Cardiac Stress MR

- Pharmacologic stress perfusion cardiac MR is an effective method of revealing flow-limiting coronary artery disease.
- Multicenter studies have consistently demonstrated that the accuracy of the technique is equal or superior to SPECT myocardial perfusion imaging.
- Cardiac stress MR is a comprehensive study to assess cardiac anatomy, function, perfusion, and viability.
- The strength of cardiac stress MR lies in high spatial resolution and excellent tissue contrast. It has high specificity, sensitivity and has excellent prognostic value for predicting the risk of major adverse cardiac events.

*D*uring the past decade, cardiac stress MR has been developed into an effective technique for examining myocardial perfusion and diagnosing obstructive coronary artery disease (CAD). The technique has the advantages of high spatial resolution, lack of ionizing radiation, and ease of assessing myocardial viability, wall motion, and cardiac anatomy. In addition, cardiac stress MR is not compromised by attenuation artifacts due to obesity or breast tissue, which can confound SPECT imaging.

Cardiac stress MR has a very high prognostic value. In a multicenter prospective clinical trial, it was shown to have higher sensitivity than SPECT myocardial perfusion imaging (AUC: 0.86 ± 0.06 vs. 0.67 ± 0.05, p = 0.013). 99.2% of patients with a normal cardiac MR perfusion examination did not have any adverse cardiac event within three years, whereas the event-free survival of those with perfusion abnormalities was 83.5%. The likelihood of death or non-fatal myocardial infarction in patients with abnormal myocardial perfusion was increased (likelihood ratio, $\chi 2 = 16.0-34.3$, P = 0.001), and cardiac stress MR clearly identified patients at risk.

Indications for Cardiac Stress MR

Cardiac stress MR is not recommended for patients at minimal or low risk for CAD. Stress MR is a valuable tool for risk stratification in patients with known CAD or high risk of CAD, and expert panels have deemed it appropriate for patients with newly diagnosed heart failure. Cardiac stress MR is particularly valuable for patients who have moderate-to-high pre-test probability of CAD and whose SPECT imaging did not reveal any myocardial perfusion abnormalities. CAD can be more difficult to diagnose in patients with limited exercise tolerance as well as women because of small heart size and potential breast attenuation artifacts. In such cases, cardiac stress MR may reveal reduced myocardial perfusion reserve in patients with chest pain but no coronary artery stenosis 50% (*i.e.,* microvascular ischemia).

The Cardiac Stress MR Examination

In preparation for cardiac stress MR, patients should not take any medications for angina or drink any caffeinated beverages for at least 12 hours prior to their test.

Cardiac stress MR is not performed in patients who are claustrophobic, unable to lie flat, have a pacemaker or metallic implants, have renal failure, are pregnant, or are lactating. In addition, patients must be able to hold their breath for 10–15 seconds and follow breathing instructions. In patients with COPD and asthma, stressor administration is typically discussed with the referring physician to assess benefit versus risk.
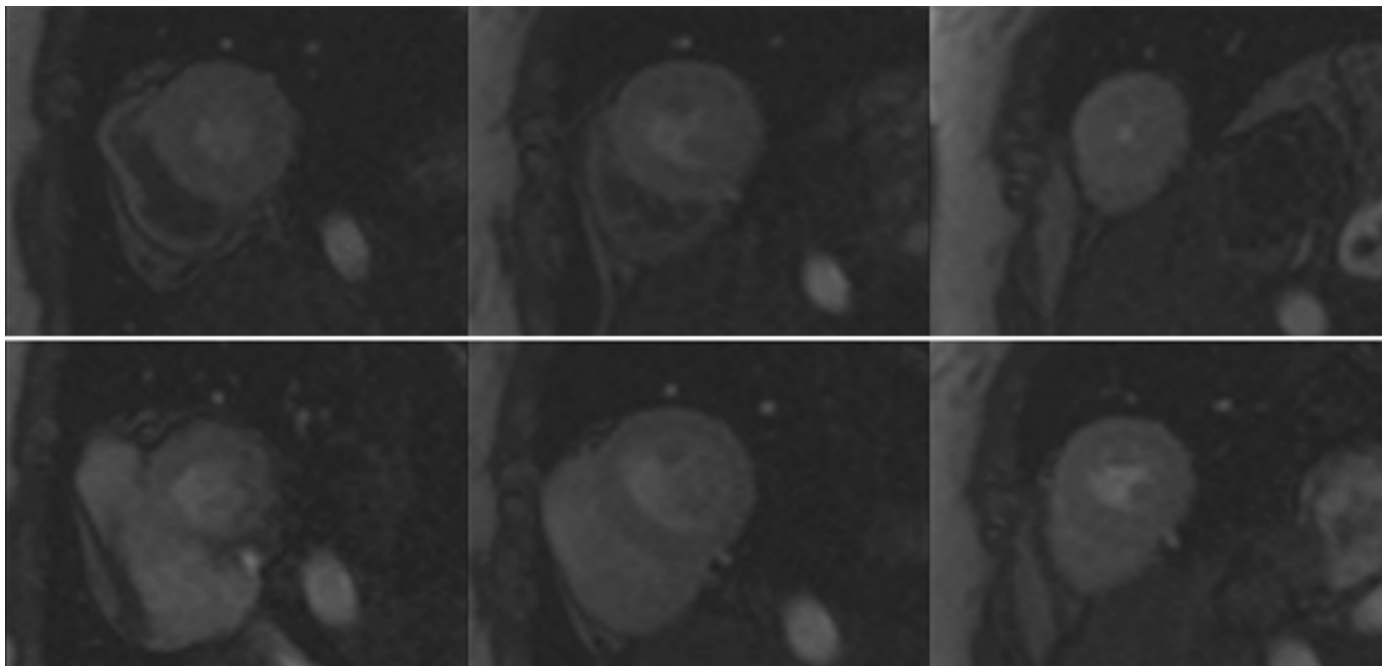
Figure 1. Figure showing normal myocardial perfusion with stress (top row) and rest (bottom row) at base, mid and apex (L->R).

Cardiac stress MR takes a total of 50-60 minutes. Unlike nuclear techniques, the examination allows integration of myocardial perfusion imaging with a comprehensive high-resolution/high-tissue contrast examination of the heart to evaluate biventricular function and detect the presence of wall thickening, edema, and myocardial scar. Distinct patterns of late gadolinium enhancement can also characterize ischemic versus non-ischemic causes of cardiomyopathy. In case of infarction, the cardiac stress MR allows assessment of the transmural extent of injury, which predicts the likelihood of functional recovery after revascularization (*i.e.,* viability).

Stress myocardial perfusion images are acquired during approximately 60-80 heartbeats during the first pass of the gadolinium enhancement, which typically occurs 2-3 minutes after pharmacologic stress administration. Patients are asked to hold their breath during the initial acquisition. Motion-related artifacts are further reduced by novel correction algorithms. Three serial three short-axis slices (base, mid, and apical) and one four-chamber view of the heart are acquired during each phase of perfusion (Figure 1). Real-time cine images can be obtained for wall motion evaluation at stress and at rest. After stress phase imaging is complete, aminophylline may be administered to reverse the effects of regadenoson in the event of persistent chest pain, pressure, or nausea.

The stress phase of the examination is performed before the rest phase to optimize first-pass tissue contrast. Regadenoson, a short-acting adenosine receptor agonist with a half life of 2–4 minutes, is

Figure 2. Perfusion deficit in a patient with severe stenosis in the left anterior descending coronary artery.

administered as an intravenous bolus. Thus, regadenoson vasodilator stress can result in up to a four-fold increase in coronary flow in healthy adults, and minimizes resistance of distal coronary perfusion. The resultant steal phenomenon in myocardium perfused by stenotic arteries causes a first-pass perfusion deficit (Figure 2), which raises the sensitivity for coronary stenosis from a threshold of 95% diameter stenosis at rest to approximately 50% diameter stenosis during pharmacologic stress.
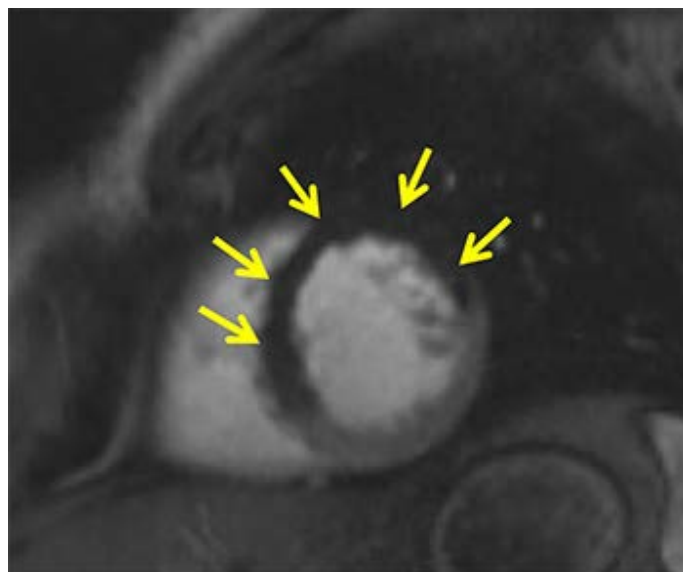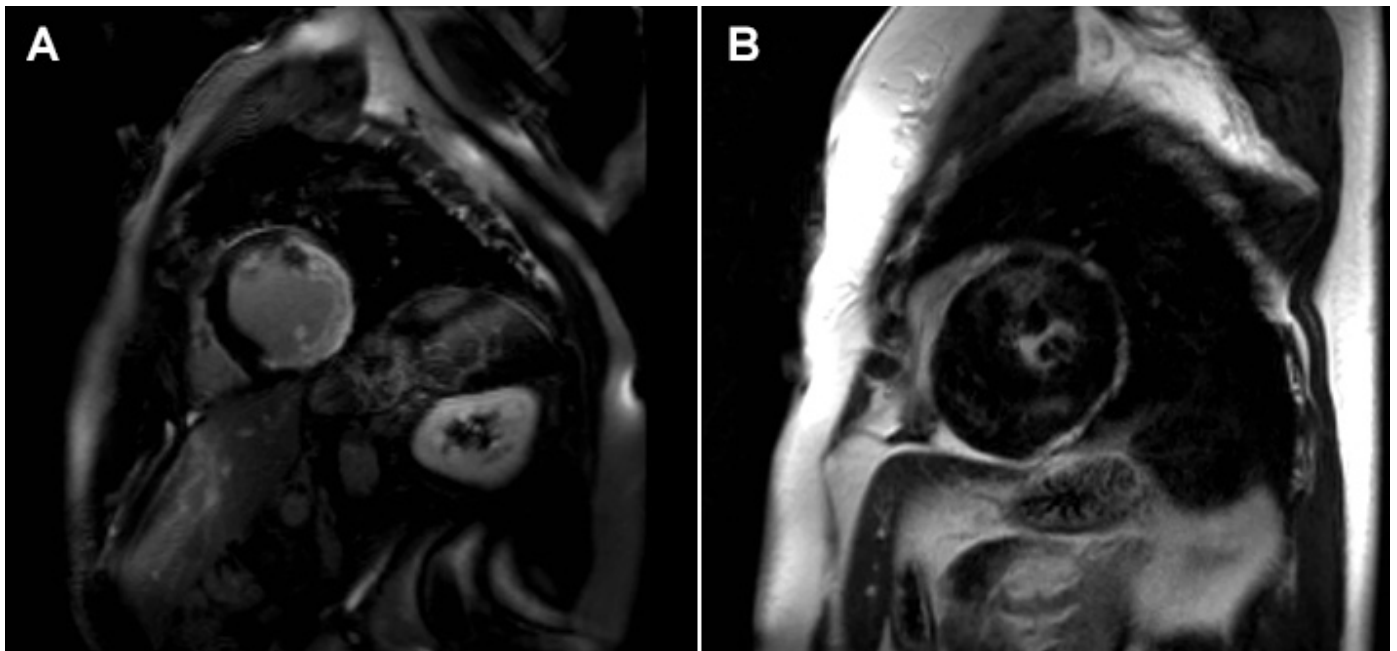
Figure 3. The distinct patterns of late gadolinium enhancement are helpful in identity the underlying etiology. **(A)** 62 year old man with CAD and circumflex coronary artery territory infarct. Short axis late gadolinium enhanced image showing transmural infarction in the circumflex territory compatible with non-viable myocardium. **(B)** 64 year old woman with hypertrophic cardiomyopathy. Short axis late gadolinium enhanced image showing patchy mid wall late gadolinium enhancement suggestive of fibrosis.

In some cases, image quality can be affected by dark-rim artifacts, which appear during first-pass perfusion and can mimic ischemia; optimized acquisition methods and careful image analysis can eliminate and mitigate these artifacts.

After the stress phase, a 7–8 minute recovery period allows the heart rate to return to normal. A second bolus of gadolinium contrast is then administered, and resting myocardial perfusion images are acquired. Finally, short and long axis and possibly 3D volume late gadolinium enhancement images are acquired for scar evaluation (Figure 3). Cardiac stress MR is performed in conjunction with pre- and post-exam 12-lead ECG evaluation and is monitored in real-time by trained physicians.

Interpretation is performed by experts using a dedicated post-processing workstation, which allows for: comprehensive evaluation of dynamic stress and rest datasets for inducible ischemia; precise quantification of biventrular ventricular volumes and wall motion; and assessment for scar and viability.

Scheduling

Cardiac stress MR is performed on the main campus of Massachusetts General Hospital. Appointments can be made made through EPIC (inside the Partners network) or Physician Gateway (outside the Partners network) or by calling 617-724-XRAY (9729).

Further Information

For further information on cardiac stress MR, please contact Brian Ghoshhajra, MD, MBA, FSCCT, Division of Cardiovascular Imaging, Department of Radiology, Massachusetts General Hospital, at 617-643-0239.

We would like to thank Sandeep Hedgire, MD and Brian Ghoshhajra, MD, MBA, FSCCT, Division of Cardiovascular Imaging, Department of Radiology; and David E. Sosnovik, MD, FACC, Cardiology Division, Massachusetts General Hospital, for their advice and assistance in preparing this article.

References

Abbasi SA, Heydari B, Shah RV, et al. (2014). *Risk stratification by regadenoson stress magnetic resonance]a U[ ]b[˙in patients with known or suspected coronary artery disease.* Am J Cardiol **114**:1198-203

Campbell F, Thokala P, Uttley LC, et al. (2014). *Systematic review and modelling of the cost-effectiveness of cZˊcardiac magnetic resonance imaging compared with current existing testing pathways in ischaemic WｌﾌfXﾉca mＣdUh\m*.Health Technol Assess **18**:1-120

Cardona A, Zareba KM and Raman SV (2016). *The role of stress cardiac magnetic resonance in women.* J Nucl Cardiol

Coelho-Filho OR, Rickers C, Kwong RY, et al. (2013). *MR myocardial perfusion imaging.* Radiology **266**:701-15
Greenwood JP, Maredia N, Radjenovic A, et al. (2009). *Clinical evaluation of magnetic resonance imaging in coronary heart disease: the CE-MARC study.* Trials **10**:62

Mauricio R, Srichai MB, Axel L, et al. (2016). *Stress Cardiac MRI in Women With Myocardial Infarction and Nonobstructive Coronary Artery Disease.* Clin Cardiol

McGraw S, Romano S, Jue J, et al. (2016). *Impact of Stress Cardiac Magnetic Resonance Imaging on Clinical 7UfYˮ* Am J Cardiol

Schwitter J, Wacker CM, van Rossum AC, et al. (2008). *MR-IMPACT: comparison of perfusion-cardiac magnetic resonance with single-photon emission computed tomography for the detection of coronary artery disease in a multicentre, multivendor, randomized trial.* Eur Heart J **29**:480-9

Schwitter J, Wacker CM, Wilke N, et al. (2013). *MR-IMPACT II: Magnetic Resonance Imaging for Myocardial Perfusion Assessment in Coronary artery disease Trial: perfusion-cardiac magnetic resonance vs. single-photon emission computed tomography for the detection of coronary artery disease: a comparative multicentre, multivendor trial.* Eur Heart J **34**:775-81

Shah R, Heydari B, Coelho-Filho O, et al. (2013). *Stress cardiac magnetic resonance imaging provides effective cardiac risk reclassification in patients with known or suspected stable coronary artery disease.* Circulation **128**:605-14

Sharif B, Dharmakumar R, LaBounty T, et al. (2014). *Towards elimination of the dark-rim artifact in first-pass myocardial perfusion MRI: removing Gibbs ringing effects using optimized radial imaging.* Magn Reson Med **+&**:124-36

Wolk MJ, Bailey SR, Doherty JU, et al. (2014). *ACCF/AHA/ASE/ASNC/HFSA/HRS/SCAI/SCCT/SCMR/STS 2013 multimodality appropriate use criteria for the detection and risk assessment of stable ischemic heart disease: a report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Thoracic Surgeons.* J Am Coll Cardiol **63**:380-406

Janet Cochrane Miller, D. Phil., Author
Raul N. Uppot, M.D., Editor