

MR Imaging of the Coronary Vasculature

Imaging the Lumen, Wall, and Beyond



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KEYWORDS

• Coronary artery disease • Magnetic resonance imaging • Noninvasive

KEY POINTS

- Magnetic resonance (MR) imaging is a useful noninvasive tool for the detection of coronary stenosis.
- MR imaging can detect morphologic and functional changes of remodeled coronary artery.
- Many technical advances have been adopted to improve the performance of coronary MR imaging/MR angiography for cardiovascular risk estimation.

INTRODUCTION

Coronary artery disease (CAD) is the leading cause of death worldwide. The characteristics of CAD are gradual thickening of the coronary walls and narrowing of the vascular lumen caused by the buildup of atherosclerosis plaques. Subclinical CAD may silently progress over a long time period until coronary events (a group of symptoms attributed to myocardial ischemia) affect patients.^{1,2} Therefore, the detection of CAD in its early stage is clinically significant. However, the morphologic and functional features of the remodeled coronary artery, which may convey risk of subclinical CAD, have not been comprehensively investigated in asymptomatic individuals who do not have documented or suspected structural cardiovascular disease. This knowledge gap exists mainly because clinical examinations for detecting coronary wall are either invasive or require x-ray exposure. Therefore, noninvasive imaging methods for the evaluation of coronary artery are highly desired for optimal cardiovascular prevention.

Over the past decade, magnetic resonance (MR) imaging/MR angiography (MRA) has emerged as a promising noninvasive method for observing both morphologic and functional changes on coronary walls.^{3,4} This article summarizes state-of-art coronary MR imaging/MRA techniques for detecting CAD from various aspects, including luminal stenosis, coronary wall plaques, and coronary functional changes. In addition, clinical applications and limitations of current coronary MR imaging techniques in clinical practice are also discussed.

IMAGING OF CORONARY LUMEN USING MAGNETIC RESONANCE IMAGING

In the past, stenosis of the coronary lumen was considered to be an indicator of obstructive CAD, and subsequent treatments, such as coronary artery bypass graft surgery and percutaneous transluminal coronary angioplasty were based on extent and severity of disease. Multiple bright-blood MR imaging pulse sequences can be used

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to rapidly image the coronary lumen and detect coronary stenosis, such as spoiled gradient echo and steady-state free precession (SSFP) (Table 1).⁵

Regenfus and colleagues⁶ evaluated 50 patients with suspected CAD using a turbo fast low-angle shot MR imaging (FLASH) sequence within a single breath-hold. Of 350 coronary segments, 268 (76.6%) could be evaluated. In those coronary segments, 48 of 56 luminal stenoses could be detected by MR imaging. With T1-shortening contrast agents, such as gadolinium, spoiled gradient echo sequences can be used to depict contours of the coronary lumen. In a study with 9 healthy volunteers, Bi and colleagues⁷ showed that gadolinium may significantly increase the image quality of coronary MRA. However, spatial resolution and coverage of coronary MRA may be limited by the length of breath hold and the duration of sustainable blood pool enhancement generated by contrast agents.⁸ Using a free-breathing technique and a scheme of slow infusion (0.3 mL/s) of the contrast agent (for prolonged T1 contrast between vessel wall and the blood pool), Bi and colleagues⁹ showed that coronary MRA (FLASH sequence) is capable of imaging the whole coronary tree within a short period (4.5 ± 0.6 minutes) for 8 volunteers. In a single-center study, Yang and colleagues¹⁰ performed contrast-enhanced whole-heart MRA in 69 consecutive patients with suspected CAD. Whole-heart MRA identified clinically significant coronary stenosis in 32 patients and ruled out CAD in 23 patients. On a per-segment basis, MRA had high sensitivity (91.6%), specificity (83.1%), and accuracy (84.1%) for the detection of CAD (using x-ray angiography as the gold standard). On a per-patient basis, these values for accurate CAD diagnosis were 94.1%, 82.1%, and 88.7%, respectively. The same group recently showed a comparable diagnostic accuracy for the detection of CAD (significant coronary luminal stenosis) in 110 patients using similar imaging techniques with a 32-channel coil.¹¹

Patients with CAD have varying degrees of coexisting kidney dysfunction.¹² Therefore, noncontrast coronary MRA techniques may provide added benefits in this patient population by avoiding nephrotoxic contrast agents and the risk of nephrogenic systemic fibrosis. The high T2/T1 ratio of the blood provides strong blood signal and may serve as an intrinsic contrast agent for the SSFP technique in coronary MRA.^{13,14} Using noncontrast whole-heart coronary MRA, Kato and colleagues¹⁵ detected significant CAD in 138 patients with suspected CAD with high sensitivity and high negative predictive value (88%). Using quantitative analysis of coronary MRA, Yonezawa and colleagues¹⁶ found that receiver operating characteristic (ROC) curve analysis in a segment-based analysis for identifying significant coronary stenosis was 0.96. In a multicenter study, coronary MRA provided an accuracy of 72% (95% confidence interval, 63%–81%) in diagnosing CAD.¹⁷ Stuber and colleagues¹⁸ showed good agreement of anatomy and disorder between coronary MRA and x-ray angiography in depicting the coronary tree in 7 patients with CAD confirmed by x-ray angiography and 15 healthy adult volunteers. Indicated by higher sensitivity, specificity, and area under the ROC curve (AUC), Liu and colleagues¹⁹ found that noncontrast coronary MRA is superior to coronary CT angiography (CTA) for delineating luminal narrowing of the coronary artery in the segments with heavy calcification. Yoon and colleagues²⁰ studied 207 patients with suspected CAD using noncontrast whole-heart coronary MRA. The investigators observed 10 coronary events (half of them were deadly events) in 84 patients with significant coronary stenosis identified with MRA during a follow-up of 25 months. However, only 1 coronary event happened in 123 patients without CAD (also defined using MRA findings). Cox regression showed that a coronary stenosis on MRA is an independent risk factor associated with significant increase for all cardiac events (risk ratio = 20.78; $P = .001$). Figs. 1 and 2 show that coronary MRA (with and without contrast enhancement) is able to show coronary stenosis.

Table 1 MR imaging sequences used in the evaluation of coronary luminal stenosis (bright blood)				
Sequences				Need Contrast Agent?
Spoiled gradient echo	FLASH	SPGR	T1 FFE	Yes
SSFP	FISP	GRASS	FFE	No

Names vary between different MR imaging scanner manufacturers.
Abbreviations: FFE, fast field echo; FISP, fast imaging with steady-state precession; FLASH, fast low-angle shot MR imaging; GRASS, gradient recall acquisition using steady states; SPGR, spoiled gradient recall acquisition using steady states.

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