Magnetic Resonance Imaging at 1.5-T in Patients With Implantable Cardioverter-Defibrillators

Claas P. Naehle, MD,* Katharina Strach, MD,* Daniel Thomas, MD,* Carsten Meyer, MD,* Markus Linhart, MD,‡ Sascha Bitaraf, MD,‡ Harold Litt, MD, PtlD,§ Jörg Otto Schwab, MD,† Hans Schild, MD,* Torsten Sommer, MD||
Bonn, Koblenz, and Neuwied, Germany; and Philadelphia, Pennsylvania

Objectives
Our aim was to establish and evaluate a strategy for safe performance of magnetic resonance imaging (MRI) at 1.5-T in patients with implantable cardioverter-defibrillators (ICDs).

Background
Expanding indications for ICD placement and MRI becoming the imaging modality of choice for many indications has created a growing demand for MRI in ICD patients, which is still considered an absolute contraindication.

Methods
Non–pacemaker-dependent ICD patients with a clinical need for MRI were included in the study. To minimize radiofrequency-related lead heating, the specific absorption rate was limited to 2 W/kg. ICDs were reprogrammed pre-MRI to avoid competitive pacing and potential pro-arrhythmia: 1) the lower rate limit was programmed as low as reasonably achievable; and 2) arrhythmia detection was programmed on, but therapy delivery was programmed off. Patients were monitored using electrocardiography and pulse oximetry. All ICDs were interrogated before and after the MRI examination and after 3 months, including measurement of pacing capture threshold, lead impedance, battery voltage, and serum troponin I.

Results
Eighteen ICD patients underwent a total of 18 MRI examinations at 1.5-T; all examinations were completed safely. All ICDs could be interrogated and reprogrammed normally post-MRI. No significant changes of pacing capture threshold, lead impedance, and serum troponin I were observed. Battery voltage decreased significantly from pre- to post-MRI. In 2 MRI examinations, oversensing of radiofrequency noise as ventricular fibrillation occurred. However, no attempt at therapy delivery was made.

Conclusions
MRI of non–pacemaker-dependent ICD patients can be performed with an acceptable risk/benefit ratio under controlled conditions by taking both MRI- and pacemaker-related precautions. (Implantable Cardioverter Defibrillators and Magnetic Resonance Imaging of the Heart at 1.5-Tesla; NCT00356239) (J Am Coll Cardiol 2009;54: 549–55) © 2009 by the American College of Cardiology Foundation

Recent studies have suggested that magnetic resonance imaging (MRI) at 1.5-T can be performed safely in patients with implanted cardiac pacemakers (PMs) in carefully selected circumstances. In comparison with PMs, safety issues in imaging of patients with implantable cardioverter-defibrillators (ICDs) are more complex. Although MRI was performed without complications previously (1–5), the presence of an ICD is still considered an off-label procedure and a strong relative contraindication for MRI (6,7), and most patients with ICDs are denied for MRI despite its unparalleled capabilities for diagnosis and planning of treatment. The purpose of our study was to establish a strategy for safe performance of MRI at 1.5-T in ICD patients and to evaluate the safety and feasibility of this strategy.

Methods

Study subjects. Eighteen patients with an ICD and an urgent clinical indication for MRI were enrolled prospectively. Inclusion and exclusion criteria are shown in Table 1.

See page 556

The study design is summarized in Table 2. The institutional review board of the relevant institution approved the study protocol. Signed informed consent was obtained from all subjects.
Pre/post-MRI ICD evaluation and reprogramming. All ICDs were interrogated before and immediately after MRI (Fig. 1). The following parameter changes pre/post MRI were defined to be clinically significant and MRI-related: 1) pacing capture threshold increase ≥1.0 V at 0.4 ms pulse duration; 2) increase or decrease of pacing lead impedance to >2,000 Ω or <200 Ω; 3) increase or decrease of high-voltage lead impedance to >80 Ω or <10 Ω (8); and 4) ability to interrogate the device. If any MRI-related parameter changes were noted, a chest X-ray and an ICD test were performed. Before MRI, all ICDs were reprogrammed to minimize the risk of interference with the MRI system (Fig. 1). Serum troponin I was measured within 1 h before and 12 min after MRI to detect myocardial injury. Each patient was asked to immediately inform the investigator of any torquing, movement, or heating sensation about the ICD pocket, and other unusual sensations during MRI.

Statistical analysis. Troponin I levels were compared using the Student t test; all other parameters were compared using the Wilcoxon signed rank test. The level of significance was set to a value of 0.05.

Results

The study group consisted of 18 consecutive patients (mean age 61.8 years) on which a total of 18 MRI examinations were performed. ICD models, ICD leads, and scanned MRI regions are given in Table 3. The 3-month follow-up interrogation was performed after 18 of 18 (100%) examinations (mean follow-up interval 92.8 days, range 73 to 115 days).

Clinical events during the MRI examinations. All MRI examinations (100%) were completed safely. None of the patients reported any torque or heating sensations, or other unusual symptoms during MRI. No unexpected changes in heart rate or rhythm, indicating inhibition of ICD output, shock delivery, or sustained atrial or ventricular arrhythmias were observed during any MRI examination (0 of 18, 0%).

ICD reprogramming. In 18 of 18 (100%) patients, the underlying intrinsic heart rate was >50 beats/min, and the ICDs were reprogrammed to an inhibited pacing mode with subthreshold pacing, or pacing was programmed “off” (Table 3). In 17 of 18 patients (94.4%), the ICD was programmed to a monitor-only mode (arrhythmia detection on, therapies delivery off). In 1 patient (1 of 18, 5.6%), both arrhythmia detection and therapy delivery were programmed “off,” as a monitor-only mode was not available in the specific device (Atlas, St. Jude Medical, St. Paul, Minnesota). In no patient (18 of 18, 100%) did an electrical reset occur during MRI.

ICD status. In all devices (18 of 18, 100%), the capability to interrogate the ICD device using telemetry remained preserved. No clinically significant change of pacing capture threshold or lead impedance was observed (Table 4). Mean
percentage change in lead impedance from pre-MRI to post-MRI was $-1.86 \pm 5.10 \Omega$, and from pre-MRI to follow-up $0.57 \pm 4.43 \Omega$. Mean battery voltage was $3.86 \pm 1.48$ V pre-MRI, $3.83 \pm 1.48$ V post-MRI, and $3.90 \pm 1.52$ V at follow-up (Table 4). The decrease in battery voltage from pre- to post-MRI was statistically significant ($p = 0.0420$). A full recovery of battery voltage at follow-up was observed after 4 of 16 (25.0%) MRI examinations.

Mean charge time pre-MRI, post-MRI, and at follow-up are given in Table 4. There was a significant decrease in the charge time from 11.15 $\pm 4.86$ s pre-MRI to 9.48 $\pm 4.28$ s post-MRI ($p = 0.0034$).

**RF oversensing/therapy delivery.** For 1 device (St. Jude Medical, Atlas) assessment of RF oversensing was not possible, as both tachyarrhythmia detection and therapy had to be deactivated in this device. For the remaining 17 magnetic resonance (MR) examinations, RF oversensing as ventricular arrhythmia occurred in 2 of 17 examinations (11.8%). As both devices (Guidant CPI Ventak Prizm DR and Guidant CPI Ventak Prizm 2 VR, Guidant [now Boston Scientific], Indianapolis, Indiana) had been reprogrammed to a detection-only mode before MRI according to the study protocol, no attempt at therapy delivery (0 of 2, 0%) was made.

**Troponin I.** Eighteen blood samples were analyzed, and no increase of troponin I level above the upper normal limit of 0.1 ng/ml was observed after any of the examinations (0 of 18, 0%) (Table 4).

**Discussion**

ICDs primarily monitor heart rate and rhythm for malignant tachycardia and deliver antitachycardia pacing (ATP) or direct current (DC) shock delivery to restore normal heart rate and rhythm. Therefore, ICDs differ from PMs to a great extent: 1) increased ferromagnetic mass (larger battery, presence of transformer and capacitor), increasing magnetic translation forces and torque; 2) longer leads with a larger diameter with shock coils; 3) advanced integrated circuitry allowing for analysis of both heart rate and rhythm; and 4) additional hardware (e.g., transformer, integrated circuitry, capacitor) and software to allow for therapy delivery with risk of damage to hardware components and inappropriate therapy delivery due to oversensing of electromagnetic noise by the MRI system.

**RF-related heating.** RF-related heating for ICD leads has been shown to reach up to 7.2°C in vitro (9), which is generally considered negligible in terms of safety and biologic effects (10). However, RF-induced heating is difficult to simulate in vitro given the numerous possible combinations of devices and leads and the infinite number of possible different geometric configurations of the leads within the chest, which are known to alter the amount of heating considerably (11). Therefore, to be conservative, we limited the SAR to 2.0 W/kg in our study to minimize the risk of RF-related lead heating. Maximum RF-induced heating occurs at the electrode-tissue boundary and may lead to deterioration of pacing thresholds (9,12). The finding that lead impedances and pacing thresholds remained unchanged in our study and that no increase in troponin I was measured after MRI confirm that no clinically relevant thermal injury occurred at the ICD lead tips (Fig. 2). These findings are concordant with previous studies and several case reports, which also did not find any evidence for thermal injury after MRI in ICD patients (1–5,9).
### Table 3  Patient, MRI Examination, and ICD System Characteristics Including Programmed Parameters During MRI

<table>
<thead>
<tr>
<th>MRI Examination</th>
<th>Patient Age (yrs)</th>
<th>Scanned Region</th>
<th>ICD Manufacturer and Model*</th>
<th>Leads</th>
<th>Pacing Mode</th>
<th>Antitachycardia Mode</th>
<th>RF Oversensing</th>
<th>Battery Voltage at Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69.3</td>
<td>Heart</td>
<td>Medtronic GEM III</td>
<td>A: —</td>
<td>V: Medtronic 6947 (Sprint Quattro Secure) Add: —</td>
<td>VVI/sth</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>43.9</td>
<td>Brain</td>
<td>Biotronik Lexos VR</td>
<td>A: —</td>
<td>V: Medtronic 6943 (Sprint) Add: —</td>
<td>Off</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>76.9</td>
<td>Cervical spine</td>
<td>Ela Medical Defender</td>
<td>A: Medtronic 5068 (CapsureFix) V: Medtronic 6943 (Sprint) Add: —</td>
<td>VVI/sth</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
<td>No data</td>
</tr>
<tr>
<td>4</td>
<td>84.2</td>
<td>MRA legs</td>
<td>Ela Medical Alto</td>
<td>A: unknown V: Ela 4041 (AngePass) Add: —</td>
<td>VVI/sth</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
<td>No data</td>
</tr>
<tr>
<td>5</td>
<td>49.3</td>
<td>Heart</td>
<td>Guidant CPI Vitality 2</td>
<td>A: —</td>
<td>V: Medtronic 6943 (Sprint) Add: —</td>
<td>Off</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>72.6</td>
<td>Abdomen</td>
<td>Medtronic GEM II VR</td>
<td>A: —</td>
<td>V: Medtronic 6942 (Sprint) Add: —</td>
<td>VVI/sth</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>46.9</td>
<td>Entire spine</td>
<td>Medtronic Jewel 7221 Cx</td>
<td>A: —</td>
<td>V: Medtronic 6936 (Transvene RV) Add: —</td>
<td>OV0</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>64.4</td>
<td>Thoracic and lumbar spine</td>
<td>Medtronic Maximo VR 7232</td>
<td>A: —</td>
<td>V: Medtronic 6947 (Sprint Quattro Secure) Add: —</td>
<td>OV0</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>70.9</td>
<td>Brain</td>
<td>Guidant CPI Ventak PRIZM 2 VR</td>
<td>A: —</td>
<td>V: Guidant 0155 (Endotak Endurance EZ) Add: —</td>
<td>Off</td>
<td>Detection enabled, therapy disabled</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>60.8</td>
<td>Brain</td>
<td>Medtronic GEM II VR 7229 Cx</td>
<td>A: —</td>
<td>V: Medtronic 6943 Sprint Add: Medtronic 6996 (SQ)</td>
<td>VVI/sth</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>11</td>
<td>51.9</td>
<td>Lumbar spine</td>
<td>St. Jude Medical Atlas VR</td>
<td>A: —</td>
<td>V: St. Jude Medical 1582 (Riata) Add: —</td>
<td>Off</td>
<td>Off (detection disabled, therapy disabled)</td>
<td>No</td>
</tr>
<tr>
<td>12</td>
<td>78.2</td>
<td>Thoracic and lumbar spine</td>
<td>Guidant CPI Vitality 2 PRIZM DR</td>
<td>A: —</td>
<td>V: Guidant 0176 (Endotak Reliance G) Add: —</td>
<td>Off</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>13</td>
<td>54.1</td>
<td>Heart</td>
<td>Medtronic GEM III</td>
<td>A: Ela BSC45 (Stela) V: Medtronic 6943 Sprint Add: —</td>
<td>VVI/sth</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
<td>Partial recovery</td>
</tr>
<tr>
<td>14</td>
<td>38.7</td>
<td>Heart</td>
<td>Guidant CPI Ventak PRIZM DR</td>
<td>A: Medtronic 4269 (Sweet Tip) V: Guidant 0125 (Endotak DSP) Add: —</td>
<td>Off</td>
<td>Detection enabled, therapy disabled</td>
<td>Yes</td>
<td>Complete recovery</td>
</tr>
<tr>
<td>15</td>
<td>54.5</td>
<td>Heart</td>
<td>Medtronic GEM III</td>
<td>A: Ela BSC45 (Stela) V: Medtronic 6943 Sprint Add: —</td>
<td>VVI/sth</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
<td>Partial recovery</td>
</tr>
<tr>
<td>16</td>
<td>66.5</td>
<td>Brain</td>
<td>Biotronik Lexos VR-T</td>
<td>A: —</td>
<td>V: Biotronik Kentrox RV 75 Add: —</td>
<td>Off</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>17</td>
<td>67.0</td>
<td>Brain</td>
<td>Biotronik Lexos VR-T</td>
<td>A: —</td>
<td>V: Biotronik Kentrox RV 75 Add: —</td>
<td>Off</td>
<td>Detection enabled, therapy disabled</td>
<td>No</td>
</tr>
<tr>
<td>18</td>
<td>73.0</td>
<td>Knee</td>
<td>Medtronic Insync III Marquis</td>
<td>A: Medtronic 4076 V: Medtronic 6943 Sprint Add: Medtronic 4194 (coronary sinus)</td>
<td>VVI/sth</td>
<td>Detection enabled, therapy disabled</td>
<td>OVO</td>
<td>No recovery</td>
</tr>
</tbody>
</table>

Complete recovery = recovery of battery voltage at follow-up compared with pre-MRI baseline value; No recovery = decrease of battery voltage ≥0.05 V at follow-up compared with pre-MRI baseline value; Partial recovery = decrease of battery voltage −0.01 V and −0.05 V at follow-up compared with pre-MRI baseline value. *Manufacturers: Biotronik, Berlin, Germany; Ela Medical (now Sorin Group), Munich, Germany; see text for details of the other manufacturers.

A = atrial; Add = additional lead(s); MRA = magnetic resonance angiography; RF = radiofrequency; sth = subthreshold; V = ventricular; OVO = sense-only mode; other abbreviations as in Table 1.
MRI interference with ICD functionality. Oversensing of RF fields. In our study, oversensing of RF noise as ventricular fibrillation was observed in 2 of 17 MRI examinations (Fig. 3). Due to deactivation of therapy delivery before MRI, no attempt at therapy delivery was recorded (Fig. 4). To date, it seems highly unlikely that ICDs can perform DC shock delivery within the MR environment. For DC shock delivery (20 to 700 V), the battery voltage (3 to 6 V) has to be transformed to charge the capacitor. However, the static magnetic field saturates the transformer, resulting in a short circuit with ineffective voltage transformation and the inability to charge the capacitor (13). However, other important safety issues are associated with oversensing of MR noise by ICDs: 1) unintended attempts to charge the capacitor can cause battery depletion; 2) some ICD devices permanently inactivate therapy delivery after a certain number of unsuccessful attempts to charge the capacitor, which might necessitate device replacement; 3) inappropriate ATP due to RF oversensing could induce ventricular arrhythmia due to asynchronous stimulation; and 4) a short circuit within the electronic circuits may permanently damage the ICD (14,15), necessitating device replacement. Therefore, to minimize the risk of attempted inadequate therapy delivery due to RF oversensing, therapy delivery (ATP and DC shock) was completely deactivated before MRI.

Reed switch. In magnetic fields >200 mT, the reed switch remains open in 50% of spatial orientations and is closed only in 50% of spatial orientations (13) with consecutive deactivation of therapy delivery. Reactivation of therapy delivery after opening of the reed switch is manufacturer dependent (16). Therefore, ICD reprogramming before MRI with deactivation of therapy delivery and ICD interrogation after MRI is mandatory to ensure appropriate device programming with reactivated arrhythmia detection and therapy delivery.

Capacitor testing. The time needed to fully charge the capacitor is an important indicator for effective therapy delivery, because a prolonged charge time can lead to ineffective therapy delivery (17,18). In our study, the charge time decreased significantly from pre- to post-MRI measurement. We theorize that this decrease in charge time is not MRI related, but rather due to the charge test performed before MRI, leaving the capacitor already reformatted for post-MRI testing and leading to a decreased charge time by itself.

Table 4 ICD Data Before and After MRI and at Follow-Up in 18 ICD Patients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-MRI</th>
<th>Post-MRI</th>
<th>Follow-Up</th>
<th>p Value (Pre-/Post-MRI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCT (V)</td>
<td>1.01 ± 0.83</td>
<td>1.00 ± 0.84</td>
<td>1.03 ± 0.80</td>
<td>0.5000 (n = 23)</td>
</tr>
<tr>
<td>Lead impedance (Ω)</td>
<td>594.0 ± 151.7</td>
<td>581.0 ± 145.4</td>
<td>595.6 ± 153.4</td>
<td>0.1297 (n = 23)</td>
</tr>
<tr>
<td>HV impedance (Ω)</td>
<td>39.4 ± 18.4</td>
<td>39.6 ± 19.2</td>
<td>37.6 ± 17.6</td>
<td>0.8125 (n = 14)</td>
</tr>
<tr>
<td>Battery voltage (V)</td>
<td>3.86 ± 1.48</td>
<td>3.83 ± 1.51</td>
<td>3.90 ± 1.52</td>
<td>0.0420 (n = 16)</td>
</tr>
<tr>
<td>Charge time (s)</td>
<td>11.2 ± 4.9</td>
<td>9.5 ± 4.28</td>
<td>10.6 ± 4.6</td>
<td>0.0034 (n = 12)</td>
</tr>
<tr>
<td>Troponin (ng/ml)</td>
<td>0.01 ± 0.01</td>
<td>0.01 ± 0.01</td>
<td>—</td>
<td>0.2596 (n = 18)</td>
</tr>
</tbody>
</table>

HV = high-voltage; PCT = pacing capture threshold; other abbreviations as in Table 1.

Figure 2 Midventricular Short-Axis MRIs of the Heart in a Patient With a Chronic MI

(Left) Steady-state free precession sequence, demonstrating wall thinning of the septal wall. (Right) Three-dimensional inversion recovery viability imaging, indicating the myocardial scar in the septum (black arrow). Note the susceptibility artifacts in the right ventricle due to the implantable cardioverter-defibrillator lead (open arrows) and in the pectoral region due to the implantable cardioverter-defibrillator (*). MI = myocardial infarction; MRI = magnetic resonance imaging.
BATTERY VOLTAGE. In the present study on ICDs in the MRI environment, a slight, but significant (p = 0.0420) decrease in battery voltage (3.86 ± 1.48 V vs. 3.83 ± 1.51 V) was demonstrated from pre- to post-MRI. Several mechanisms can lead to battery depletion: 1) charging of the capacitor due to oversensing of RF noise; 2) sustained activation of telemetry due to closure of the reed switch; and 3) electrical short circuits within the ICD. In the present studies, no attempts to charge the capacitor were noted, and it is unknown to what extent the activation of telemetry and possible short circuits contributed to the drop in battery voltage. Therefore, it is mandatory to perform a complete device interrogation immediately after MRI to assess if: 1) battery depletion; 2) an electrical reset with subsequent restoration of factory default settings; or 3) permanent inactivation of therapy delivery due to multiple attempts to charge the capacitor has occurred.

Contrary to previous PM studies, in which a complete recovery was noted in 66.1% of the MRI examinations (12), in this study a complete recovery of battery voltage was noted in only 4 of 16 examinations (25.0%). In addition, after 3 of 16 (18.8%) examinations in our study, a persisting decrease in battery voltage ≤0.05 V was observed. This finding may be of major importance for several reasons: 1) a decrease in battery voltage can lead to a prolonged charge time, which, in turn, delays therapy delivery for malignant ventricular tachycardia and decreases the likelihood of successful rhythm conversion (19); and 2) a decrease in battery voltage may necessitate early device replacement.

---

**Figure 3** EGM Recorded at the Beginning of an MRI Sequence

Traces shown from top to bottom are: ventricular electrogram (EGM), shock coil EGM, and marker channel. Initial ventricular EGM shows regular sensing of intrinsic ventricular signals with correct classification as ventricular sensing (VS) (*). After the start of the scan sequence with radiofrequency pulses for image acquisition, oversensing of radiofrequency noise in the ventricular EGM occurs with classification as ventricular fibrillation (VF) (arrows) by the arrhythmia detection algorithm (see marker channel). MRI = magnetic resonance imaging.

**Figure 4** EGM With Sustained Oversensing of RF Noise by an ICD During MRI

Traces shown from top to bottom are ventricular electrogram (EGM), shock coil EGM, and marker channel. Radiofrequency (RF) noise (ventricular channel, top trace) is classified as ventricular fibrillation (VF) (arrows) by the arrhythmia detection algorithm (see marker channel). However, no therapy delivery was attempted as the device was reprogrammed to a monitor only mode (*) before MRI. Abbreviations as in Figure 1.
Conclusions

The results of the present study demonstrate that MR examinations in patients with ICDs may be performed safely under controlled conditions and using several precautionary measures, including: 1) minimizing the risk of RF-related lead heating and myocardial thermal injury limitation by limiting the SAR to 2.0 W/kg; 2) reprogramming the ICD with deactivation of therapy delivery; 3) reprogramming the ICD to VVI pacing with the lowest possible lower rate limit; 4) continuous monitoring of electrocardiogram and pulse oximetry; 5) presence of an electrophysiologist and full resuscitation facilities at the MRI site; 6) ICD interrogation immediately after MRI to exclude clinically relevant changes in the technical and functional ICD parameters; and 7) exclusion of PM-dependent ICD patients. Utilizing these ICD, MRI, and monitoring-related safety precautions, we did not observe any damage to the ICD systems, any unexpected changes in heart rate or rhythm, any attempted therapy delivery, or any evidence for RF-related myocardial thermal damage during or after MRI. Therefore, we believe that in selected patients with an urgent clinical need to undergo MRI in the absence of an alternative imaging modality, MRI in patients with ICDs at 1.5-T carries an acceptable benefit/risk ratio.

Reprint requests and correspondence: Dr. Claas P. Naehle, Department of Radiology, University of Bonn, Sigmund-Freud-Str. 25, 53105 Bonn, Germany. E-mail: cp@naehle.net.

REFERENCES


Key Words: magnetic resonance imaging • implantable cardioverter-defibrillator • safety.