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MR Imaging of Coronary Arteries and Plaques

Marc R. Dweck, MD, PhD,[a,b] Valentina O. Puntmann, MD, PhD,[c] Alex T. Vesey, MD,[b] Zahi A. Fayad, PhD,[a] Eike Nagel, MD, PhD[d]

ABSTRACT

Cardiac magnetic resonance offers the promise of radiation-free imaging of the coronary arteries, providing information with respect to luminal stenosis, plaque burden, high-risk plaque characteristics, and disease activity. In combination, this would provide a comprehensive, individualized assessment of coronary atherosclerosis that could be used to improve patient risk stratification and to guide treatment. However, the technical challenges involved with delivering upon this promise are considerable, requiring sophisticated approaches to both data acquisition and post-processing. In this review, we describe the current status of this technology, its capabilities, its limitations, and what will be required in the future to translate this technology into routine clinical practice. (J Am Coll Cardiol Img 2016;9:306–16)

Myocardial infarction (MI) is a leading cause of death and a major health resource burden that by 2030 is estimated to cost the global economy more than U.S. $1 trillion per year (1). The majority of these events occur as a consequence of atherosclerotic plaque rupture. Identifying plaques at risk of rupture is challenging, however—in particular because these lesions are frequently nonobstructive on antecedent angiography and therefore also missed with conventional ischemia imaging. Interest has therefore developed in novel strategies for improving the prediction of cardiovascular risk in patients. Measures of plaque burden, such as computed tomography (CT) calcium scoring, offer some improvements, particularly in low-risk populations, whereas advances in scanner technology now allow measurement of disease activity and the visualization of high-risk plaque characteristics. A single imaging modality that can assess each of these parameters of coronary atherosclerosis would potentially be a major advance. Specific imaging protocols could then be tailored to different patient populations and combined protocols designed to provide complementary information and to maximize the technique's prognostic capability. Ideally such a scan would be safe, widely available, and repeatable, allowing us to track coronary atherosclerosis during a patient's lifetime. This review investigates the promise that cardiac magnetic resonance (CMR) holds in imaging coronary atherosclerosis, with a particular focus on magnetic resonance angiography (MRA), assessments of plaque burden and plaque characteristics alongside evolving molecular technologies that target disease activity (**Central Illustration**). We examine some of the technical challenges facing CMR, its current capabilities, and how in the future it may become the imaging modality of choice for investigating coronary atherosclerosis.

RATIONALE FOR CMR IMAGING OF THE CORONARY ARTERIES

Magnetic resonance has become a routine clinical imaging investigation used to assess a wide range of

From the [a]Translation Molecular Imaging Institute, Icahn School of Medicine at Mount-Sinai, New York, New York; [b]British Heart Foundation Centre for Cardiovascular Science, University of Edinburgh, Edinburgh, United Kingdom; [c]Cardiovascular Imaging Center Goethe University Frankfurt, Germany; and the [d]Institute for Experimental and Translational Cardiovascular Imaging, DZHK Centre for Cardiovascular Imaging, University Hospital Frankfurt, Frankfurt am Main, Germany. Dr. Nagel has received research support from Siemens Healthcare, Bayer Healthcare, Philips Healthcare, TomTec, and MEDIS; educational support from CVI42 and MEDIS; and speaker honoraria from Bayer Healthcare. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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tissues and pathophysiological conditions. Although its application to the heart was delayed compared with stationary structures, technological advances in software and hardware components have now lead to its widespread clinical adoption for imaging the myocardium. Applying CMR to the coronary arteries offers further challenges because of both their small caliber and complex motion. As a consequence, coronary CMR has to date lagged behind CT. However, CMR holds several key advantages over CT that might ultimately see it become the imaging modality of choice for assessing the coronary vasculature. First, CMR offers superior soft-tissue contrast, potentially allowing improved detection of high-risk plaque characteristics such as intra-plaque hemorrhage, thrombus, and positive remodeling (**Figure 1**). Second, CMR is not affected by the calcium blooming that hampers CT and frequently renders luminal assessments impossible in patients with advanced atheroma. Finally and, perhaps most importantly, CMR does not involve exposure to ionizing radiation. This makes it attractive as a screening modality, allows multiple vascular beds to be imaged simultaneously, and renders serial imaging to track disease progression feasible. Moreover, there is the opportunity to image younger patients so that we can better understand the early stages of atherosclerosis and how subjects transition from health to disease. Indeed, it is worth noting that these various advantages have seen CMR, not CT, emerge as the imaging modality of choice for assessing the carotid and peripheral arteries. The challenge therefore is to successfully apply these various techniques to the coronary arteries.

TECHNICAL CHALLENGES AND SOLUTIONS. The coronary arteries are small tortuous structures, have variable 3-dimensional (3D) branches and cover a large volume. A clinically useful assessment requires visualization of the proximal and mid-vessels, which often only measure 3 to 4 mm in diameter (smaller vessels and side branches are less important in guiding patient management) and is made even more difficult by the rapid movement of these arteries with the cardiac cycle and breathing. The requirements for both high spatial resolution and complex motion correction are highly challenging for any imaging modality, but in CMR create a particular tension with respect to scanning times and data acquisition. Although most strategies to improve spatial resolution generate exponential increases in the scanning time required, current motion correction approaches discard large amounts of data while the heart is moving. The future challenge is therefore to find fast CMR techniques capable of high spatial resolution without compromising motion correction and vice versa.

To suppress cardiac motion, data are currently only acquired during end-systolic or mid-diastolic standstill. These periods vary for different coronary arteries and between patients but are around 70 ms for most patients and can be lengthened by reducing heart rate with beta-blockade (2). To suppress respiratory motion, images can be obtained during breath-holding; however, this limits scan time to <20 s and therefore the data that can be acquired. As a consequence, the 3D coverage of these scans is limited to a thin slab with a spatial resolution of $\sim$0.7 × 0.7 × 4 to 5 mm. Alternatively, more detailed images can be obtained during free breathing, using navigator sequences, which measure the position of the diaphragm and only allow data acquisition when the diaphragm is close to a predefined position. Such scans take much longer, between 10 and 15 min. For small deviations of the diaphragmatic position, corrections can be applied; however, even then this approach remains highly wasteful given the amount of data that is discarded. Recent advances in self-navigated techniques measure displacement of the heart directly and then attempt to correct the data for motion rather than discarding it. This has the potential to greatly improve scanner efficiency and to increase spatial resolution (3). This coupled with parallel imaging, higher field strengths, dedicated multichannel receiver coils, fully digital systems, and compressed sensing techniques promise rapid improvements in the image quality associated with coronary magnetic resonance.

MAGNETIC RESONANCE ANGIOGRAPHY. The standard assessment of the coronary vasculature remains the coronary angiogram, which focuses on delineating the arterial anatomy and detecting focal narrowings in its lumen. Various sequences are available for performing coronary MRA (**Figure 1**). In the cerebral and peripheral arteries, MRA is now clinically established. Translating these successes into reliable coronary MRA has been a focus of research for 25 years since the first reports by Edelman (4) and Manning (5). This section describes current state-of-the-art techniques and some of the more clinically focused research validating coronary MRA against CT and invasive coronary angiography.

For coronary MRA, rapid sequences are essential and most centers use either spoiled gradient echo

ABBREVIATIONS AND ACRONYMS

CAD = coronary artery disease

CMR = cardiac magnetic resonance

CT = computed tomography

18F-FDG = 18F-flurodeoxyglucose

MI = myocardial infarction

MRA = magnetic resonance angiography

MRI = magnetic resonance imaging

PET = positron emission tomography

SSFP = steady-state free precession

STIR = short tau inversion recovery

3D = 3-dimensional

2D = 2-dimensional

USPIO = ultrasmall superparamagnetic particles of iron oxide