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Cardiac implanted electronic devices and MRI safety in 2018—the state of play

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Abstract

Traditionally, the presence of cardiac implanted electronic devices (CIEDs) was a contra-indication to magnetic resonance (MR) imaging. Professional groups from around the world are releasing updated guidelines for the imaging of MR-conditional and legacy CIEDs, reflecting increasing evidence that this can be performed safely when strict protocols are followed.

Key Points

- *The presence of a pacemaker or automatic implanted cardioverter defibrillator is no longer an absolute contraindication to magnetic resonance imaging.*
- *Strict protocols enable diagnostic quality images to be obtained with minimal risk.*
- *Close collaboration among radiologists, cardiologists and device manufacturer representatives is required.*

Keywords Artificial cardiac pacemaker · Imaging, magnetic resonance · Equipment safety · Cardiac imaging techniques

Abbreviations

AICD	Automatic implanted cardioverter defibrillator
B1+RMS	Derived from the root mean square [RMS] of the flip angle [B_{1+}]
CIED	Cardiac-implanted electronic device
MR	Magnetic resonance
MRI	Magnetic resonance imaging
SAR	Specific absorption rate
1.5T	1.5 Tesla
3T	3 Tesla

Introduction

In 2018, cardiac implanted electronic devices (CIEDs) such as pacemakers and automatic implanted cardioverter defibrillators (AICDs) are no longer an absolute contraindication to magnetic resonance imaging (MRI) in many clinical scenarios. High-quality diagnostic images can now be obtained safely under strict conditions.

The German Roentgen Society [1], British Heart Rhythm Society [2], Heart Rhythm Society [3] and European Society of Cardiology [4], in collaboration with other professional groups, each provide guidelines for magnetic resonance (MR) imaging in the setting of conditional and non-conditional CIEDs. They recommend close cooperation between cardiologists and radiologists.

Safety concerns

Potential safety concerns exist in this setting, which include Reed switch activation, induced currents, heating, torque, antenna effects, device re-programming, 'power on reset' and inappropriate therapies [1, 3]. Deaths have occurred in cases of inadvertent MRI of patients with CIEDs, where tailored protocols were not instituted [5]. However, a recent systematic review identified only 19 clinically relevant

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adverse events from 6237 MRI studies performed under controlled conditions with no fatalities [6].

MR-conditional status

Considerable research and development have resulted in CIEDs that exhibit minimal response to the static magnetic, gradient and RF fields present during MRI. MR-conditional status is granted to leads and generators in specific combinations at specific field strengths. Combinations of components from different vendors (even if individually meeting appropriate criteria) are not granted MR-conditional status.

Conditions for MRI vary between devices and their manufacturers. These should be reviewed on a case-by-case basis and usually include time since device insertion, region being scanned, specific device programming, residual battery power and MRI system parameters and acquired sequences.

MRI in the presence of MR-conditional CIEDs

Institutional protocols should be established that include the CIED managing physician's determination of MR-conditional status in each case. The manufacturer and model of the generator and leads should be documented as well as the insertion date. A chest radiograph can help to determine the presence of epicardial, abandoned or fractured leads, which can render an otherwise MR-conditional system non-conditional. Prior to scanning, the imaging service should coordinate with device manufacturer representatives to arrange for appropriate CIED reprogramming [7].

If the CIED and MRI system meet MR-conditional requirements, an imaging protocol should be designed that ensures the estimated energy absorbed by the device does not breach mandated thresholds for each sequence. The device should be returned to its standard settings at the completion of the study, clear of the scanner magnetic field.

Advanced Cardiac Life Support-trained staff should be available for the duration of the study from the time the CIED is reprogrammed until reassessed and declared stable to return to unmonitored status. ECG, blood pressure and pulse-oximetry monitoring should occur over this period [1, 3, 8].

MRI can be reasonably performed within the post-insertion exemption period (technically outside the MR-conditional criteria), where the cardiology/radiology consensus concludes that benefit outweighs the risk [9]. In such cases, e.g. with AICD and pacemakers, scanning with the arms by the paient's side may be useful.

Table 1. Techniques to reduce B_{1+RMS} [12] (with permission)

Increased RF pulse duration
Use of "low SAR mode"
Increased TR without reducing slice number
Reduced slices for set TR
Reduced ETL
Reduced refocusing angle (FSE sequences)
Reduced flip angle (GRE sequences)
Use of GRE sequences in place of SE or FSE sequences

Radiofrequency (RF); specific absorption rate (SAR); repetition time (TR); echo train length (ETL); fast spin echo (FSE); gradient recalled echo (GRE); spin echo (SE)

Specific absorption rate (SAR) and B1+RMS

SAR is the traditional metric used for estimating whole-body energy deposition during an MRI study and is still used widely for scanning thresholds. However, it has been found to be variable and potentially unreliable when used to guide imaging protocols in the setting of in-situ CIEDs [10, 11]. B1+RMS (derived from the root mean square [RMS] of the flip angle [B_{1+}]) is reportedly a more accurate estimation of energy deposition. It is increasingly being used to define thresholds for devices at 3T. Techniques used to reduce SAR will also usually reduce B1+RMS (Table 1 [12]).

MRI in the presence of non-conditional CIEDs

Imaging with legacy CIEDs in situ is inconsistent between institutions, partly because of limited experience as well as uncertainty related to legal ramifications of complications in the setting of 'off-label' use. Risks posed by imaging patients with AICD are considered higher than for other CIEDs as most have underlying structural heart disease and more complex interactions between the device and MRI components. Registry data [8] and recent large series [13, 14] have provided evidence that in appropriate circumstances, MRI (including cardiac imaging [15]) can be reasonably performed at 1.5T in patients with non-conditional CIEDs. Strict adherence to an institutional protocol that documents the risk-benefit analysis, pre- and post-imaging CIED settings and imaging sequence design is essential.

Pacemaker dependence should be identified and documented: In those patients identified as dependent, the device should be programmed to asynchronous pacing (VOO/DOO) and output set to maximum to account for possible threshold changes [11]. In those not dependent, devices should be programmed to a non-pacing mode (ODO/OVO) or inhibited mode (VVI/DDI)[1–3, 13]. For patients with an AICD, all tachycardia detection and therapies should be programmed off [1–3].

Despite small series with evidence to the contrary, [16, 17] the presence of fractured, abandoned or epicardial leads (not including retained temporary surgical pacing leads) remains a contraindication to MRI scanning. MRI of non-conditional pacemakers implanted before 1998 and AICDs before 2000 is not recommended [18].

Device interrogation clear of the magnetic field should be performed and results documented before returning the patient to their original device settings. Follow-up should occur at a time predetermined by the electrophysiologist or earlier based on their assessment of any adverse incidents or device parameter changes during or after the MRI [1–3].

Imaging at 3T

Many new MR-conditional devices allow imaging at 3T with high-quality diagnostic imaging achievable even with the device within the imaging field [19]. An MRI system capable of displaying B1+RMS information is a prerequisite for an increasing number of CIEDs at this field strength.

Only small series [20, 21] have demonstrated successful and safe imaging at high field strengths in patients with non-conditional CIEDs. Most were studies imaging the brain and none were performed of the thorax or heart. No clear guidance on the MRI of non-conditional CIEDs at 3T is available at this time.

Summary

Despite opinions to the contrary [22], evidence demonstrates that when strict institutional protocols are adhered to, MRI in the presence of a CIED can be performed with low risk. This requires collaboration among cardiology, radiology and device manufacturers.

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Compliance with ethical standards

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