexpansion of the compressed ventricle in the range of 4 to 8 mm (mean 5.6 mm) and a shift in the midline ranging from 2 to 5 mm (mean 3.6 mm) was also observed. Immediately after evacuation of necrotic material, a decrease in the maximum diameter of the contrast-enhancing margins of the gliomas ranged from 12 to 28 mm (mean 23 mm). As in the cases of abscesses, no significant shift (toward movement) in the cortical surface was detected in any case. In the paraventricular ependymal cyst, the endoscope was used to perforate the wall of the cyst and establish a communication with the lateral ventricle. In no case did follow-up CT scans obtained within 24 hours after the procedure reveal increased cerebral edema or increased mass effect, and all patients exhibited clinical improvement. Eventually, two patients with high-grade lesions underwent open craniotomy and tumor resection, a procedure that was facilitated by the evacuation of the cystic or necrotic portion and the significant reduction in mass effect.

In patients with intracranial cysts, administration of diluted (1:100) paramagnetic contrast material within the cyst demonstrated the presence of internal septa and loculations, as well as communication with the subarachnoid space or the ventricular system (Fig. 3). The neurosurgical endoscope was navigated using real-time imaging to fenestrate the septa, and a ventricular catheter was inserted successfully under MR imaging guidance in two cases. In the third patient, who harbored a large, multiseptated, infratentorial arachnoid cyst and had hydrocephalus, the endoscope was used to establish a communication with the
third ventricle; eventually a ventricular catheter was inserted with interactive imaging guidance.

The median imaging time, from the point at which the first baseline image was obtained until the last control MR sequence, was 1.4 hours. This duration was reduced from 2 to 3 hours in the first procedures to less than 1 hour in the last procedures. There were no instances of adverse outcomes, such as deaths, postoperative neurological worsening, subclinical hemorrhagic episodes, or nondiagnostic biopsy samples. No patient suffered from dissemination of the neoplasm or abscess from the biopsy specimen. The pathway of the aspiration needle was identified on control contrast-enhanced images as a linear enhancement caused by extravasation of contrast material. A CT scan obtained 24 hours postprocedure occasionally revealed minimal hemorrhage along the pathway of the needle track; this did not increase on follow-up monitoring, and in no case was there any intraslesional hemorrhage or other complication that would necessitate surgical intervention.

**Discussion**

In the past 5 years, MR imaging technology has been adapted to assist neurosurgeons in intraoperative procedures, with the aim of achieving an accurate diagnosis and an effective therapy with minimal morbidity and preservation of neurological function. The development of intraoperative MR imaging systems allows a real-time interactive approach to intracranial lesions, with direct observation of the course of the procedure and monitoring of its therapeutic effects. By providing the neurosurgeon with information on the dynamic changes occurring intraoperatively, this technology can potentially be used to detect unexpected intraoperative complications, avoid inaccuracies associated with brain shifting, and provide reassurance about the effectiveness of the therapeutic procedure, which is not available when using either frame-based or frameless technologies, in which images acquired preoperatively are used.

In the present work, we have tried to define useful clinical applications of intraoperative MR imaging in circumstances that are associated with a high degree of brain shift, such as drainage of intracerebral cystic structures associated with abscesses and tumors, management of intracranial arachnoid cysts, and decompression of hydrocephalic ventricles. We report our initial experience with the safety and efficacy of these applications and the advantages of operating interactively within the open-configuration MR imager.

**Abscess Drainage**

Since Dandy’s recognition that drainage of brain abscesses may cause trauma to delicate brain parenchyma,7 neurosurgical management of brain abscesses has become...
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less invasive, resulting in lower rates of morbidity and better outcomes in patients with intracerebral infections.14 Aspiration and drainage of brain abscesses as a method of treatment is recommended by numerous authors as an alternative for surgery, a procedure complementary to conservative treatment, or the treatment of choice in cases in which neurosurgery is contraindicated.5-11 Modern neuroimaging, particularly CT and MR imaging, has significantly improved outcomes in these patients by enabling earlier diagnosis and, thus, earlier treatment.1-3,13-20,37 Combination of these imaging modalities with stereotactic techniques has allowed neurosurgeons to reach areas of the brain with minimal risk, compared with the risks of craniotomy, which contributes to even lower rates of surgical morbidity and mortality in the treatment of uncomplicated brain abscesses.38 Over the last two decades, CT-guided aspiration of brain abscesses has been the primary therapeutic modality and excellent results have been reported.2,9,19,22-32,39 Although the benefits from this method of guidance are beyond question, our experience indicates that MR imaging guidance is as safe and effective as CT guidance and has certain advantages that are related to the better soft-tissue resolution of MR imaging and to the interactive feature of the procedure.

Magnetic resonance imaging is the modality of choice for the characterization of intracranial infection related to better spatial resolution, diagnostic accuracy, image quality, soft-tissue discrimination, and lack of radiation exposure. It is much more reliable than CT scanning for differentiating cystic from solid lesions and for demonstrating septa and the thickness of the abscess wall and its state of development. The T1- and T2-weighted signal intensities can be used to predict the relative viscosity and composition of intracranial cystic contents, thus aiding in treatment planning and selecting the appropriate instrumentation in the management of intracranial cystic masses.1 The uniform, ringlike enhancement of an abscess in the capsular stage provides excellent definition of the lesion and aids in the selection of an optimal target point. In our study we have routinely used a double dose of contrast agent to optimize visualization of the target lesion. The axial three-dimensional radiofrequency–SPGR echo sequence used in T1-weighted imaging offers excellent differentiation of gray and white matter, visualization of medium-sized vessels, and the spatial and contrast resolution necessary for accurate anatomical localization and planning an optimal surgical approach, particularly in cases of deep-seated lesions.

During the actual puncture and drainage of the abscess, the main advantage of interactive MR imaging guidance is the direct control it provides the surgeon over the procedure. The operator has immediate feedback during the introduction of the needle and the evacuation of the abscess, which are monitored in real time on the LED screen. The treatment of brain abscesses depends on eliminating the infectious process and reducing the mass effect, both caused by the necrosis of brain tissue, the inflammatory supplicative response, and the surrounding cerebral edema.11 Drainage of the infected material reduces the number of organisms and the size of the abscess cavity, which in turn decreases the mass effect and allows for better penetration of antibiotic agents. The diminution of infected material by aspiration also has the potential for reducing the magnitude of the brain’s inflammatory response and the reactive edema, which may also be of benefit. Despite these benefits, the procedure is associated with significant shifting of tissue, and real-time imaging capability is important not only for accurate targeting but also for monitoring the aspiration of the abscess. Sources of brain shifting include head positioning in an orientation different from that in which the preoperative data were acquired, CSF loss during cranial and dural penetration, and drainage of the abscesses cavity. We observed additional intraoperative changes in tissue position, as the aspiration needle indented the fibrous capsule of the abscess by approximately 1 cm before its actual perforation. After using both the frameless and frame-based methods simultaneously, Nauta15 reported that limiting factors in the usefulness of this method of guidance are not image accuracy or the mechanical accuracy of the instrument; rather, errors in stereotactic neurosurgery are caused by changes in tissue position, which occur during the procedure. He has emphasized that the potential errors appear to be worse in cases of hydrocephalus, intraoperative dehydration, collapse of large cysts, and debulking of large tumors and that intraoperative updates of images are necessary if greater accuracy is required.29 Intraoperative real-time imaging monitoring, as it was achieved in our study, was important because information about the anatomy was available immediately, without the need to interrupt the procedure. This allowed positional adjustments of the needle tip at the center of the abscess during drainage, which was particularly important in treating multiloculated abscesses. This is crucial because aspirating the abscess near its margins increases the risk of hemorrhage, due to the neovascularity and friability of the abscess wall interface.5,11,19,22 Other factors related to management failure include inadequate or overvigorous aspiration,19 which can both be prevented using real-time imaging. Following the evacuation, accurate placement of an intraabscess catheter was also facilitated by interactive imaging. In our series of seven consecutive patients with infections unrelated to acquired immune deficiency syndrome, no patient died as a result of the procedure and no new neurological deficits appeared after surgery. We recorded only one case in which there was a minor hemorrhage along the path of the needle, and this complication spontaneously resolved. Long-term clinical evaluation confirmed disease resolution after single-procedure stereotactic management in six patients, and only one patient required a second procedure for evacuation of a new abscess that developed in an adjacent location 2 days following evacuation of the first abscess. Eventually, all patients returned to their premorbid functional capacity.

Decompression of Cystic Tumors

Similar tissue-shifting phenomena have also been observed in patients with cystic tumors who underwent biopsy sampling and tumor evacuation with the aid of interactive MR imaging. Magnetic resonance imaging–guided aspiration may be performed to establish an accurate histological diagnosis and to effect partial decompression of the lesion. Using real-time monitoring, the aspiration needle is guided safely into different areas of the neoplasm or into a region of particular interest to reduce the chance of a sampling error.18 Moran, et al.,35 described worthwhile
palliation of symptoms by CT-guided surgery in patients harboring cysts in both primary and secondary tumors. This approach is particularly valuable in patients with recurrent cystic neoplasms and a short life expectancy, as well as in patients with large space-occupying necrotic or cystic intracranial tumors because it facilitates surgery. Amelioration of clinical symptoms after aspiration was observed in all four patients in the present study.

**Endoscopic Procedures**

The limitation of visualization in neuroendoscopy to internal surfaces of the ventricular system or cystic lesions can be complemented by simultaneous inclusion of a larger volume of interest. Using real-time imaging, the neurosurgeon can control the position of the endoscope and simultaneously guide the procedure by obtaining intraluminal information. This expansion of the operating field can significantly improve both the diagnostic and surgical use of endoscopes, without increasing the risk associated with the procedure. Endoscopic methods were used in four patients in this series without complication and with satisfactory cyst aspiration. Administration of diluted Gd-DTPA within the cystic cavity in these cases was useful for demonstrating any communication with the subarachnoid space or the ventricular system. Although free Gd is neurotoxic, chelation with DTPA results in a marked reduction of its toxicity. The contrast agent Gd-DTPA is approved only for intravenous administration. There are only a few animal studies about intrathecal and intraventricular injection of diluted Gd.3,27 The results of preliminary human studies3,5,50 have shown that low doses of intrathecal Gd do not lead to clinical evidence of gross neurological abnormalities, CSF changes, or electroencephalographic alterations. Depending on the laws of various countries, intrathecal Gd may legally be used by physicians, on their own responsibility, in individual patients.65

**Alternatives to MR Imaging**

Probably the most important advantage of the method described is that it provides an interactive one-step method of localization and targeting and continuous monitoring of the positions of the aspiration needle, catheters, and endoscope. Surgical intervention is accomplished on-line along with the imaging process, without the delays involved in moving the patient into and out of the magnet. This interactive feature exists with the use of ultrasonography, but not with CT or conventional MR imaging. Intraoperative ultrasonography is a comparably inexpensive imaging modality for interactive guidance, and like intraoperative MR imaging, the introduction of the needle and the evacuation of a cyst or an abscess can be followed on the screen. The use of ultrasound for guidance has been reported by previous authors in connection with biopsy sampling, aspiration of abscesses, placement of an aspiration catheter or endoscope into cysts, hydrocephalic ventricles, or the equivalent, emphasizing its main advantages over conventional CT stereotaxy, namely the shorter preparation time, the low cost, and the direct control over the procedure.1,3,13,14,21,29,36 Despite the technical advances, there are still limitations, among which is the spatial resolution resulting from use of this method, as compared with other imaging techniques (CT or MR imaging), principally with regard to the restricted penetration depth and the localization of very small lesions. Furthermore, the actual borders of the lesion may not be easily identifiable because of the hyperechoic appearance of perilesional edema. When considerable angulation of the needle is necessary, there may also be shadowing artifacts caused by the bone edges of the burr hole. Other artifacts may be the result of refractive or repetitive phenomena giving rise to “ghost” or “specular” images without an anatomical verification. Hemostasis material, fresh blood clots, and small air bubbles may also be the source of hyperechoic artifacts.

**Conclusions**

In summary, the results of our study demonstrate that rapid and accurate abscess drainage, cyst evacuation, and placement of a drainage catheter can be safely performed using the interactive guidance of an open-configuration MR imaging system. With routine precautions, the theoretical hazards of local infection, dissemination of tumor or infection, and CSF leakage are not practical problems in the performance of the procedure. Intraoperative MR imaging can provide information on the course of the surgical action, such as the degree of cyst aspiration, the presence or absence of hemorrhage, or induced swelling. It can also confirm the accuracy of a biopsy site and reveal whether an error has occurred so that a correction can be made. The serial intraoperative images obtained using our system have shown striking changes in the shape of the lesions and significant displacement of brain tissue. These direct observations should prompt heightened caution when using navigational systems that guide surgical maneuvers on the basis of preoperatively acquired imaging data. Incorporation of intraoperative imaging seems to be an effective and accurate way to solve the problems of changes in anatomical relations during surgery, and our findings indicate the benefit gained from a more extensive use of MR imaging technology for intraoperative guidance.

**References**


S. S. Kollias and R. L. Bernays
Interactive MR imaging–guided management of intracranial cystic lesions


Address reprint requests to: Spyros S. Kollias, M.D., Institute of Neuroradiology, University Hospital of Zurich, Frauenklinikstrasse 10, CH 8091, Zurich, Switzerland. Email: kollias@dmr.usz.ch.