Cardiovascular MR Imaging: Bridging the Gap Between Research & Clinical Problems

Lumen & Vessel Wall Imaging: Coronary Arteries

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Atherosclerosis and Vessel wall Imaging

Despite improvements in prevention, diagnosis, and treatment, cardiovascular disease remains the leading cause of morbidity and mortality in the Western world [1–4]. Atherosclerosis is a systemic and progressive disease of the vessel wall and the most frequent cause of coronary artery disease (CAD). Atherosclerosis alone is rarely fatal; however, sudden luminal thrombosis, superimposed on a ruptured or eroded atherosclerotic plaque, causes life-threatening clinical events such as acute coronary syndromes and stroke [5–7]. Plaques assumed to result in luminal thrombosis are referred to as vulnerable plaques. These plaques are usually relatively large and associated with positive remodeling of the vessel wall and tend to preserve a normal vessel lumen [8]. Today's clinical assessment of CAD is based on the severity of luminal narrowing, flow restriction, or functional indices of cardiac ischemia. Therefore, unlike the detection of plaque underlying stable angina, which is associated with a significant lumen narrowing, a priori detection of vulnerable plaques remains challenging [8,9]. Noninvasive techniques for imaging atherothrombosis currently include cardiovascular magnetic resonance (CMR), multidetector CT, and ultrasound. Among these modalities, CMR has emerged as the most comprehensive noninvasive in vivo imaging modality, offering several different methods to assess and characterize atherosclerotic plaque burden. These methods, which include non-contrast and contrast-enhanced vessel wall imaging, have shown great promise to assess morphological characteristics of vulnerable plaques, such as inflammatory activity, neovasculature, and positive vessel wall remodeling. Furthermore, the advent of molecular contrast agents has allowed interrogating biological processes at a molecular and cellular level and experiments in large animal models have shown potential for clinical translation. With further development, CMR imaging of the carotid, aortic, and coronary walls may prove to be clinically beneficial in identifying subclinical disease and unstable lesions.

MRI Coronary Angiography

In the early 1990s, Edelman et al. [10] were among the first to demonstrate the feasibility of magnetic resonance angiography (MRA) to visualize the proximal coronary arteries in healthy volunteers. Coronary MRA examinations are typically performed without intravenously administered contrast agents. The contrast between the coronary arteries and surrounding tissues such as epicardial fat and myocardium is typically augmented using fat-saturation prepulses [10], magnetization transfer contrast prepulses [11], or T2 preparatory pulses [12,13]. The latter take advantage of the natural T2 differences between the blood and the surrounding myocardium. In bright blood coronary MRA the coronary lumen appears bright, whereas the surrounding myocardium has reduced signal intensity. Recent technical developments include the use of 1) steady-state with free-precession to obtain high signal intensity from the coronary arteries and very high contrast between the ventricular blood pool and the myocardium [14,15]; 2) whole-heart coronary MRA [16] to simplify data acquisition and to shorten examination duration [17]; 3) parallel imaging to reduce scanning time [18]; 4) blood pool, contrast agents [19] to enhance contrast between the coronary artery lumen and myocardium; 5) high field [20,21] coronary MRA to benefit from the improved signal to noise at higher field strength and 6) novel motion compensation techniques [22-25] to make coronary MRA more reliable and less user dependent.

In the past decade, MRA has emerged as a noninvasive tool for the diagnosis of CAD and was intensively investigated at research-oriented centers. Recently published single-center trials demonstrated a sensitivity of 80% to 90% and a specificity of greater than 90% for the identification of coronary stenosis in the proximal to mid native vessel segments [26–28]. Although the utility of coronary MRA has not been established in general practice, coronary MRA seems to be particularly helpful for the exclusion of left-main or multivessel disease [29].

Literature

1. Jemal A, Ward E, Hao Y, Thun M: **Trends in the leading causes of death in the United States, 1970-2002.** *JAMA* 2005, **294:**1255–1259.
2. Braunwald E: **Shattuck lecture–cardiovascular medicine at the turn of the millennium: triumphs, concerns, and opportunities.** *N Engl J Med* 1997, **337:**1360–1369.
3. Yusuf S, Reddy S, Ounpuu S, Anand S: **Global burden of cardiovascular diseases: part I: general considerations, the epidemiologic transition, risk factors, and impact of urbanization.** *Circulation* 2001, **104:**2746–2753.
4. Lopez AD, Mathers CD, Ezzati M, et al.: **Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data.** *Lancet* 2006, **367:**1747–1757.
5. Fuster V, Badimon L, Badimon JJ, Chesebro JH: **The pathogenesis of coronary artery disease and the acute coronary syndromes (1).** *N Engl J Med* 1992, **326:**242–250.
6. Shah PK, Falk E, Badimon JJ, et al.: **Human monocyte-derived macrophages induce collagen breakdown in fibrous caps of atherosclerotic plaques. Potential role of matrix-degrading metalloproteinases and implications for plaque rupture.** *Circulation* 1995, **92:**1565–1569.
7. Falk E, Shah PK, Fuster V: **Coronary plaque disruption.** *Circulation* 1995, **92:**657–671.
8. Virmani R, Burke AP, Farb A, Kolodgie FD: **Pathology of the vulnerable plaque.** *J Am Coll Cardiol* 2006, **47:**C13–C18.
9. Falk E: **Pathogenesis of atherosclerosis.** *J Am Coll Cardiol* 2006, **47:**C7–C12.
10. Edelman RR, Manning WJ, Burstein D, Paulin S: **Coronary arteries: breath-hold MR angiography.** *Radiology* 1991, **181:**641–643.
11. Li D, Paschal CB, Haacke EM, Adler LP: **Coronary arteries: three-dimensional MR imaging with fat saturation and magnetization transfer contrast.** *Radiology* 1993, **187:**401–406.
12. Brittain JH, Hu BS, Wright GA, et al.: **Coronary angiography with magnetization-prepared T2 contrast.** *Magn Reson Med* 1995, **33:**689–696.
13. Botnar RM, Stuber M, Danias PG, et al.: **Improved coronary artery definition with T2-weighted, free-breathing, three-dimensional coronary MRA.** *Circulation* 1999, **99:**3139–3148.
14. Deshpande VS, Shea SM, Laub G, et al.: **3D magnetization-prepared true-FISP: a new technique for imaging coronary arteries.** *Magn Reson Med* 2001, **46:**494–502.
15. Spuentrup E, Buecker A, Stuber M, et al.: **Navigator-gated coronary magnetic resonance angiography using steady-state-free-precession: comparison to standard T2-prepared gradient-echo and spiral imaging.** *Invest Radiol* 2003, **38:**263–268.
16. Weber OM, Martin AJ, Higgins CB: **Whole-heart steady-state free precession coronary artery magnetic resonance angiography.** *Magn Reson Med* 2003, **50:**1223–1228.
17. Jahnke C, Paetsch I, Nehrke K, et al.: **Rapid and complete coronary arterial tree visualization with magnetic resonance imaging: feasibility and diagnostic performance.** *Eur Heart J* 2005, **26:**2313–2319.
18. Weiger M, Pruessmann KP, Boesiger P: **Cardiac real-time imaging using SENSE. SENSitivity Encoding scheme.** *Magn Reson Med* 2000, **43:**177–184.
19. Kelle S, Thouet T, Tangcharoen T, Nassenstein K, Chiribiri A, Paetsch I, Schnackenburg B, Barkhausen J, Fleck E, Nagel E. **Whole-heart coronary magnetic resonance angiography with MS-325 (Gadofosveset).** Med Sci Monit. 2007 Nov;13(11):CR469-474.
20. Stuber M, Botnar RM, Fischer SE, Lamerichs R, Smink J, Harvey P, Manning WJ. **Preliminary report on in vivo coronary MRA at 3 Tesla in humans.** Magn Reson Med. 2002 Sep;48(3):425-9.
21. Bi X, Carr JC, Li D. Whole-**heart coronary magnetic resonance angiography at 3 Tesla in 5 minutes with slow infusion of Gd-BOPTA, a high-relaxivity clinical contrast agent.** Magn Reson Med. 2007 Jul;58(1):1-7.
22. Stehning C, Börnert P, Nehrke K, Eggers H, Stuber M. **Free-breathing whole-heart coronary MRA with 3D radial SSFP and self navigated image reconstruction.** Magn Reson Med. 2005 Aug;54(2):476-80.
23. Nguyen TD, Spincemaille P, Cham MD, Weinsaft JW, Prince MR, Wang Y. **Free-breathing 3D steady-state free precession coronary magnetic resonance angiography: comparison of diaphragm and cardiac fat navigators.** J Magn Reson Imaging. 2008 Aug;28(2):509-14.
24. Keegan J, Gatehouse PD, Yang GZ, Firmin DN. **Non-model-based correction of respiratory motion using beat-to-beat 3D spiral fat-selective imaging.** J Magn Reson Imaging. 2007 Sep;26(3):624-9.
25. Lai P, Bi X, Jerecic R, Li D. **A respiratory self-gating technique with 3D-translation compensation for free-breathing whole-heart coronary MRA.** Magn Reson Med. 2009 Sep;62(3):731-8.
26. Sakuma H, Ichikawa Y, Chino S, et al.: **Detection of coronary artery stenosis with whole-heart coronary magnetic resonance angiography.** *J Am Coll Cardiol* 2006, **48:**1946–1950.
27. Dewey M, Teige F, Schnapauff D, et al.: **Combination of free-breathing and breathhold steady-state free precession magnetic resonance angiography for detection of coronary artery stenoses.** *J Magn Reson Imaging* 2006, **23:**674–681.
28. Sakuma H, Ichikawa Y, Suzawa N, et al.: **Assessment of coronary arteries with total study time of less than 30 minutes by using whole-heart coronary MR angiography.** *Radiology* 2005, **237:**316–321.
29. Kim WY, Danias PG, Stuber M, et al.: **Coronary magnetic resonance angiography for the detection of coronary stenoses.** *N Engl J Med* 2001, **345:**1863–1869.