Physiological support and monitoring of critically ill patients during magnetic resonance imaging

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Magnetic resonance (MR) imaging has been largely restricted to patients who are neurologically and hemodynamically stable. The strong magnetic field and radiofrequency transmissions involved in acquiring images are potential sources of interference with monitoring equipment. A method of support and physiological monitoring of critically ill neurological and neurosurgical patients during MR imaging using a 0.6-tesla MR system is reported. This technique has not caused degradation of the MR image due to electrical interference. Adequate preparation and precautions allow many critically ill neurological and neurosurgical patients to safely undergo MR imaging.

Key Words: intracranial pressure monitoring • ventilation • magnetic resonance imaging

MAGNETIC resonance (MR) imaging provides diagnostic information which is superior to x-ray computerized tomography (CT) findings in many central nervous system disorders,1,2,7,8 but MR imaging has been largely restricted to medically stable patients. Magnetic resonance imaging systems employ a large constant magnetic field and a variety of radiofrequency (RF) pulse sequences applied only during image acquisition. Both the high static magnetic field (0.12 to 2.00 tesla) and the RF energy transmitted during acquisition may damage or cause malfunction of electrical, electronic, or mechanical life-support and monitoring equipment. Conversely, the RF energy generated by these devices may interfere with MR signal detection and produce artifacts that degrade image quality.5

During image acquisition, the patient lies inside the bore of the magnet. Although staff can see and hear the patient, a period of approximately 10 seconds is required to move the imaging table so as to gain necessary access such as to examine cranial nerve functions or catheterization sites. Reliable monitoring procedures are therefore of particular importance. Techniques for critical care support and monitoring during MR imaging have been developed. These methods have been used during the MR imaging of six critically ill neurological and neurosurgical patients (Table 1), with satisfactory results.

Clinical Material and Methods

Magnetic Resonance Imaging

The patients at this institution are imaged with a Technicare MR system* operating at 0.6 tesla. Head, body, and surface RF coils are used as required. The standard pulse sequences for head and spine imaging include spin echo (TR 400, 1500, 2000 msec; TE 20, 60, 120 msec), gradient echo (TR 100 msec; TE 16, 30, 50 msec), and composite inversion recovery spin echo (TR 1500 msec; TI 450 msec; TE 20 msec).

Respiratory Support and Monitoring

Mechanical ventilation is provided by a Monaghan 225 ventilator† that was factory-modified to be compatible with MR imaging (Fig. 1). Large or critical ferromagnetic parts were replaced with plastic, stainless steel, or aluminum components. An articulated aluminum arm to support the tubing within the magnet bore was machined at our institution. As the ventilator does not use electricity or magnets, it does not produce RF waves or magnetic fields that could potentially interfere with imaging.

* Magnetic resonance imaging system manufactured by Technicare Corp., Solon, Ohio.
† Ventilator, Model 255, manufactured by Monaghan Medical Corp., Plattsburgh, New York.
Critical care during MR imaging

Fig. 1. Arrangement of ventilator and transducers in the magnetic resonance imaging suite. Transducers are clamped to a nonferromagnetic pole alongside the scanner at its mid-position. Placing the ventilator at the foot of the magnet facilitates moving the patient and allows use of standard-length (6-ft) ventilator tubing.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Diagnosis</th>
<th>Image Quality</th>
<th>Paralyzed or Sedated</th>
<th>Support</th>
<th>Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>brain-stem encephalitis</td>
<td>good</td>
<td>no</td>
<td>ventilator</td>
<td>EKG, ABP</td>
</tr>
<tr>
<td>2</td>
<td>SSS thrombosis</td>
<td>excellent</td>
<td>sedated</td>
<td>none</td>
<td>EKG, ABP</td>
</tr>
<tr>
<td>3</td>
<td>encephalitis</td>
<td>excellent</td>
<td>both</td>
<td>ventilator, pressors</td>
<td>EKG, ABP, ICP</td>
</tr>
<tr>
<td>4</td>
<td>lt frontal AVM, hemorrhage</td>
<td>excellent</td>
<td>both</td>
<td>both ventilator, pressors</td>
<td>EKG, ABP</td>
</tr>
<tr>
<td>5</td>
<td>C1-2 fracture</td>
<td>good</td>
<td>no</td>
<td>ventilator</td>
<td>EKG</td>
</tr>
<tr>
<td>6</td>
<td>putaminal hemorrhage</td>
<td>excellent</td>
<td>both</td>
<td>ventilator, pressors</td>
<td>EKG, ABP</td>
</tr>
</tbody>
</table>

* MR = magnetic resonance; SSS = superior sagittal sinus; AVM = arteriovenous malformation; EKG = electrocardiogram; ABP = arterial blood pressure; ICP = intracranial pressure.

The ventilator is powered solely by high-pressure oxygen (> 50 psi) supplied through high-pressure tubing. Initially, this was delivered by large "H" oxygen cylinders located outside the imaging suite. Oxygen consumption by this ventilator can be sufficiently high to deplete such a tank in less than an hour. Connecting two or more tanks provides a substantial gas reserve during a typical imaging session; however, an oxygen outlet installed in the magnet room facilitates prescan preparations and eliminates the risk of exhausting the oxygen supply during the study.

The patient is connected to the ventilator. Arterial blood gas determinations are made before the patient is placed in the magnet and are repeated midway through the imaging procedure or whenever changes in blood pressure, pulse, or intracranial pressure (ICP) occur. A Puritan-Bennett ventilatory pressure alarm,‡ located outside the magnet room, is connected to the patient's endotracheal tube by means of a T-piece and high-pressure tubing. Disconnection of the patient from the ventilator or loss of ventilatory pressure can be detected immediately during the study. A full complement of resuscitation equipment and medication is

‡ Ventilatory pressure alarm manufactured by Puritan-Bennett, Linthicum Heights, Maryland.
located 10 m from the patient outside the magnet room, where the magnetic field is approximately 10 gauss.

Physiological Monitoring

Electrical Connections. A shielded electric extension cable couples the transducer to a physiological monitor located outside the magnet room. This portable two-channel monitor accompanies the patient during transfer to the MR imaging area and allows continuous monitoring of two physiological pressures, typically arterial blood pressure and ICP. The extension cables can be routed through a small hole in the room’s Faraday shield.

Static Pressure Loads. Gould DTX physiological transducers were chosen as they have minimal metallic components and our personnel is familiar with them. Prior to patient studies, the effects of transducer location, vibration, and MR pulse sequence on monitoring stability were assessed. Hydrostatic pressures ranging from 10 to 120 cm H2O were recorded at multiple locations in the magnet room with and without image acquisition in progress. The static magnetic field did not affect pressure measurements, but waveforms during image acquisition were subject to artifact (Fig. 2). Electrical transients produced spurious systolic and diastolic pressure readouts capable of indicating false pressures as great as 124 mm Hg. This interference appears to be due to radiated RF energy, as it was greatest with the transducer at either end of the magnet, was minimal with the transducer located alongside at its midpoint, and was eliminated by turning off the RF signal despite ongoing gradient switching. Also, this effect was more prominent while using the head or surface coil compared to the body coil. Mean physiological pressures were stable during imaging unless the monitor was overloaded by these signal transients. The artifact was most prominent during inversion recovery and spin-echo acquisition techniques. Waveform artifacts were also caused by vibration from the shell of the MR imager, by placing the transducers on ferromagnetic stands, or while using pressure bags with ferromagnetic materials. The MR image quality was unaffected by the use of this monitoring equipment (Fig. 3).

Patient Monitoring. Nonmetallic radial artery catheters are inserted prior to imaging. Sixteen feet of heparinized saline-filled high-frequency pressure tubing is interposed between the catheter and transducer. Although some signal damping occurs (Fig. 4 and Table 2), substantial errors in systolic and diastolic pressure are not observed when compared to those obtained using 4 ft of tubing. A three-way stopcock is placed 4 ft from the arterial catheter, allowing access to arterial
Critical care during MR imaging

**Fig. 4.** Typical arterial and intracranial pressure (ICP) waveforms obtained from a patient during magnetic resonance image acquisition. Arrows point to a small radiofrequency artifact in the ICP tracing.

**TABLE 2**

<table>
<thead>
<tr>
<th>Tubing Length (ft)</th>
<th>Resonance Frequency (Hz)</th>
<th>Damping Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>33.3</td>
<td>0.50</td>
</tr>
<tr>
<td>16</td>
<td>10.0</td>
<td>0.45</td>
</tr>
<tr>
<td>20</td>
<td>8.7</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Intravenous Medication and Infusions

Most of these critically ill patients must have intravenous access during imaging. Medications administered by motor-driven infusion pumps, such as vasopressor agents, antihypertensive drugs, insulin, and sedatives, are transferred to microdrip burets. These pumps are not used in the magnet room because they may be subject to damage or malfunction from high magnetic fields. Although very long extension tubing (> 30 ft) may allow the pump to be positioned outside the magnet room, we have not found this approach to be practical.

**Personnel**

A physician and respiratory therapist attend the patient throughout MR imaging. They may remain in the imaging room indefinitely without risk of exposure to ionizing radiation.

**Discussion**

Magnetic resonance imaging provides superior sensitivity to CT scanning in many neurological conditions including head trauma, ischemia, and multiple sclerosis, but physicians are reluctant to image patients who are neurologically unstable or who require mechanical ventilation. The methods of physiological monitoring described here do not replace a careful neurological examination; however, they can provide a greater margin of safety during imaging.

Ventilatory support during imaging allows continuation of controlled hyperventilation and the use of pharmacological paralysis (pancuronium hydrochloride) to prevent artifact from patient movement. The low-ventilatory-pressure alarm allows detection and correction of ventilator dysfunction or disconnection. End-tidal CO₂ monitoring during MR imaging may prove to be a useful adjunct to monitoring (FG Sherlock, unpublished data, 1986). At present, invasive pressure monitoring has been limited to arterial blood pressure and ICP. Although our ICP measurements are performed using a ventricular catheter, Gosch and Kindt measured ICP using a plastic stopcock inserted in a twist-drill hole. Newly available plastic subarachnoid screws may also prove useful during MR imaging.

Some of the patients have central venous pressure (CVP) catheters in place; however, we have not monitored CVP during imaging because of the limited number of channels on our monitoring system.

Any unexplained change in pulse, blood pressure, or ICP requires prompt removal of the patient from the magnet and clinical evaluation. Patients who are at risk of neurological deterioration should be withdrawn from the magnet between image acquisitions for clinical assessment. Also, imaging should be limited to the minimum sequences required to assess the patient’s problem. In the event of an emergency, patients can be removed from the bore of the magnet in less than 10 seconds. Evoked potential monitoring may provide ear-
lier warning of neurological deterioration than raised ICP; however, image distortion due to electrode artifact and electromagnetic interference with the recorded potentials may preclude its use during imaging.

It is unclear to what degree the observed monitoring artifact is a function of our choice of transducer and monitor. As such, optimal transducer placement may also be specific to this combination of devices. A system that is free of waveform artifact with the transducers located near the patient’s feet would allow considerably shorter lengths of coupling tubing to be used. It is recommended that prior to initiating invasive physiological monitoring at an MR site, thorough static pressure testing should be performed. With adequate preparation and precautions, many critically ill neurological and neurosurgical patients can safely undergo MR imaging.

References

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