

Multi-center Evaluation of Accelerated 3D Magnetic Resonance Perfusion Imaging for Assessing Myocardial Ischemic Burden to Detect Coronary Heart Disease

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Introduction: First-pass myocardial perfusion cardiovascular magnetic resonance (CMR) imaging yields high diagnostic accuracy for the detection of coronary artery disease (CAD) ¹. However, standard 2D multi-slice CMR perfusion techniques provide only limited cardiac coverage and hence considerable assumptions are required to assess myocardial ischemic burden. In order to address the limited, non-contiguous coverage of 2D multi-slice myocardial perfusion CMR techniques, three-dimensional (3D) methods have been developed based on recent advances in CMR scan acceleration methodology ²⁻⁶. Whole-heart coverage may be achieved by employing data undersampling strategies in conjunction with appropriate image reconstruction techniques such as (k-t) imaging including sensitivity encoding (SENSE) or principal component analysis (PCA) ⁴⁻⁵.

The objective of the present study was to prospectively evaluate the diagnostic performance of dynamic whole-heart 3D myocardial perfusion CMR for the detection of significant CAD as defined by FFR in 150 patients in a multi-center setting.

Methods: The study was conducted at five European centers (University Hospital Zurich, Switzerland; University Hospital RWTH Aachen, Germany; German Heart Institute Berlin, Germany; King's College London, United Kingdom; University of Leeds, United Kingdom) upon approval by the local ethics review boards. CMR imaging was performed using 3.0 Tesla MR systems (Philips Healthcare, Best, The Netherlands). 3D myocardial perfusion CMR imaging was planned in short-axis geometry with full left-ventricular coverage. Adenosine was administered intravenously at a dose of 140µg/kg/min under continuous monitoring of heart rate and blood pressure. Stress first-pass perfusion imaging (i.v. bolus application of 0.075mmol/kg b.w. of a gadolinium-based contrast agent, Gadovist, Bayer Healthcare, Berlin, Germany; at 4.0ml/s followed by 30ml saline flush) was performed. After a 15-minute waiting period, the identical 3D myocardial perfusion CMR scan was repeated at rest. Dynamic perfusion data were acquired in every heartbeat over 30 cardiac cycles with a 3D saturation prepared spoiled turbo gradient echo sequence (TR/TE/flip angle 1.8ms/0.7ms/15°, saturation pre-pulse delay 150ms, acquisition timed to end-systole, 75% partial Fourier sampling in two directions including an elliptical k-space shutter, 10x k-t acquisition with 49 training profiles resulting in a net acceleration of 7x and an acquisition window per heartbeat of 200ms, k-t principal component analysis reconstruction of 16 contiguous slices of 5mm thickness, acquired voxel size 2.3x2.3mm²) ⁵. Perfusion imaging was performed during a single inspiration breathhold. Shallow expiration was permitted in case the inspiration breathhold could not be sustained during the scan.

Myocardial ischemic burden (MIB) was estimated using dedicated software (GTVolume, GyroTools LLC, Zurich, Switzerland). For determination of myocardial hypo-enhancement the dynamic frame of the stress perfusion scan showing the maximum extent of regional hypo-enhancement during peak signal enhancement was selected. In the presence of extensive ischemia-related hypo-enhancement (e.g. high grade triple vessel disease) remote myocardium either represented an entire myocardial segment or its subepicardial layer. The left ventricular endo- and epicardial borders were manually identified in all slices to determine myocardial volume. Myocardial ischemic burden (MIB) was defined by the volume of hypo-enhancement normalized to total left ventricular myocardial volume and is quoted in percentage. In case of concurrent presence of myocardial scar as identified on LGE images, the amount of scar tissue volume was calculated based on segmentation of hyper-intense tissue. Subsequently, the scar tissue volume was subtracted from the volume of hypo-enhancement prior to MIB calculation.

Results: Example whole-heart 3D myocardial perfusion CMR images acquired during adenosine stress including an overlay of the segmented area of hypoenhancement is presented in Figure 1. The prevalence of CAD as defined by FFR <0.8 was 56.7% (85 of 150 patients) and the sensitivity of 3D perfusion CMR based on visual analysis was 84.7% (95% CI: 75.3 to 91.6) with a specificity of 90.8% (95% CI: 81.0 to 96.5) and diagnostic accuracy of 87.3% (95% CI: 81.1 to 91.7). Positive and negative predictive values were 92.3% (95% CI: 84.0 to 97.1) and 81.9% (95% CI: 71.1 to 90.0), respectively. The mean MIB in all patients was 10.1±12.2% (range, 0 to 51.7%). The mean MIB in patients grouped by FFR status is given in Figure 2. The diagnostic accuracy of MIB to detect significant CAD as defined by FFR was 0.91; and the optimal MIB cut-off value was 4.1%, which resulted in a sensitivity and specificity of 84.7% (95% CI 75.3-91.6) and 92.3% (95% CI 82.9 to 97.3), respectively (Figure 3).

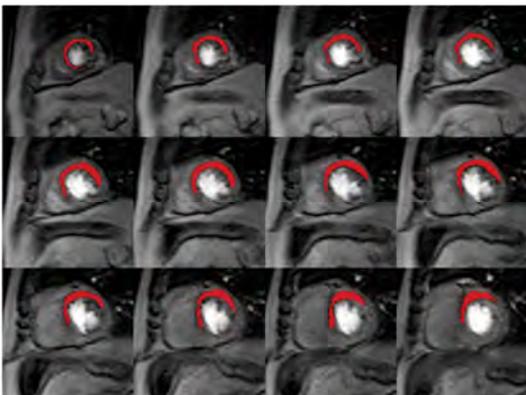


Figure 1: Example whole-heart 3D CMR perfusion data acquired during adenosine stress. A perfusion defect (red) is seen in the anterior and anteroseptal segments extending from base to apex.

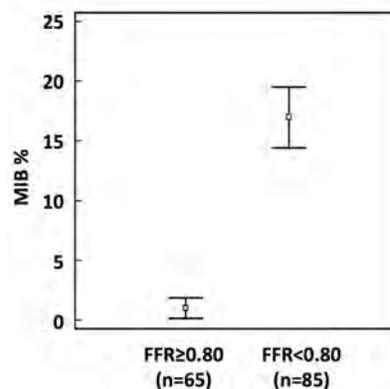


Figure 2: Myocardial ischemic burden (MIB) as function stenosis significance as defined by fractional flow reserve (FFR). Differences are statistically significant.

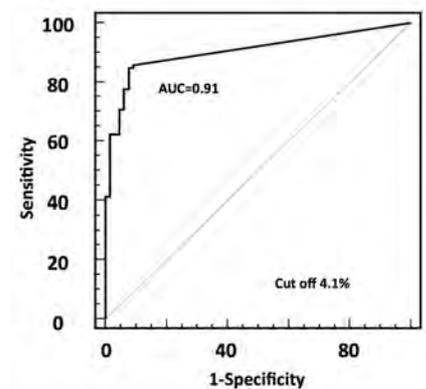


Figure 3: Receiver-operator characteristic (ROC) analysis. A cut-off value of myocardial ischaemic burden >4.1% was found to be most significant.

Conclusion: In this multi-center study 3D myocardial perfusion CMR proved highly diagnostic for the detection of significant CAD as defined by FFR.

References: ¹Greenwood JP et al. Lancet 2012 ; ²Shin T et al. Magn Reson Med 2012 ; ³Manka R et al. JACC 2011; ⁴Pedersen H et al. Magn Reson Med. 2009; ⁵Vitanis V, et al. Reson Med. 2011; ⁶Jogiya R et al. Circulation Cardiovasc Imaging. 2014