Magnetic Resonance Imaging–Guided Cardiac Interventions

Ehud J. Schmidt, PhD

KEYWORDS

• MR imaging • Cardiac • Interventions • Electrophysiology • Therapy • Outcomes • Acute ischemia

KEY POINTS

- Advantages of MR imaging for cardiac interventions include visualizing vessel lumen and wall anatomy, scar tissue, acute ischemia and hemorrhage.
- Therapeutic outcomes may be improved utilizing real-time MR monitoring.
- MR imaging–guided cardiac intervention is finally becoming a clinical reality, after years of technological development and preclinical testing.
- Cardiac electrophysiology (EP) is the first field for which clinical grade device development is complete and in which human clinical trials are currently underway.

INTRODUCTION

Specific issues that result from performing procedures inside the beating heart are as follows: (1) the complex and nonrigid respiratory and cardiac motion of the heart affects both MR imaging and MR imaging–guided navigation and (2) the lack of robustness of MR imaging, in tissues other than the lumen and wall of the major vessels, makes the imaging of small and moving vessels difficult.[1–10] A practical result of the current MR imaging limitations has been the concentration of efforts on regions where diagnostic cardiac MR imaging is more mature, namely, procedures in the greater cardiac vessels such as the ventricles and the atria.

With diagnostic cardiac MR imaging increasingly available in hospitals and clinics throughout the world, the most well-developed MR imaging–guided procedures are those in which the cardiac MR imaging is performed before or after the actual intervention, while the interventional procedure itself is performed in the classical X-ray-guided operating room (OR) or interventional suite. All commercial medical imaging equipment vendors now offer "X-MR suites," which are MR imaging scanners and X-ray interventional suites that share a transport table, facilitating patient transfer between the imaging and interventional modalities. Commercial image processing tools are also available from these vendors and from the major catheter companies, which allows transformation of the images from the MR imaging to the X-ray or OR frame of reference (which can also be the frame of reference of an interventional workstation with integrated electromagnetic positional tracking[11–16]). As a result, in preoperative planning of cardiac EP procedures, in valve repair procedures, and for implantable cardioverter-defibrillator (ICD) placement procedures, use of MR vascular and scar images has become routine. Excellent reviews on these subjects are available.[17–32]

This review focuses on intraoperative use of MR imaging during cardiovascular interventions. This field is clinically in its infancy. Present work is primarily dedicated to removing some of the major hurdles to its use, although several clinical efficacy studies have recently emerged. Prior reviews on this subject exist.[3,33–46]

E.J. Schmidt acknowledges funding from NIH U41-RR019703, NIH R03 EB013873-01A1, and AHA 10SDG261039.
E.J. Schmidt receives research funding support from E-TROTZ Inc, St. Jude Medical, and Siemens Healthcare.
Radiology Department, Brigham and Women's Hospital, 221 Longwood Avenue, Room BRB 34C, Boston, MA 02115, USA
E-mail address: ESCHMIDT3@PARTNERS.ORG

Magn Reson Imaging Clin N Am 23 (2015) 563–577
http://dx.doi.org/10.1016/j.mric.2015.05.011

mri.theclinics.com

Although MR imaging–guided procedure development began with coronary intervention, the greatest effort today is on MR imaging–guided therapeutic cardiac EP, primarily using radiofrequency ablation. It is clear that MR imaging provides several imaging contrasts that are useful for the diagnosis of chronic (or temporally stable) cardiac disease. The ability to visualize fat, see scar tissue, detect fibrosis, separate edema and hemorrhage from myocardial tissue, visualize the vascular tree, and assess mechanical function are well-known advantages of MR imaging. In the context of intraoperative MR imaging, however, there is also a need to assess acute or temporally changing conditions. Understanding the appearance of pathologic conditions during the interventional procedure is an evolving field that may weigh heavily on the ultimate utility of MR imaging–guided procedures in the heart. Predicting the ultimate state of myocardium from its intraoperative appearance, where transient effects such as blood by-products, edema, hemorrhage, and reduced perfusion are prevalent, is a challenge that several research groups are currently addressing.

In addition, the need to provide solutions for emergency interventions inside the MR imaging suite is a challenge that must be resolved, because large patient populations are excluded from MR imaging–guided interventions because of the lack of equipment for rapidly detecting and treating cardiac events.

The most dramatic recent progress has been in the field of MR imaging–guided EP. (1) In Europe,[4–6,47] clinical trials are being carried out to assess the effectiveness of MR imaging–guided atrial ablation. (2) Several entrepreneurial companies, such as Imricor Medical Systems, Inc, and MRI Interventions, Inc, are developing MR imaging–compatible clinical grade EP catheters, sheathes, and guidewires in collaboration with major MR imaging vendors, such as Philips Healthcare and Siemens Healthcare. (3) It has been established that there is close agreement between the EP intracardiac voltage mapping as performed with commercial electroanatomic mapping (EAM) systems, such as the NavX-Velocity (St. Jude Medical, Inc, St Paul, MN, USA) or the CarTo3 (Biosense-Webster, Inc, Diamond Bar, CA, USA), and MR imaging–based late gadolinium enhancement (LGE) images in the case of chronic ischemic lesions.[48,49] (4) There are pioneering results on visualizing acute tissue necrosis using T1 or T2* mapping methods, which are critical to the use of MR imaging for monitoring the quality of ablation lesions in the intraoperative acute setting.[50–52]

TOPICS

Coronary Artery Interventions for the Diagnosis or Treatment of Coronary Artery Disease

Coronary artery disease (CAD) is one of the most frequent causes of patient morbidity. The common intervention for CAD is X-ray-fluoroscopy-guided angioplasty in which the culprit (partially or completely) occluded vessels are either opened by balloon expansion followed by stent placement or replaced with a grafted bypassing vessel.

There are several reasons for replacing X-ray as the modality used for procedural guidance. (1) X-rays can visualize only the vessel lumen and not the surrounding soft tissue such as the vessel wall; this reduces the clinician's ability to gauge the extent of injury to surrounding myocardial tissue during the procedure or the amount of restenosis that occurs afterward because of soft tissue regrowth. (2) When the coronary vessel is entirely occluded, chronic total occlusion (CTO), X-rays cannot visualize the occluded region because contrast cannot enter this region, which makes it difficult to guide a device to the proper location for opening the occlusion. Such poor visualization may result in vessel perforation. (3) The X-ray dose that clinicians carrying out coronary procedures are exposed to is quite high, which limits the number of procedures they perform. In addition, the heavy lead aprons clinicians wear to shield from radiation are a significant cause of back pain.

Another role for MR imaging guidance is to monitor the treatment of preexisting cardiac myocardial infarcts. Several innovative therapeutic strategies have been proposed to prevent the remodeling of the myocardium postinfarction and the ensuing progression to heart failure. There are also experimental therapies to induce the (re) growth of myocytes within the infarct such as the induction of specific pharmaceuticals, viruses, and stem cells. For these applications, MR imaging–guided therapy delivery is highly advantageous because of the following reasons. (1) MR imaging visualizes the infarct borders, including the inactive but perfused (stunned) myocardium that surrounds the necrotic area, identifying optimal regions for therapy delivery. (2) MR imaging can monitor the concentration of agents that enters into the injected region during the delivery process. (3) Longitudinal MR imaging can be used to assess the effectiveness of therapy, such as the improvement in myocardial mechanical function.

Coronary vascular access

In animal models, MR imaging–guided navigation through the arterial tree and into the coronary