HANDS ON

How to perform magnetic resonance imaging on patients with implantable cardiac arrhythmia devices

Saman Nazarian, MD, Henry R. Halperin, MD, MA, FHRS

From the Division of Cardiology/Cardiac Arrhythmia, Johns Hopkins University, Baltimore, Maryland.

Introduction

Magnetic resonance imaging (MRI) offers unrivaled soft tissue resolution and multiplanar imaging capabilities. Cardiac MRI is capable of accurate characterization of cardiac function and is uniquely capable of identifying scar fibrosis and fat deposition, thus making it an ideal imaging modality for the evaluation of patients presenting with arrhythmia. In addition, the absence of x-ray radiation makes MRI suitable for follow-up of chronic disease and for imaging in young patients and women of childbearing age. Due to the ever expanding indications for implantation of permanent pacemakers and implantable cardioverter-defibrillators (ICDs), advancing severity of disease and age of the population, and advances in device technology, the number of patients with implantable cardiac devices will continue to increase. It has been estimated that each patient with a pacemaker or ICD has a 50% to 75% likelihood of having a clinical indication for MRI over the lifetime of their device. When performed with appropriate supervision and following a protocol for safety, many studies over the past 10 years have reported the safety of MRI with selected devices. However, catastrophic complications with older devices have been reported. Familiarity with each device class and its potential for electromagnetic interaction is essential for electrophysiologists whose patients may require MRI.

Potential for interaction with implanted devices

The static and gradient magnetic fields and radiofrequency energy of MRI are associated with several potential risks involving implanted devices.

Force and torque. Ferromagnetic devices in a magnetic field are subject to static and gradient magnetic field–induced force and torque. The potential for movement of an implanted device in the MRI environment depends on the magnetic field strength, the ferromagnetic properties of the device, the implant distance from the magnet bore, and the stability of the implant. In our *in vitro* analysis of modern permanent pacemakers (manufactured after 1996) and ICDs (manufactured after 2000), we found that the maximal force acting upon devices was less than 100 g in a 1.5-T MRI scanner.[1] This amount of force is unlikely to dislodge a chronic device that is anchored to the surrounding tissue. However, this observation led to our adaptation of a 6-week waiting period prior to MRI after device implantation.

Current induction. The radiofrequency and pulsed gradient magnetic fields in the MRI environment may induce electrical currents in leads within the field. Lead length (vs radiofrequency wavelength) and conformations such as loops favor improved transition of energy to the implanted device. A study from our laboratory assessed the magnitude of MRI-induced current using a current recorder connected in series to single-chamber permanent pacemakers programmed to subthreshold asynchronous output during unipolar and bipolar pacing. Under conventional implant conditions (without additional lead loops), the magnitude of induced current was less than 0.5 mA. With the addition of five lead loops, current induction at greater than 30 mA was possible and resulted in myocardial capture. Additionally, breaking the return pathway by electrically isolating the pulse generator case from the circuit abolished low-frequency–induced current.[2]

Heating. The extent of radiofrequency energy deposition in tissues is described by the specific absorption rate (SAR). Metallic devices and leads can act as an antenna, thus amplifying local radiofrequency energy deposition, which may lead to heating and tissue damage at the device–tissue interface. Fractured leads or lead loop configurations may increase the potential for heating. Epicardial leads that are not cooled by blood flow may also be prone to increased heating. In our *in vivo* analysis of modern permanent pacemakers and ICDs, when performing clinical MRI protocols (SAR <2.0 W/kg), temperature changes were limited to 0.5°C.[1] However, it is important to note that due to poor correlation of heating at different SAR of sequences across different scanners, even within the same manufacturer, the

KEYWORDS Magnetic resonance imaging; Permanent pacemaker; Implantable cardioverter-defibrillator; Safety (Heart Rhythm 2009;6:138–143)

Dr. Halperin is a scientific advisor for Boston Scientific Inc. The Johns Hopkins University Advisory Committee on Conflict of Interest manages all commercial arrangements. **Address reprint requests and correspondence:** Dr. Saman Nazarian, Department of Medicine, Division of Cardiology, Johns Hopkins Hospital, Carnegie 568, 600 North Wolfe Street Baltimore, Maryland 21287. E-mail address: snazari1@jhmi.edu.

1547-5271/$ -see front matter doi:10.1016/j.hrthm.2008.10.021

SAR limits from each study should not be directly applied to other MRI systems.

Inappropriate pacing and shocks or inhibition of therapies. Pacemakers and ICDs have the potential for receiving electromagnetic interference in the MRI environment, resulting in radiofrequency noise tracking, asynchronous pacing, inhibition of demand pacing, delivery of ICD therapies, programming changes, or loss of function. The static magnetic field of the MRI scanner can alter device function by inducing unexpected reed switch opening or closure.

Such potential risks have led to concerns from device manufacturers and MRI authorities regarding the performance of MRI procedures in cardiac implantable device recipients. However, several studies have assessed techniques to safely perform MRI in recipients of implanted cardiac devices.

Implantable monitors

Patients with an implantable loop recorder (Reveal, Medtronic, Inc., Minneapolis, MN, USA) can be safely scanned.[3] However, the device may record MRI electromagnetic interference artifacts as arrhythmia. Care should be taken to clear episodes recorded during MRI to prevent future misinterpretation of artifact as clinically significant arrhythmia.

Temporary pacemakers

The majority of temporary pacemakers (implanted outside of the electrophysiology laboratory) have no-fixation leads that are prone to movement. Furthermore, the leads are longer and potentially more susceptible to induction of lead currents and heating. An *in vitro* study of temporary transvenous pacing leads showed that lead heating exceeding 15°C is common, and temperature rises up to 63.1 °C are possible.[4] Additionally, the electronic platform of external temporary pacemakers is less sophisticated and has less filtering compared with modern permanent pacemakers. Therefore, such devices likely are more susceptible to electromagnetic interference in the MRI environment, and imaging of patients with temporary pacemakers cannot be recommended.

Permanent pacemakers

Previous studies of clinical MRI in the setting of implanted devices are reviewed in Table 1. At our institution, we began the process of imaging patients with permanent pacemakers by extensive *in vitro* testing. Roguin et al[1] tested *in vitro* and *in vivo* lead heating, device function, torque, and image distortion at 1.5 T. Based on our *in vitro* and *in vivo* analyses, we then developed a protocol that included (1) device selection based on previous testing, (2) device programming to minimize inappropriate activation or inhibition of brady/tachyarrhythmia therapies, and (3) limitation of the specific absorption rate of MRI sequences (<2.0 W/kg).[5] The protocol is discussed in detail below. Using this protocol, we now have safely performed MRI on more than 200 patients with implantable devices. Our initial report of safety included 31 patients with permanent pacemakers, 22% of whom were pacemaker dependent. Pacing mode was changed to an asynchronous mode for pacemaker-dependent patients and to demand mode for other patients. Blood pressure, ECG, oximetry, and symptoms were monitored. In this initial study, we successfully limited the system-estimated whole-body average SAR to 2.0 W/kg in more than 99% of sequences while maintaining the diagnostic capability of MRI. No episodes of inappropriate inhibition or activation of pacing were observed, and there were no significant differences between baseline and immediate or long-term (median 99 days after MRI) sensing amplitudes, lead impedances, or pacing thresholds.[5]

Implantable cardioverter-defibrillators

During our *in vitro* testing of ICDs, several generators (manufactured before 2000) were damaged by MRI. Therefore, we focused our *in vivo* testing on ICDs manufactured after 2000. Such systems from the three major manufacturers were implanted in 18 dogs. After 4 weeks, 3- to 4-hour MRI scans were performed under worst-case scenario conditions (imaging over the region containing the generator and SAR up to 3.5 W/kg). No device dysfunction occurred. After 8 weeks of follow-up, pacing threshold and intracardiac electrogram amplitude were unchanged, except for one animal with transient (<12 hours) capture failure. Due to this observation, we currently do not perform MRI on pacemaker-dependent ICD patients. ICD leads are generally longer than pacemaker leads and therefore may be at higher risk for heating at the lead tip. Pathologic data of the scanned animals revealed very limited necrosis or fibrosis at the tip of the lead area, which was not different from controls not subjected to MRI.[1]

Based on our prior *in vitro* and *in vivo* testing, the safety protocol now has been used to safely scan more than 75 patients with ICDs. Our initial report of safety included 24 patients with ICDs. No episodes of inappropriate inhibition or activation of pacing were observed, and there were no significant differences between baseline and immediate or long-term sensing amplitudes, lead impedances, or pacing thresholds.[5]

Retained leads

No systematic studies assessing the potential risks associated with retained permanent pacemaker and ICD leads have been performed. Retained leads are prone to previously described risks of movement, heating, and current induction. Depending on their length and configuration, retained segments may be prone to significant temperature rises than leads that are attached to pulse generators. It has been our practice to exclude patients with retained lead fragments and unused capped leads from MRI. More studies to delineate risks in this patient group are warranted.