09/14/15 | 4 Color Fig: F1 | 20:43 | Art:CIR014640

October 6, 2015

CARDIOLOGY PATIENT PAGE

Magnetic Resonance Imaging in Patients With Cardiac Implantable Electronic Devices

Allon Eyal, MD PhD; Ariel Roguin, MD, PhD

MRI is an imaging modality that uses electromagnetic fields to generate anatomic and, at times, functional information. The combination of superb image quality and lack of hazardous ionizing radiation have made its use very popular. This is the image modality of choice for imaging of the brain, lower spine, and complex joints such as the shoulder, hip, or knee.

The electromagnetic fields used to obtain the MR image have the potential to interfere with the proper function of cardiac implantable electronic devices (CIEDs) such as pacemakers, implantable cardioverter defibrillators, and more complex devices such as cardiac resynchronization therapy with a defibrillator. Therefore, for many years, it was feared that performing MRI in patients with such devices may be associated with adverse effects.

However, an estimated 2 million patients in the United States alone have CIEDs, and likely half of these patients will someday need an MRI. As such, the dilemma of exposing patients carrying such devices to MRI is common and is expected to become even more frequent as both the implantation of CIEDs and performance of MRI examinations steadily grow.

What Are Cardiac Implantable Electronic Devices?

The conduction system in the heart generates and propagates electric signals that activate the heart muscle cells, leading to their contraction. Heart rhythm disorders are characterized by an abnormal heart rate, resulting in improper heart function. Some disorders can result in severe dysfunction of the heart and even death.

CIEDs monitor the intrinsic heart rate and detect the presence of rhythm abnormalities. They can deliver electric signals to the heart to treat detected abnormalities. Pacemakers can activate the heart once an inappropriately slow rhythm is detected, and implantable cardioverter defibrillators are used for the detection and treatment of disorders with an abnormally fast rhythm.

How Can an MRI Scan Interfere With the Function of CIEDs?

Pacemakers and implantable cardioverter defibrillators have 2 components. The first is a pulse generator, usually located underneath the skin in the left upper chest region. The second is leads that connect between the heart tissue and the pulse generator and convey the electric signals. Both of these components have the potential to interact with and be affected by the electromagnetic fields generated during an MRI examination.

There are several potential interactions (Table):

A. Movement of the pulse generator and dislodgement of the leads owing to the presence of ferromagnetic materials present in device components and the strong magnetic field.
B. Damage to the heart tissue caused by heating of the lead tip.
C. Change in device function and programming.
D. Detection of electric signals generated during the scan by the CIED and falsely relating them to the electric activity of the heart.

Performance of MRI Scans in Patients With CIEDs

Despite these potential adverse effects, many preclinical and clinical studies

From Cardiology Department, Rambam Medical Center, Rappaport - Faculty of Medicine, Technion - Israel Institute of Technology, Haifa, Israel.

Correspondence to Ariel Roguin, MD, PhD, Cardiology, Rambam Medical Center, Rappaport - Faculty of Medicine, Technion - Israel Institute of Technology, Haifa 31096, Israel. E-mail aroguin@technion.ac.il

(*Circulation*. 2015;132:00-00. 10.1161/CIRCULATIONAHA.114.014640.)

***Circulation* is available at http://circ.ahajournals.org**

DOI: 10.1161/CIRCULATIONAHA.114.014640

09/14/15 | 4 Color Fig: F1 | 20:43 | Art:CIR014640

Table. Potential Problems Encountered During an MRI Examination of Patients Harboring a CIED and Suggested Management Options

Problem	Problem Description	Suggested Measures to Prevent Problem
A	Movement of pulse generator or dislodgment of leads	Perform examination at least 6 weeks after device implantation
B	Damage to heart tissue caused by lead tip heating	Theoretical problem – does not exist in clinical practice
C	Changes in device function or programming during the examination	1. Device checking before the examination and performance of adequate programming
		2. Use of an MRI-conditional device
D	Detection of false electric signals by the device	1. Adequate programming of the device before the examination
		2. Use of an MRI-conditional device
		3. Continuous monitoring during the examination
A–D		Perform the examination only if deemed necessary and it provides information that cannot be obtained by other means

CIED indicates cardiac implantable electronic device.

demonstrate them to be exaggerated and mostly theoretical. Experiments show that there is no tissue damage and, when imaging is performed at least 6 weeks after implantation, there is no device movement.

Several studies had consistently demonstrated that, when patients carrying a CIED are appropriately screened and the device is both checked and adequately programmed beforehand, they may safely undergo MRI scans.[1] Recently, the largest series was presented at the 2014 American Heart Association Scientific Sessions. The MagnaSafe analysis included 1500 patients and proved that MRI, at 1.5 Tesla, can be performed for patients with standard devices at no significant clinical risk, while adhering to several important safety rules.

The mandatory steps to allow the safe performance of MRI imaging in patients with CIEDs are (Table):

1. Only patients for whom MRI is deemed absolutely necessary should undergo an examination. In addition, only patients in whom the device was implanted >6 weeks before should undergo an examination.
2. The device must be checked before the scan by a person experienced with device handling. The device settings should be adjusted before the MRI scan, with the exact setting chosen depending on both patient and device characteristics.
3. The patient must be continuously monitored during the scan, and both personnel and equipment for cardiac resuscitation should be readily available.
4. After the scan, the device should be examined to verify its proper function and to be reprogrammed to its original prescan setting. At least 1 month later, the device should be reexamined to verify that it functions properly.

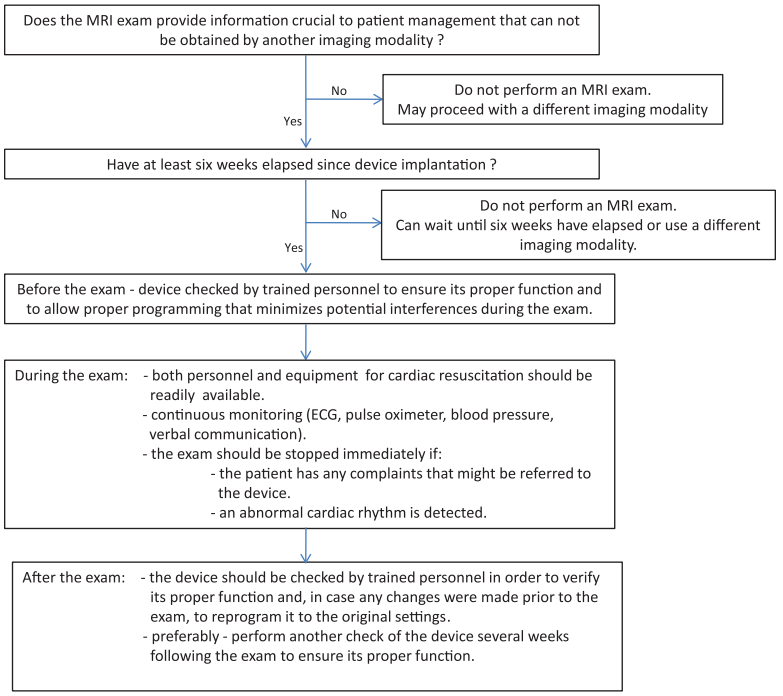

Figure. An algorithm for the management of patients with a CIED planned to undergo MRI imaging. CIED indicates cardiac implantable electronic device.

Because the safety and feasibility of MRI in patients with a CIED have been demonstrated, professional association guidelines have recently changed their definition from absolute to relative contraindication.[2–4] Nevertheless, the major MRI vendors still do not allow performance of a scan in a patient with any CIED.

Recent Improvement in MRI-Conditional Devices

Manufacturers have raced to develop and market CIEDs that can operate safely in the MRI environment. In recent years, several such devices, termed MRI-conditional, have been marketed. These devices were modified to have less ferromagnetic interference and are equipped with special hardware and software designs that allow the safe performance of MRI

09/14/15 | 4 Color Fig: F1 | 20:43 | Art:CIR014640

examinations.[5] The use of such devices still necessitates performance of the examination under certain patient and MRI-system conditions.

An MRI-safe device, one that needs no special handling or monitoring before and during an MRI scan, has yet to be developed.

Conclusion

Because the use of both CIEDs and MRI imaging is increasing, more patients with such devices will need to undergo a MRI examination. Protocols allow patients carrying conventional, non–MRI-conditional, devices to F1 undergo imaging safely (Figure). Recently, MRI-conditional devices, which maximize safety in the MRI environment, have entered the market.

Today, under specific conditions, when there is a clinical need, patients with CIEDs can usually undergo MRI.

Disclosures

None.

References

1. Nazarian S, Hansford R, Roguin A, Goldsher D, Zviman MM, Lardo AC, Caffo BS, Frick KD, Kraut MA, Kamel IR, Calkins H, Berger RD, Bluemke DA, Halperin HR. A prospective evaluation of a protocol for magnetic resonance imaging of patients with implanted cardiac devices. *Ann Intern Med*. 2011;155:415–424. doi: 10.7326/0003-4819-155-7-201110040-00004.
2. Roguin A, Schwitter J, Vahlhaus C, Lombardi M, Brugada J, Vardas P, Auricchio A, Priori S, Sommer T. Magnetic resonance imaging in individuals with cardiovascular implantable electronic devices. *Europace*. 2008;10:336–346. doi: 10.1093/europace/eun021.
3. Brignole M, Auricchio A, Baron-Esquivias G, Bordachar P, Boriani G, Breithardt Ole-E, Cleland J, Deharo J, Delgado V, Elliott PM, Gorenek B, Israel CW, Leclercq C, Linde C, Mont L, Padeletti L, Sutton R, Vardas PE. 2013 ESC guidelines on cardiac pacing and AQ5 cardiac resynchronization therapy. *Europace*. 2013;15:1070–1118. doi: 10.1093/europace/eut206.
4. Verma A, Ha AC, Dennie C, Essebag V, Exner DV, Khan N, Lane C, Leipsic J, Philippon F, Sampaio M, Schieda N, Seifer C, Berthiaume A, Campbell D, Chakraborty S. Canadian Heart Rhythm Society and Canadian Association of Radiologists consensus statement on magnetic resonance imaging with cardiac implantable electronic devices. *Can J Cardiol*. 2014;30:1131–1141. doi: 10.1016/j.cjca.2014.07.010.
5. Ahmed FZ, Morris GM, Allen S, Khattar R, Mamas M, Zaidi A. Not all pacemakers are created equal: MRI conditional pacemaker and lead technology. *J Cardiovasc Electrophysiol*. 2013;24:1059–1065. doi: 10.1111/jce.12238.

AUTHOR QUERIES

Authors please note: Authors are responsible for any page charges as outlined in the acceptance letter or as indicated on the Instructions for Authors (http://circ.ahajournals.org/site/misc/ifora.xhtml). Unless you have selected open access for your article, or it is otherwise noted on the acceptance letter, page charges are as follows: $70 per black and white page (print articles only) or $35 per page (online-only articles only). For each color page (print only), please add $653/page. If there are any concerns regarding these charges, these should be addressed within 48 hours of receiving the s-proof. Author(s) will be invoiced for all color and page charges post publication. If you have selected open access for your article, please refer to details in the queries below.

AUTHOR PLEASE ANSWER ALL QUERIES

AQ1—Please turn to page 3 of your proof and review the running head, which will appear in the upper right-hand margins of odd-numbered pages. Running heads must be 50 or fewer characters in length, including spaces and punctuation. If your original short title was longer than 50 characters, we may have shortened it. Please modify if necessary (but observe our length guidelines).

AQ2—Please confirm that all authors are included in the correct order in the byline and that all names are spelled correctly, including special characters, accents, middle initials, and degrees if applicable.

AQ3—Please confirm that all authors' institutional affiliations (including city/state/country locations) are correct as shown in the affiliations footnote.

AQ4—Please review the typeset table(s) carefully against your original table(s) to verify accuracy of editing and typesetting.

AQ5—Please carefully review any Acknowledgments, Sources of Funding, and/or Disclosures listed at the end of the manuscript (before the References), and confirm that they are accurate and complete for all authors.