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Patient Monitoring during Magnetic Resonance Imaging

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Magnetic resonance (previously called nuclear magnetic resonance)[1] is a recently developed noninvasive diagnostic technique that employs a strong magnetic field and radio frequency (RF) pulses to generate images.[2] Initial reports indicate effectiveness of the technique in producing high-contrast images.[3–8] Patient monitoring during scanning poses problems because ferrous metal contained in most monitoring equipment can distort the magnetic field. In addition, ECG and other monitoring wires attached to the patient and leaving the scanner act as antennae for stray radio frequency signals. Both these disturbances of magnetic resonance (MR) function may result in image degradation. Currently, at our institution patients are placed inside the MR scanner and monitored by closed-circuit television and a two-way intercommunication system. However, seriously ill or semicomatous patients and children may require sedation or ventilatory assistance and more extensive monitoring. A monitoring system was assessed, and its effects upon MR image quality were determined.

METHODS

Twenty fully conscious patients without respiratory or cardiovascular support participated in a study approved by the Human Research Committee. Patients with cardiac pacemakers, intravascular wires, or neurovascular aneurysm clips were excluded from the study. Monitoring consisted of a blood pressure cuff with plastic connectors and 2.5 meters of rubber tubing, an Aneuroid Chest Bellows® chest-wall movement sensor (Coulbourn Instruments, Allentown, Pennsylvania), a Hewlett–Packard 78 100A ECG telemetry system (Hewlett–Packard, Waltham, Massachusetts), NDM® ECG lead wires (NDM Corporation, Dayton, Ohio), NDM Plia-Cell® ECG electrodes, and a Parks® Model 811 Doppler (Parks Medical Electronics, Beaverton, Oregon). The ECG and respiratory movements were displayed on a Saturn® monitor (Spacelabs Inc., Chatsworth, California). Twenty scans consisting of 13 head, two abdominal, four leg, and one thoracic were performed. The ECG electrodes were placed either on the hands and thigh, or shoulders and chest. Systolic blood pressure (BP) was obtained by the "bounce" method in three patients and with the Doppler in 17 patients. The Doppler flow probe was positioned over the radial artery in 18 patients and over the dorsalis pedis artery in two. The chest wall movement sensor was placed around the chest.

Monitoring equipment was applied, and the patients were placed on the scanner couch (twelve head first and eight feet first) and moved into the Picker® 1500 Gauss MR imaging system (Picker International, Cleveland, Ohio). A cylindric radiofrequency shield then was extended out from the opening of the scanner (fig. 1). The ECG telemetry transmitter and Doppler were placed on the couch midway between the opening of the scanner and the outer edge of the radio frequency shield. Two scans were taken of the same anatomic area using identical scanning technique with and then without monitoring equipment. Three blinded observers independently evaluated the 20 pairs of scans to determine differences between the two scans in terms of image degradation and diagnostic quality. Agreement between two or more observers was necessary before image degradation was considered to have occurred.

RESULTS

Satisfactory monitoring of BP, heart rate (HR), ECG, and chest wall motion was obtained on all 20 MR patients. All scans were assessed as being diagnostically adequate both with and without monitoring devices. Evaluations of the 20 pairs of images by individual observers are listed in table 1. Only two scans, both of unmonitored patients, met the criteria for degradation. None of the scans from monitored patients were degraded. The monitoring technique described did

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not interfere with MR function or produce image degradation.

Discussion

A system was used that monitored blood pressure, heart rate, ECG, and chest wall movement in 20 patients without image degradation. Monitoring a patient undergoing MR scanning presents several problems. The patient is placed on the scanner couch and moved into a cyclindric opening within the scanner and becomes inaccessible. A cylindric shield used to reduce radio frequency interference then is pulled out from the opening, further isolating the patient. The head of the patient can be as much as 2.5 meters from the opening.

Wires attached to the patient and leaving the scanner can act as antennae for stray radio frequency signals decreasing scan quality. By using a telemetric ECG, the need for wires leaving the scanner was eliminated. Fiberoptic transmission of ECG signals for gated cardiac imaging has been described[8] (Diasonics Inc., South San Francisco, California), although this system is not commercially available for patient monitoring.**

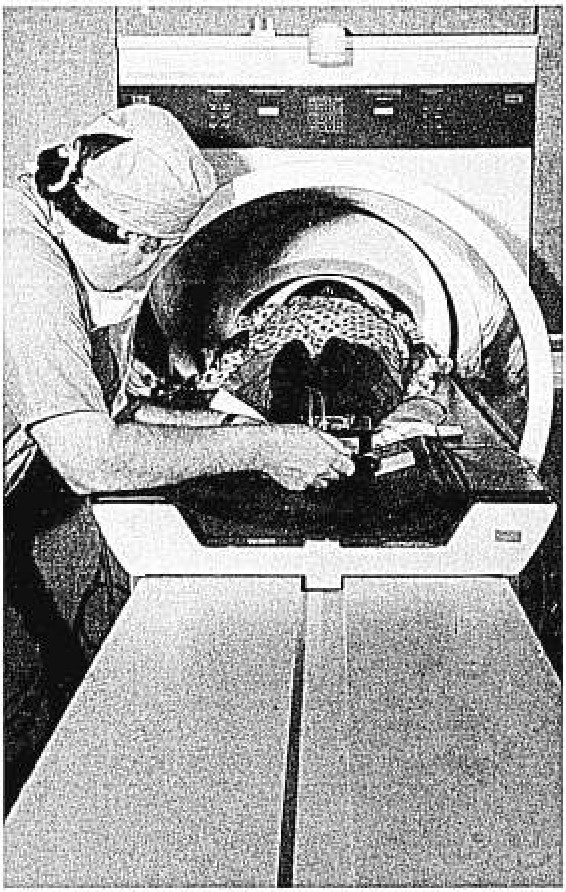

FIG. 1. Illustrates the inaccessibility of a patient during magnetic resonance imaging. The Doppler and telemetric ECG transmitter are seen at the foot of the patient. Tubing from the BP cuff and chest wall movement sensor are seen leaving the scanner.

TABLE 1. Observer Evaluation of Paired MR Images

Patient (Numbered in Order Studied)	Observers		
	DBK	PRJ	THB
5	M	=	=
4	=	=	M
15	=	=	M
11	U	U	U
14	U	U	=
3	U	=	=
6	U	=	=
17	U	=	=
20	=	=	U
Remaining 11 patients	=	=	=

=—Paired NMR images of equal quality with and without monitoring. M—image degraded when patient monitored; U—image degraded when patient unmonitored.

ECG artifacts are produced by the RF pulses from the scanner, which interfere with ECG interpretation when rapid pulse rates are used (fig. 2). Using a standard vascular Doppler, we were able to monitor the heart rate, even during periods when rapid RF pulsing obscured the ECG. If cardiac rhythm irregularities had been detected by Doppler, then the RF pulsing could have been stopped and the artifact would have ceased, permitting ECG interpretation. The RF pulse artifact also is present on the Diasonic fiberoptically transmitted ECG.** During general anesthesia, an esophageal stethoscope could replace the Doppler if adequate heart sounds were auscultated. A laser–Doppler system (Medpacific Inc., Seattle, Washington) with fiberoptic signal transmission has been used to measure ear lobe or lip capillary blood flow during MR imaging.[8] This system is much more expensive than the standard vascular Doppler and, as a routine monitoring device, offers no specific advantages.

The arterial blood pressure was monitored outside the scanner by lengthening the rubber tubing connected to a blood pressure cuff. A chest wall sensor monitored respiratory movement. Pressure changes in the chest wall bellows secondary to respiratory movements were converted to electrical signals and displayed on an oscilloscopic screen. For general anesthesia purposes, we extended the tubing on a Rees-type[9] modification of the Ayers T-system, thus enabling us to ventilate and maintain visual contact with a patient (with the trachea intubated) inside the scanner.

Ferromagnetic material within or near the scanner

** Diasonics, Inc., Personal communication.

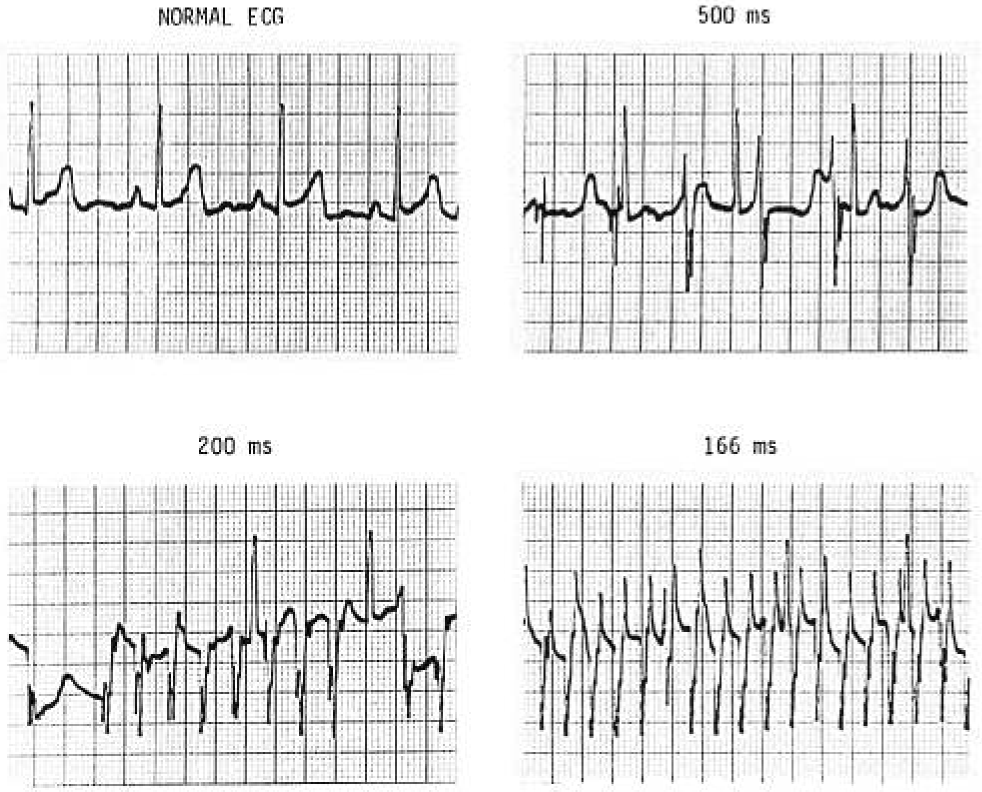

FIG. 2. Artifact on the ECG at 500-, 200-, and 166-ms radio frequency pulsing.

can distort the magnetic field decreasing scan quality. The Doppler and telemetric ECG didn't contain enough ferromagnetic material to cause visible image degradation. The anesthesia machine is wall mounted, approximately 3 m from the scanner, minimizing its interference with the scan's magnetic field. A metal apical stethoscope used in a pilot study distorted the MR scan (fig. 3). A plastic apical stethoscope did not permit consistent ausculation of heart and breath sounds.

FIG. 3. Two scans of the same thoracic area using identical scanning techniques. The upper scan was taken with a metal precordial stethoscope, resulting in anterior chest wall artifact.

Patients with cardiac pacemakers, intravascular wires, or cerebral vascular aneurysm clips were excluded from the study. Potential problems with cardiac pacemakers during MR scanning include possible reed switch closure or damage, pacemaker inhibition or reversion to an asynchronous pacing mode, programming changes, torque on the pacemaker itself, or development of a voltage across the pacemaker leads.[10,11] If cerebral vascular aneurysm clips contain ferromagnetic material, these could become displaced while under the influence of the magnetic field.[12] The heating of ferromagnetic prosthetic devices or major image artifacts secondary to these devices was not reported at our magnetic field strength or RF power levels,[13] and, therefore, patients with prosthesis were not excluded from the study. An additional danger arises from the placement of ferromagnetic objects such as tools near the scanner, because these objects could be attracted toward the center of the magnetic field and cause injury to patients and attending personnel or damage equipment.[14]

Of the 20 pairs of scans, individual observers interpreted nine control scans and three monitored scans as degraded. Clearly, factors other than the monitoring equipment influence scan quality. Wheelchairs, stretchers, and large gas cylinders all can distort the magnetic field and degrade the final scan. Radio frequency signals in the environment can effect scan quality, and furthermore, these radio frequency signals can change with the time of day and vary depending on the scanner's location within the hospital. Mechanical equipment also can malfunction when brought near the scanner. In the event of a cardiac arrest in or near the MR scanner resuscitation could be a problem. Electrocardiograms, defibrillators, pacemakers, and perfusion pumps may malfunction. In such a situation, the magnetic field of a resistive magnet can be turned off quickly, however, several hours will be needed to reestablish a stable magnetic field before routine scans can be continued. Magnetic fields produced by superconducting magnets cannot be turned off, so it would be necessary to remove arrested patients from the vicinity of the magnet. The influence of the MR scanner on equipment depends upon the strength of the MR magnetic field, the equipment's proximity to the scanner, the amount of ferromagnetic material it contains, and the design of its electrical circuitry.

A monitoring system made up of commercially available components, permitting monitoring of BP, HR, ECG, and chest wall motion during MR scanning, is described and is shown to be free of disturbances to MR imaging function. Because MR scanners differ in their operating characteristics, it is to be expected that this monitoring system may require modification when used with higher field strength scanners. However, we believe optimal image quality and patient safety can be achieved.

Since completion of this study, two patients requiring iv sedation and one unconscious patient whose trachea was intubated were monitored successfully with the system described in this article.

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