Randomized trial of pacemaker and lead system for safe scanning at 1.5 Tesla

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BACKGROUND Magnetic resonance imaging (MRI) of pacemakers is a relative contraindication because of the risks to the patient from potentially hazardous interactions between the MRI and the pacemaker system. Chest scans (ie, cardiac magnetic resonance scans) are of particular importance and higher risk. The previously Food and Drug Administration-approved magnetic resonance conditional system includes positioning restrictions, limiting the powerful utility of MRI.

OBJECTIVE To confirm the safety and effectiveness of a pacemaker system designed for safe whole body MRI without MRI scan positioning restrictions.

METHODS Primary eligibility criteria included standard dual-chamber pacing indications. Patients (n = 263) were randomized in a 2:1 ratio to undergo 16 chest and head scans at 1.5 T between 9 and 12 weeks postimplant (n = 177) or to not undergo MRI (n = 86) post-implant. Evaluation of the pacemaker system occurred immediately before, during (monitoring), and after MRI, 1-week post-MRI, and 1-month post-MRI, and similarly for controls. Primary end points measured the MRI-related complication-free rate for safety and compared pacing capture threshold between MRI and control subjects for effectiveness.

RESULTS There were no MRI-related complications during or after MRI in subjects undergoing MRI (n = 148). Differences in pacing capture threshold values from pre-MRI to 1-month post-MRI were minimal and similar between the MRI and control groups.

CONCLUSIONS This randomized trial demonstrates that the Advisa MRI pulse generator and CapSureFix MRI 5086MRI lead system is safe and effective in the 1.5 T MRI environment without positioning restrictions for MRI scans or limitations of body parts scanned.

KEYWORDS Advisa MRI; CapSureFix MRI; Chest scan; EnRhythm MRI; Magnetic resonance imaging; Pacemaker; Revo MRI; Safety; SureScan; 5086MRI

ABBREVIATIONS AEAC = adverse events adjudication committee; **MR** = magnetic resonance; **MRI** = magnetic resonance imaging; **PCT** = pacing capture threshold; **RF** = radiofrequency; **SAR** = specific absorption rate

(Heart Rhythm 2013;10:685–691)

Introduction

Safe, unrestricted whole body imaging, particularly of the thoracic region, is a critical unmet need for patients with pacemakers

Before the Food and Drug Administration approval of the Medtronic Revo MRI system, all pacemakers had a label warning against magnetic resonance imaging (MRI) scanning. The Revo MRI system has positioning restrictions for MRI scans around the chest region; the position of the isocenter of the radiofrequency (RF) transmitter coil must be above the C1 vertebra or below T12. This may pose a challenge to readily image thoracic structures optimally without degrading the resolution of the image.

Cardiac magnetic resonance (CMR) defines cardiac masses,[1] detects ischemia,[2] helps manage heart failure,[3] defines coronary flow reserve,[4] optimizes placement of cardiac resynchronization therapy leads,[5] and helps guide RF ablation therapy through the integration of MRI into clinical mapping systems.[6] CMR is being integrated wholesale into ablation/imaging suites.[7]

The Advisa MRI System Study was funded by Medtronic. The following persons are consultants to Medtronic: David Bello, David L. Hayes, Emanuel Kanal, J. Rod Gimbel, Juerg Schwitter, and Torsten Sommer. The following persons are employed by Medtronic: Yanping Chang and Sarah Willey. **Address reprint requests and correspondence:** Dr J. Rod Gimbel, Cardiology Associates of East Tennessee, 9330 Park West Blvd Ste 202, Knoxville, TN 37923-4310. E-mail address: gimbeljr@ix.netcom.com.

1547-5271/$-see front matter http://dx.doi.org/10.1016/j.hrthm.2013.01.022

Complex chronic cardiovascular disease requires safe, repeatable imaging defining a broad spectrum of cardiovascular pathologies coexisting within the same patient (with pacemaker). Without the development of pacing systems capable of easily and safely undergoing chest scans without positioning restrictions, many patients with cardiovascular diseases who would benefit most from MR scanning would be excluded.

Risks associated with MRI of patients with pacemakers

MRI of pacing systems not labeled MR conditional remains a cause of concern. Complications appear to occur at a frequency of $<10\%$,[8] and while some are rare[9] and clinically benign without a permanent impact, others are serious[10] and potentially life-threatening.[11] Underreporting of the ill effects of off-label scanning is probably common. In addition, when an adverse outcome occurs, litigation may follow,[12] further shrouding the details of the event.

Patient deaths during inadvertent scans or when patients were insufficiently monitored have been documented.[13–15] Despite an infrequent occurrence, the seemingly occasional random occurrence of life-threatening asystole[11] or ventricular fibrillation[15] may not provide satisfactory comfort for the device patient or physician contemplating MRI if technology exists that anticipates and addresses the risks involved in scanning patients with pacemakers. Within this context, the Advisa MRI pacemaker and CapSureFix 5086MRI lead system was developed to provide a safe, reliable access to MRI at 1.5 T without anatomical positioning restrictions.

Methods

Pacemaker system

Before the introduction of the Advisa MRI system for human use, preclinical testing involving bench and animal investigations as well as computer modeling was conducted to understand the effects of MRI on pacing systems.[16] Multiple system design modifications were required to ameliorate the adverse interactions seen in these investigations: (1) the leads were modified to reduce RF heating, (2) internal circuitry was designed to reduce the potential for inappropriate cardiac stimulation, (3) the amount of ferromagnetic materials was limited, (4) a robust front-end protection network and hybrid filtering was implemented to prevent disruption of the internal power supply and mitigate the effects of MRI energy coupling to the telemetry coil, (5) the reed switch was replaced with a Hall sensor (disengaged during the MRI SureScan mode) helping to provide predicable pacing during MRI, and (6) a dedicated programming care pathway was implemented to facilitate execution of a pre-MRI checklist and selection of tailored pacing settings appropriate for the patient during MRI. These modifications combine to effectively address the risks of MRI scanning in patients with pacemakers.

Trial design and patient selection

This was a prospective randomized controlled, nonblinded, multicenter trial (ClinicalTrials.gov Identifier NCT01110915). The Declaration of Helsinki was followed, as well as laws and regulations of participating countries. The institutional review board approval and patient informed consent were obtained. Enrollment required class I or II dual-chamber pacemaker indications[17] and pectoral implant. Patients agreed to undergo a protocol-required MRI without intravenous sedation, had no implanted non-MRI compatible devices or materials, had no other implantable-active medical devices, and had no abandoned leads. Assuming the actual atrial or ventricular pacing capture threshold (PCT) success rates were 96% in both the MRI and control groups, sample sizes of approximately 133 MRI and 67 control subjects would achieve 90% power to detect a 10% noninferiority margin difference by using the 1-sided Farrington and Manning method. The overall sample size was increased to 270 subjects to account for up to 25% attrition from enrollment to 1-month post-MRI to ensure 200 subjects would have primary end point data.

Randomization

After successful device implant, randomization took place in a 2:1 ratio to undergo (MRI group) or to not undergo (control group) an MRI scan 9–12 weeks after implant. Statisticians created randomization schedules stratified by center by using randomized block methods. The center-specific randomization schedule was transferred in sequence to labels in individually sealed envelopes, which were then opened in order.

Data collection and analysis

Follow-up occurred 2 months postimplant, 9–12 weeks postimplant, 1-week post-MRI/control, 1-month post-MRI/control, 6 months postimplant, and then every 6 months until study closure. The 9–12-week visit consisted of an evaluation immediately before MRI (pre-MRI evaluation), during MRI, and immediately after MRI (post-MRI evaluation), as well as at corresponding time points for the control group. During these evaluations, PCT at a pulse width of 0.5 ms, sensed electrocardiogram amplitude, and lead impedance were collected. Adverse events and technical observations were evaluated at all visits, including before and after the MRI scan. Pacemaker stored data, rhythm strips during PCT testing, and case report forms were collected.

MRI

The MRI scans were performed with 1.5 T systems from 3 commercially available MRI manufacturers (General Electric, Philips, and Siemens). MRI sequences were chosen to represent clinically relevant scans that were similar between scanners. Sixteen MRI head and chest scan sequences were performed. The scan protocol included MR scans with maximized RF energy deposition up to specific absorption rate (SAR) levels of 2 W/kg body and scans with maximized gradient slew rates. The body coil served as the RF transmit