Magnetic resonance imaging of acute subarachnoid hemorrhage


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The feasibility, safety, and diagnostic value of magnetic resonance (MR) imaging versus computerized tomography (CT) scanning were compared in 30 patients with clinical evidence of subarachnoid hemorrhage. Subarachnoid blood was identified more often and more information was available about the site and source of the hemorrhage on MR imaging than on CT. Magnetic resonance imaging could be used safely both before and after the operation, provided that nonferromagnetic clips were used and that comprehensive monitoring and cardiorespiratory support were available. Postoperative studies showed that artifacts from metallic implants and from patient movement caused less image degradation on MR images than on CT scans.

Key Words • magnetic resonance imaging • computerized tomography • subarachnoid hemorrhage • aneurysm clip

Magnetic resonance (MR) imaging is challenging computerized tomography (CT) scanning as the initial investigation of choice in a wide range of central nervous system disorders, but its use has largely been confined to imaging nonacute lesions. There is minimal information about the use of MR imaging in patients with spontaneous subarachnoid hemorrhage (SAH), even though SAH forms a major part of the workload of a neurosurgical unit and imaging plays an essential part in its management. Although DeLaPaz, et al., identified signal changes on T2-weighted images in a single case of SAH, there has been doubt about the ability of MR imaging to display acute intracranial hemorrhage. Concern about the safety of metallic implants in patients exposed to a strong magnetic field has also limited MR imaging to a preoperative investigation.

We have investigated the safety and usefulness of MR imaging before and after operation in a series of patients with recent SAH.

Clinical Material and Methods

Patient Population

Patients with a history and clinical findings suggestive of SAH underwent imaging between 8 hours and 5 days after the onset of symptoms. Those in coma were excluded, but those in all other clinical grades were represented. The consciousness level and the presence or absence of focal neurological signs were recorded. If clinically indicated at this stage, each patient underwent four-vessel catheter angiography. Ten patients also had MR imaging postoperatively: four underwent both CT scanning and MR imaging. The MR examinations were performed with the approval of the Research Ethics Committee of the Institute of Neurological Sciences, Glasgow, following the guidelines of the National Radiological Protection Board. Informed consent was obtained from all patients or their relatives prior to their inclusion in the study.

Magnetic Resonance Imaging

Imaging was performed on a Picker 0.15-tesla resistive system operating at 6.3 MHz. The development of compatible monitoring and cardiorespiratory support apparatus enabled patients to be imaged safely. Blood pressure, heart rate, and respiration were continuously monitored; electrocardiography was performed during patient transfer, data processing, and image display, but gradient interference precluded its use during imaging.
TABLE 1
Results of preoperative investigation in 30 patients

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Positive Results</th>
<th>Negative Results</th>
<th>Study Not Done</th>
<th>Technically Inadequate</th>
</tr>
</thead>
<tbody>
<tr>
<td>lumbar puncture</td>
<td>16</td>
<td>2</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>computerized tomography</td>
<td>24</td>
<td>5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>magnetic resonance</td>
<td>25</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>imaging angiography</td>
<td>25</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Initial in vitro tissue analysis enabled the selection of optimal pulse sequences for the imaging of both subarachnoid blood and focal or generalized cerebral edema. On this basis, a T₂-weighted spin echo (SE) 2200/80 axial sequence with two averages and a 128 × 256 matrix (interpolated to a 256 × 256 matrix for display) was used for all patients. This took 8.5 minutes for the acquisition of 16 contiguous 8-mm thick slices. Other sequences and orientations were used in selected patients. A sagittal SE 900/40 sequence (four averages, 256 × 256 matrix) proved useful for vascular imaging and the demonstration of aneurysms, while gray matter, white matter, and ventricular outlines were best seen using a T₁-weighted inversion recovery 2000/600/40 sequence.

Results of the MR studies were reported prospectively by an experienced neuroradiologist who had no knowledge of the clinical, CT, or angiographic findings.

Assessing Implant Safety

To ensure the safety of imaging patients after operation, studies of torque and deflection in a static 0.15-tesla field were carried out on all aneurysm clips available to surgeons in our unit. The clips were suspended from a fine cotton thread within the bore of the imager. Alignment of the axis of the clip with the main magnetic field was considered acceptable because of the minimal forces involved, but clips were rejected if this magnetic attraction was greater than the gravitational force on the clip. In addition, each clip was suspended in a beaker of water that contained copper sulfate and was imaged to assess clip movement and the extent of signal artifact or spatial distortion caused by eddy current magnetic induction. The Sugita range of clips did not move detectably in the static or gradient field and produced a minimal signal artifact. Postoperative studies were therefore restricted to patients treated with this type of aneurysm clip.

Computerized Tomography Scanning

Unenhanced CT scans were carried out either on an EMI 1010 scanner (20 patients) or on a Philips Tomoscan (10 patients), depending on availability of the equipment. All patients underwent CT scanning within 48 hours after MR imaging and within 3 days following the ictus.

Lumbar Puncture

In accordance with recommendations from our unit, lumbar puncture was carried out at the hospital referring the patient if there was doubt as to the clinical diagnosis. It was also performed in patients whose CT scan showed no evidence of hemorrhage.

Angiography

Four-vessel angiography was performed via a femoral catheter under local anesthesia. Twenty-seven of the 30 patients underwent this procedure. In three patients the clinician responsible thought that angiography was inappropriate; one of the patients had a negative lumbar puncture and CT scan and was asymptomatic within 24 hours, and the other two were not candidates for operative treatment.

Results

Patients Studied

Thirty patients were studied preoperatively. In all cases, MR imaging was performed between 8 hours and 5 days after the initial ictus. The patients' ages ranged from 15 to 69 years (mean 46.6 years), with a female to male ratio of 2.7:1. The investigation results are summarized in Table 1.

Angiographic Findings and Final Diagnosis

The results of angiography and the diagnosis at discharge are shown in Table 2. Two patients whose condition deteriorated after angiography did not undergo surgery; in the remainder, the positive angiographic findings were confirmed at operation.

Angiography revealed an aneurysm in 25 patients: five pericallosal, six anterior communicating, 15 middle cerebral, 16 posterior communicating or internal carotid, three at the basilar bifurcation, and one posterior inferior cerebellar. Multiple aneurysms were shown in 12 patients.

TABLE 2
Results of angiography compared to final diagnosis

<table>
<thead>
<tr>
<th>Angiographic Findings</th>
<th>No. of Cases</th>
<th>Diagnosis at Discharge*</th>
</tr>
</thead>
<tbody>
<tr>
<td>aneurysm†</td>
<td>25</td>
<td>SAH (aneurysmal)</td>
</tr>
<tr>
<td>normal</td>
<td>2</td>
<td>SAH (cause unknown)</td>
</tr>
<tr>
<td>not studied</td>
<td>2</td>
<td>SAH (probably aneurysmal)</td>
</tr>
<tr>
<td>not studied</td>
<td>1</td>
<td>migraine (SAH excluded)</td>
</tr>
</tbody>
</table>

* SAH = subarachnoid hemorrhage.
† Twelve patients had multiple aneurysms.

A. Jenkins, et al.
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FIG. 1. Axial magnetic resonance images (spin-echo 2200/80 study) showing a normal image (left) and the high signal of blood-stained cerebrospinal fluid in the prepontine cistern and fourth ventricle 12 hours postictus (right).

Patients' Acceptance and Safety of MR Imaging

No patient refused MR studies, and the only complaints were of mild claustrophobia and an uncomfortable couch. None of the patients deteriorated while undergoing imaging. One investigation had to be discontinued due to restlessness of the patient, and diagnostic images were not obtained.

Magnetic Resonance Image Appearance in SAH

Acute SAH was demonstrated by the T2-weighted SE 2200/80 sequence, which showed that blood-stained cerebrospinal fluid (CSF) had a high signal compared to brain or normal CSF (Fig. 1). An acute hematoma was seen as a rim of high signal with a hypointense center (Fig. 2). Areas of high signal suggestive of ischemia or edema were seen in one patient whose condition deteriorated after aneurysm surgery (Fig. 3), but none of the patients in this series developed cerebral infarction. Midline and parasagittal aneurysms were shown particularly well by an SE 900/40 sequence in the sagittal plane (Fig. 4), and at least one aneurysm was seen in 14 patients.

The metallic artifact on postoperative studies was limited to a signal-void area no greater than 2 sq cm with a thin rim of hyperintensity (Fig. 5). This was noted on both T1- and T2-weighted sequences. A consistent focal area of hyperintense signal on the T2-weighted images and of hypointensity in the T1-weighted images was noted at the operative site.

Comparison of CT Scanning and MR Imaging

Preoperative Studies. Studies were performed preoperatively on 30 patients with acute SAH. The performance and diagnostic yield of both unenhanced CT and MR imaging were compared based on eight criteria. The findings are summarized in Table 3.

Magnetic resonance imaging was very similar to CT in the detection of intracranial bleeding in the subarachnoid space and ventricles, and also in the iden-

FIG. 2. Computerized tomography scan (left) and magnetic resonance image (spin-echo 2200/80 study) (right) showing an acute intracerebral hematoma 24 hours following rupture of a middle cerebral artery aneurysm.

FIG. 3. Magnetic resonance image (spin-echo 2200/80 study) showing an area of increased signal 2 days after aneurysm surgery.

FIG. 4. Sagittal magnetic resonance image (spin-echo 900/40 study) (left) and confirmatory angiogram (right), both showing a posterior communicating artery aneurysm (arrows).

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FIG. 5. Computerized tomography scan (left) and magnetic resonance image (right) following aneurysm surgery showing the artifact produced by each method.

tification of intracerebral clots. Midline shift or local space-occupying effects were seen with both techniques. Hydrocephalus was reported slightly more often with CT than with MR imaging, but this difference represents a subjective variance in radiological interpretation rather than a conflict in the results of the two techniques. Magnetic resonance imaging revealed local abnormalities indicating the area that was likely to have been the origin of the bleed in more patients (16 cases) than did CT (11 cases). These abnormalities included small hematomas and areas of local edema at the site of aneurysm rupture.

The most striking difference between MR and CT was in the number of patients in whom the actual lesion responsible for the bleed could be seen. Fourteen patients undergoing the MR study showed a signal-void area indicative of an aneurysm associated with focal cerebral signal changes: two on the pericallosal artery, four on the anterior communicating artery, live on the middle cerebral artery, two on the posterior communicating or internal carotid artery, and one on the basilar artery. Each of these lesions was shown by the angiographic and operative findings to have been correctly identified. In these patients, six further aneurysms un-

<table>
<thead>
<tr>
<th>Feature</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
</tr>
<tr>
<td>subarachnoid blood</td>
<td>24</td>
</tr>
<tr>
<td>intracerebral blood</td>
<td>10</td>
</tr>
<tr>
<td>intraventricular blood</td>
<td>11</td>
</tr>
<tr>
<td>shift/space-occupying effect</td>
<td>9</td>
</tr>
<tr>
<td>hydrocephalus</td>
<td>11</td>
</tr>
<tr>
<td>ischemia</td>
<td>0</td>
</tr>
<tr>
<td>localization of bleed</td>
<td>11</td>
</tr>
<tr>
<td>visualization of aneurysm</td>
<td>0</td>
</tr>
</tbody>
</table>

* CT = computerized tomography; MRI = magnetic resonance imaging; SAH = subarachnoid hemorrhage.

### TABLE 4

Comparison of postoperative CT and MRI findings in four patients undergoing aneurysm surgery*

<table>
<thead>
<tr>
<th>Feature</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
</tr>
<tr>
<td>metallic artifact &gt; 2 sq cm</td>
<td>4</td>
</tr>
<tr>
<td>extracerebral collection</td>
<td>1</td>
</tr>
<tr>
<td>local edema/contusion</td>
<td>0</td>
</tr>
<tr>
<td>ischemia</td>
<td>0</td>
</tr>
<tr>
<td>hydrocephalus</td>
<td>1</td>
</tr>
<tr>
<td>space-occupying effect</td>
<td>1</td>
</tr>
</tbody>
</table>

* CT = computerized tomography; MRI = magnetic resonance imaging.

associated with focal signal changes were confirmed at angiography. In none of the patients did unenhanced CT identify an aneurysm directly as the likely source of the bleed.

**Postoperative Studies**

Magnetic resonance imaging was performed in 10 patients following aneurysm clipping. Four of these patients also had CT examinations within 24 hours after the MR study. The findings are shown in Table 4.

There was no deterioration in the clinical condition of any of the 10 patients as a result of the MR examination. Artifacts due to the metal components of the aneurysm clip were seen with both CT and MR imaging, but the extent of the artifact was consistently less with the MR study; all four CT scans showed extensive streak artifact covering the whole image on at least two slices, but no MR image showed a defect of larger than 2 sq cm. An extracerebral collection was shown in three patients with MR imaging and in one with CT scanning; none of these had to be evacuated.

Each of the four patients who underwent both studies showed evidence on T2-weighted sequences of a focal increase in signal at the operative site. Corresponding changes were seen in two patients with CT. Both MR and CT studies were similar in their ability to detect hydrocephalus and space-occupying effect. As in the preoperative studies, neither showed definite evidence of ischemia. Evidence of further bleeding from an unclipped aneurysm was seen with both techniques in one patient who had multiple aneurysms, one of which had been left unclipped.

**Discussion**

This study has shown MR imaging to be safe for investigating selected patients following a suspected SAH. Imaging time for a multislice SE sequence is comparable to that of CT, although in this study most patients underwent more than one sequence. For either CT or MR studies, disoriented patients may require sedation, but in the experience of most MR imaging personnel, only 1% of oriented patients will experience claustrophobia. Specialized monitoring and support

### TABLE 3

Comparison of preoperative CT and MRI findings in 30 patients with clinical evidence of SAH*

<table>
<thead>
<tr>
<th>Feature</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
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<tr>
<td>subarachnoid blood</td>
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<tr>
<td>hydrocephalus</td>
<td>11</td>
</tr>
<tr>
<td>ischemia</td>
<td>0</td>
</tr>
<tr>
<td>localization of bleed</td>
<td>11</td>
</tr>
<tr>
<td>visualization of aneurysm</td>
<td>0</td>
</tr>
</tbody>
</table>

* CT = computerized tomography; MRI = magnetic resonance imaging; SAH = subarachnoid hemorrhage.
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Equipment is necessary for patients who have cardiorespiratory instability or impaired consciousness.

Low-field (0.15-tesla) MR imaging is also safe for postoperative studies if the surgical clips used have a minimal ferromagnetic content. The Sugita range of clips fulfills the requirements of MR imaging and has proved generally acceptable with operators. When these clips are used, the artifact is little larger than the clip itself, and there is no danger of clip movement or distortion of vessels. Similar studies should be carried out on high-field imagers, because even if clip movement does not occur a larger signal defect that could obscure important lesions might be produced at the site of the clip.

Previous in vitro studies\(^1\) had led us to anticipate that SAH could be visualized on MR images if appropriate imaging pulse sequences were chosen. This opinion was shared by other groups.\(^6,9\) In the present study an SE 2000/80 sequence was designed to optimize the contrast between the hyperintense signal from blood-stained CSF (a markedly shortened \(T_1\) and a slightly shortened \(T_2\)) and the signal from normal CSF, which with this sequence is isointense with brain; in addition, it was sensitive to edema and gave good anatomical resolution within the constraints of a particular imaging time.

Our studies in other central nervous system disorders have shown that an abnormal hyperintense CSF signal can be seen in conditions where CSF protein is substantially raised: for example, a patient with meningeal metastases and one with severe purulent meningitis showed similar appearances on MR images. In neither case was there any clinical confusion with SAH.

The findings in the present series of patients, in whom a provisional clinical diagnosis of SAH had been made, show that MR imaging is at least as useful as CT in the demonstration of subarachnoid blood. Chakere and Bryan\(^8\) have debated whether signal changes in the narrow subarachnoid spaces might be obscured either by partial volume averaging or by flow effects. This study has shown that, even on a low-field system with a slice width of 8 mm, obvious signal changes are seen if an appropriate pulse sequence is used. These changes were most marked in the preopticine and interpeduncular cisterns even when these areas were distant from the origin of hemorrhage. The importance of hemorrhage at this site has previously been emphasized as a “specific” sign on CT\(^21\) even when contrast enhancement obscured the SAH in other positions. The present study extended up to 6 days after the initial bleed, but our own in vitro experiments\(^13\) and the in vivo and in vitro studies of Di Chiro, et al.\(^12\) suggest that the distinction between blood-stained and normal CSF will become more marked with time. This is because the relaxation times of bloody CSF decrease further. In the later stages this is shown best on \(T_1\)-weighted images (after 4 days) as a result of the paramagnetic effects of deoxyhemoglobin in intact red cells and later methemoglobin, before the denatured hemoglobin is washed out of the subarachnoid space.

Complications of SAH, such as intracerebral hemorrhage and hydrocephalus, were readily demonstrated with MR imaging. The usual appearance of an acute intracerebral hematoma 1 to 3 days after SAH was of an iso- or hypointense area (the hematoma) surrounded on the \(T_2\)-weighted image by an area of hyperintensity, presumed to be due to reactive edema in the surrounding brain. Overall, MR imaging identified more hematomas in preoperative patients than did CT scanning; however, the use of the lower-resolution EMI 1010 CT scanner in the earlier studies may account for some of the difference. Hydrocephalus was only reported on MR images if the ventricles were unequivocally enlarged; all such patients had CT findings of hydrocephalus. In the remaining patients reported to have enlarged ventricles on CT, the ventricular enlargement was minimal. Increased familiarity with MR appearances should enable identification of the milder increases in ventricle size. In addition, the recently reported method of differential intracranial and intraventricular CSF volume measurement described by Condon, et al.\(^10\) may permit accurate serial measurements of ventricular volume to be calculated.

The signal-void area produced by “time-of-flight effects” in swiftly flowing blood\(^2\) and dephasing effects in turbulent blood\(^26\) allows vessels to be imaged directly with MR studies without the use of contrast agents. The potential for visualizing aneurysms is thus much greater with MR imaging\(^14\) than with noncontrast-enhanced CT. Magnetic resonance imaging can be used to demonstrate aneurysms in most of the patients in whom a cause of SAH is found.

Magnetic resonance imaging is very sensitive to edema; each of the 10 patients with postoperative MR imaging showed a local increase in signal on the \(T_1\)- and \(T_2\)-weighted studies and a corresponding decrease in signal on the \(T_2\)-weighted studies at the site of operation, presumably as a result of operative retraction and handling. These changes were not apparent on the CT scans.

Apart from this local hyper- or hypointensity on the \(T_2\)- and \(T_1\)-weighted images, convincing evidence of delayed ischemia was not detected. Even though the patients studied did not have clinical evidence of ischemia, the reported sensitivity of MR imaging to small changes in tissue water had led us to suspect that it could disclose unsuspected minor ischemic changes. Studies of patients with clinical evidence of ischemia, and of the MR changes in response to treatment, will be of interest.

Although it is likely that CT will remain the first-line imaging strategy in cases of SAH, our study suggests that MR imaging can reliably demonstrate SAH and that it may have advantages over CT. These include: 1) its ability to demonstrate more accurately the site and source of SAH and sometimes the precise vascular lesion responsible; 2) its sensitivity to postoperative focal edema and contusion; and 3) the virtual absence of signal degradation when appropriate nonferromagnetic aneurysm clips are used. The lack of radiation
hazard makes MR imaging attractive for repeated imaging and follow-up evaluation.

While it is unlikely that MR imaging will replace angiography in the preoperative management of SAH, it can be helpful to have a working diagnosis before embarking on a potentially hazardous angiographic investigation. This is especially true of patients in the lower clinical grades. Magnetic resonance imaging can provide this information in a significant number of cases without the use of contrast media, and the total time of the study is similar to that of CT. In patients with multiple aneurysms, its sensitivity in the detection of small areas of edema means that surgery can be directed with more certainty to treatment of the aneurysm that has ruptured. In general, CT usually provides this information by inference from the area showing the highest concentration of subarachnoid blood, but this is often inaccurate or the blood so diffuse as to be of little predictive value.

In the investigation and follow-up evaluation of patients after aneurysm clipping, parenchymal changes adjacent to aneurysm clips are not masked by streak artifacts of ferromagnetic and nonferromagnetic surgical and dental materials and devices in nuclear magnetic resonance imaging. 

In vivo magnetic resonance imaging to measure intracranial cerebrospinal fluid volume. Lancet 1:1355–1357, 1986


References


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