Cardiac MR Imaging of Patients with Cardiac Implantable Electronic Devices: A Changing Landscape

Joel E. Fishman MD PhD¹
Raul Mitrani MD²
Italo Novoa MD²

Department of Radiology¹ and Division of Cardiology²
Leonard Miller School of Medicine
University of Miami, Miami FL USA
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Learning Objectives

1. Understand the documented and possible risks of performing MR in patients with non-MR conditional CIEDs (cardiac implantable electronic devices).
2. Outline the protocol for screening and scanning patients with CIEDs that either are or are not MR conditional, including the roles of radiology and cardiology personnel.
3. Recognize artifacts on cardiac MR scans of patients with CIEDs and potential methods to reduce them.

Outcomes

The ability to confidently triage, perform, and interpret non-cardiac and cardiac MR scans in patients with CIEDs.
CIEDs

• Pacemakers:
  – Single chamber: single RA or RV lead
  – Dual chamber: RA and RV leads
    • diseases of SA node, AV node, or conduction pathways
  – Biventricular (CRT/cardiac resynchronization tx): 3 leads
    • interventricular conduction delay, refractory cardiomyopathy

• ICD: one or two shock coils
  – Ventricular, also acts as pacemaker
  – Chest wall

• > 300,000 new and 150,000 revised CIEDs implanted in US in 2009
Some CIED types and configurations

**Single lead pacer on left**
- https://stanfordhealthcare.org/medical-treatments/p/pacemaker.html

**Dual lead pacer on left**
- http://dxline.info/img/new_ail/heart-pacemaker_1.jpg

**Dual lead pacer on right**

**Single lead ICD on left**

**Dual lead ICD on left**

**CRT on left**
CIEDs and MR Scanning

• ~50-75% of patients with CIEDs will require an MR scan during the lifetime of the device
  – Most NON-cardiac
  – Perhaps 200,000 patients/yr not receiving MR in US because of CIED

• Potentially serious adverse effects on CIEDs
  – Several fatalities in the 1980s (patients were scanned unaware of CIED presence)
  – Non-fatal adverse effects also documented
Factors Affecting Safe Scanning of CIEDs

- Device
  - Presence of Ferromagnetic Material (mainly ICDs)
    - Device movement rarely observed, not significant concern
  - Reed switch: present in most pacemaker/ICDs
    - Closes in response to magnet causing program change
    - MR magnet may-> reed switch activation
      - > asynchronous pacing, disabled tachycardia detection
  - Electromagnetic interference from RF and gradients
    - May cause programming changes & device malfunction
  - Lead composition, configuration, and integrity
    - Induced currents including abandoned leads->altered detection, heating of lead and tissues in contact
Factors Affecting Safe Scanning of CIEDs

• Scanner
  – Magnet strength
    • Vast majority of experience at 1.5T, fewer at 3T
      – But many MR conditional devices approved at 3T
    – RF power concern: heating esp leads, at myocardial interface -> scarring
      • Avoid fractured, abandoned, or intact epicardial leads
    – RF and gradient concern: spurious signals ➔ inhibited pacing if interpreted as cardiac activity
      • Apply limits to gradient strength and slew rate
      • Appropriate device reprogramming
Hints to an Abandoned Lead

Tip of disconnected lead near generator

Two leads in a chamber—one likely disconnected
Clinical Status of MR and CIEDs, ca. 2010

• Presence of CIED was considered absolute contraindication for MR by many providers

• Clinical need -> multiple centers with protocols for CIED MR
  – Small studies (<100 patients)
  – No fatalities and relatively few adverse effects

• AHA issued recommendations for:
  • Screening & device characterization
  • Risk/benefit analysis
  • Informed consent
  • Appropriate physician supervision/management
    – Am Heart Assoc: Circulation 2007; 116: 2878-2891
Two Large Studies Support Safety of MR in CIED Patients

- 438 patients, 555 MR scans (16% cardiac)
- 54% pacers, 46% ICD
- 3 power-on-reset events (0.7%)
- Small statistically, but not clinically, significant changes in several pacemaker parameters
- Parameter changes slightly greater for thoracic vs non-thoracic scans
- Suggestion of slightly greater changes for multiple MR

MagnaSafe Registry: Russo R et al, NEJM 2017;376:755-64
- 1500 non-thoracic MR
- 1000 PM, 500 ICD
- 1 ICD generator required replacement
- Changes in ICD lead impedance (16%), pacing threshold (<1%), others minor
- Conclusion “Device or lead failure did not occur” if procedures were followed
Safety: Repeated CMR in AICD
Junttila et al, Heart 2011;97:1852

- AICDs of potentially greater concern than pacemakers: larger generator and leads
- 10 subjects with AICD received 3 CMR
- Measured pacing capture threshold, pacing and high voltage lead impedance, battery voltage
- No acute events or significant changes in device parameters over median 370 day f/u
Summary of Risks of MR in Patients with CIEDs

Observed in Clinical Trials

- Decreased battery voltage
- Electrical changes to device parameters
  - Sensing
  - Capture
  - Impedance
  - Pacing threshold increase (prob 2° heating): 3-9% of leads but rarely needs reprogramming
- Power-on-reset
- Troponin elevation
- Ectopy

Possible

- Device movement
  - If ferromagnetic
- Inappropriate delivery of therapy (defibrillation)
  - If not correctly programmed
- VF/VT during MR requiring defibrillation
  - AICD therapy disabled during MR: crash cart outside scanner
- Device damage/altered programmability requiring device replacement

MR Conditional CIEDs

• Previous info concerned devices not approved for MR
• Terminology: MR Conditional (not “MR compatible”) or “MR safe”)
• MR Conditional: an item that has been demonstrated to pose no known hazards in a specified MR environment with specified conditions of use
  – “conditions” refer to MR specifics such as field strength, gradient strength and slew rate, SAR
  – Follow specific conditions listed by manufacturers
  – FDA approved CIEDs are classified Conditional 5
MR-Conditional CIEDs*

FDA approved^

- Medtronic: SureScan system
  - Pacemakers: Revo, Advisa#
  - ICDs: Visia#, Evera#
  - CRT-Ds: Amplia#, Compia#, Claria
- Medtronic Micra# (leadless pacemaker)
- Biotronik: ProMRI system
  - Pacemaker: Entovis, Eluna
  - ICDs: Iperia, Iventra
- Boston Scientific: Imageready system
  - Pacemakers: Accolade, Essentio
  - ICDs: Emblem S-ICD

Approved outside US or pending FDA

- St. Jude Medical
  - Pacemakers: Accent, Assurity, Endurity
  - ICD: Ellipse, Fortify Assura
  - CRT-D: Quadra Assura, Allure MP
- Sorin/LivaNova
  - Pacemaker: Kora

*As of January 2017

^All components (generator, leads, etc) require approval

#Approved at 1.5T and 3T
Some MR-Conditional CIEDs

Medtronic Revo SureScan pacemaker: first FDA approved MR-conditional CIED (2011)

Medtronic CRT-D (ICD)
www.medtronic.com

Biotronik ICD
www.biotronik.com

Boston Scientific S-ICD (chest wall lead)
www.bostonscientific.com
MR in Patients with CIEDs: Role of Radiology

1. Review request for MR
2. Indicated and Appropriate (see next slide for CMR)? Clinician documents need
   - Device related (see next slide)
   - Non-device related
3. Contraindication to MR?
   - Yes
4. MR conditional CIED?
   - Yes
   - See ahead
   - Non-MR imaging options
5. Schedule MR in coordination with EP Cardiology
6. On/before day of exam:
   - Informed Consent
   - Insure appropriate scan protocol (SAR limits, scan duration)
7. MR exam
   - Monitoring during scan
   - Radiologist availability during scan
   - Review images prior to scan termination
8. Device programming per Cardiology pre/post (see 2 slides ahead)
MR in Patients with CIEDs: Role of Cardiology  

Prescreening

Appropriate clinical indication?  
- Infiltrative disorders, eg amyloid, sarcoid, hemochrom.  
- Restrictive CMP vs constrictive pericarditis  
- Ischemic vs non ischemic CMP  
- Prediction of post MI mortality  
- Acute CMP/myocarditis  
- Intracavitary thrombosis/mass  
- Scar quantification pre ablation  
- Congenital heart disease

If Cardiac MR, is request appropriate?  
Yes

Contraindication to MR?  
No

Risk/benefit assessment performed?  
Informed consent signed (non MR-conditional device)?  
Yes

CIED related contraindications  
- Implanted < 4-6 weeks  
- Implanted lead extenders, adaptors, or abandoned leads  
- Insulation break (impedance ≤ 200 Ω) or conductor fracture (impedance ≥ 1,500 Ω)  
- Device older than 2001  
- Pacemaker dependent (AICD)  
- Pacing capture threshold > 2.0 V at 0.4 ms in pacer dependent patients (relative contraindication)

Non-MR imaging options
MR in Patients with CIEDs: Role of Cardiology Day of MR

Patient in MR holding area or nearby EP clinic

- Yes

Monitor vital signs, check device settings, device parameters, device type and generator

AICD

- Pacemaker dependent: USE ALTERNATIVE IMAGING MODALITY
- Non pacemaker dependent:
  - REPROGRAM inhibited mode (VVI/DDI usually at a backup rate of 40-50 depending on the patient’s intrinsic rate)
  - DEACTIVATE tachyarrhythmia DETECTIONS (VT /VF detect OFF)

Pacemaker

- Pacemaker dependent: MR conditional CIED-REPROGRAM asynchronous mode (VOO/DOO)
- Non-MR Conditional: relative contraindication
  - The pacing rate should exceed the patient’s intrinsic rate by 10-15 bpm to avoid competition
- Non pacemaker dependent: REPROGRAM inhibited mode (VVI/DDI usually at a backup rate of 40-50 depending on the patient’s intrinsic rate)

DEACTIVATE magnet, rate, PVC, noise, ventricular sense and conducted atrial fibrillation response
**CMR in Patients with CIEDs: Role of Cardiology During & After MR**

### Non MR-conditional devices
- A cardiac electrophysiologist/nurse trained in ACLS with implantable device programming experience must be present.

1. Monitor: Oxygen saturation, Blood pressure, EKG, Symptoms
2. Visual and verbal contact with the patient
3. Pacemaker, ICD, CRT-D Requirements: An external defibrillator must be available nearby during the MRI procedure.
4. Cardiac arrest cart available.

### MR-conditional devices
- At least one staff member who has completed online ed. must be present.

### MR complete
- Compare device parameters with baseline values (lead impedance, capture threshold, P/R wave sensing, battery voltage)
- Reprogram to original settings
- Follow-up interrogation in six months
Scanning of MR Conditional CIEDs

• Requirements for Radiology, Cardiology, Support Staff
  – Complete online education at mfr’s website
  – Verify MR conditional status of device
  – Device switched to MR-mode “ON” for scan, “OFF” afterwards
  – ICD will NOT give therapy while MR-mode “ON”

• See manufacturers website for checklists
Cardiac MR: Image Quality

- Metal causes MR artifacts esp. generator
- The larger the generator (especially if ICD) the greater the artifacts
- The proximity of the generator to the heart is a crucial factor
  - Right sided pacemakers essentially CMR artifact-free
  - Unfortunately right sided ICDs are uncommon, because defibrillation threshold is lower if generator on the left
Image Quality in CMR w/ CIED

- Artifacts affect all sequences (especially SSFP and delayed enhancement)
- Anterior/septal/apical regions most affected
- Sasaki et al, Circ Cardiovasc Imag 2011;4:662
  - ICD artifacts significantly worse than pacemaker
- Naehle et al, AHJ 2011;161:1096 (10 ICD, 22 PM)
  - GRE cine instead of SSFP if device on left side
Patient pre-CIED insertion

Gradient echo

Same patient post-CIED insertion

SSFP

LGE
How Distance from the CIED Generator to the Heart affects Delayed Enhancement CMR Image Quality

Artifact: loss of visualization of antero septal wall

Distance: generator to lead (cm)

myocardial segments degraded (AHA 17 segments)

$r^2 = .47$
SSFP sequences highly susceptible to CIED generator artifact
Use GRE cine instead of SSFP sequences if CIED on the left

Generator artifact

Click over images to play cines

SSFP

GRE
Increasing bandwidth decreases generator artifact size at cost of increased noise.
Elevation of left arm may increase distance of CIED to heart and reduce artifact:
2D LGE artifact reduction
Rashid S et al, Radiology 2014 270:1, 269-274

- 2D LGE sequence
- wideband inversion pulse
- 10/12 patients: uninterpretable segment(s) with standard but not wideband inversion pulse
3D LGE artifact reduction

- 3D LGE sequence
- wideband inversion pulse
- increased bandwidth of excitation pulse
Conclusions: MR of CIED patients

• Most existing and newly implanted CIEDs worldwide are not MR conditional

• Nevertheless, patients may be safely imaged:
  – After patient and device screening
  – With appropriate device programming & scanning protocol
  – Close collaboration between Radiology and Cardiology
  – More experience at 3T is needed

• MR conditional devices: follow manufacturer’s guidelines

• Approval status of CIEDs differs in different countries
Conclusions: CMR of CIED patients

- Image quality concerns (esp. anterior/apical)
- GRE sequences have less artifacts than SSFP
- Use increased bandwidth of inversion and excitation pulses
- Better images the further the generator is from the heart (esp R sided CIED)
References/suggested readings

1. Miller JD et al, JACC 2016;68(14):1590-8
3. Junttila et al, Heart 2011;97:1852-6
4. Rashid S et al, Radiology 2014;270:1,269-274
For more information, contact
Dr Joel Fishman at
jfisman@miami.edu