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Comparison of rest and adenosine stress quantitative and semi-quantitative myocardial perfusion using magnetic resonance in patients with ischemic heart disease

Abbas A. Qayyum [a,*], Faiza Qayyum [b], Henrik BW Larsson [c,d], Andreas Kjaer [c], Philip Hasbak [c], Niels G. Vejlstrup [a], Jens Kastrup [a]

[a] Department of Cardiology & Cardiac Catheterization Laboratory 2014, The Heart Centre, Rigshospitalet, University Hospital of Copenhagen and Faculty of Health Sciences, Copenhagen University, Blegdamsvej 9, 2100 Copenhagen, Denmark

[b] Department of Cardiology, Hvidovre Hospital, University Hospital of Copenhagen and Faculty of Health Sciences, Copenhagen University, Kettegaard Alle 30, 2650 Hvidovre, Denmark.

[c] Department of Clinical Physiology, Nuclear Medicine & PET, Rigshospitalet, University Hospital of Copenhagen and Faculty of Health Sciences, Copenhagen University, Blegdamsvej 9, 2100 Copenhagen, Denmark

[d] Functional Imaging Unit, Diagnostic Department, Glostrup Hospital, University Hospital of Copenhagen and Faculty of Health Sciences, Copenhagen University, Ndr. Ringvej 57, 2600 Copenhagen, Denmark

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ABSTRACT

The aim was to compare absolute quantified myocardial perfusion (MP) to semi-quantitative measurements of MP using MRI for detection of ischemia.
Twenty-nine patients underwent rest and stress MP imaging obtained by 1.5T MRI and analyzed using own developed software and by commercial available software.
Linear regression analysis demonstrated that absolute quantitative data correlated stronger to maxSI (rest: $r = 0.296$, $p = .193$; stress: $r = 0.583$, $p = 0.011$; myocardial perfusion reserve (MPR): $r = 0.789$, $p < 0.001$; and Δ myocardial blood flow (Δ MBF: $r = 0.683$, $p = 0.004$) than to upslope (rest: $r = 0.420$, $p = 0.058$; stress: $r = 0.096$, $p = 0.704$; MPR: $r = 0.682$, $p = 0.004$; and Δ MBF: $r = 0.055$, $p = 0.804$).
Absolute quantified MP was able to distinguish between ischemic and non-ischemic territories at rest (left anterior descending artery (LAD): 103.1 ± 11.3 mL/100 g/min vs. 206.3 ± 98.5 mL/100 g/min; $p = 0.001$, right coronary artery (RCA): 124.1 ± 45.2 mL/100 g/min vs. 241.3 ± 81.7 mL/100 g/min; $p < 0.001$, and left circumflex artery (LCX): 132.8 ± 53.8 mL/100 g/min vs. 181.2 ± 56.6 mL/100 g/min; $p = 0.060$) and at stress (LAD: 148.1 ± 47.2 mL/100 g/min vs. 296.6 ± 111.6 mL/100 g/min; $p = 0.012$, RCA: 173.4 ± 63.7 mL/100 g/min vs. 290.2 ± 100.6 mL/100 g/min; $p = 0.008$, and LCX: 206.6 ± 105.1 mL/100 g/min vs. 273.8 ± 78.0 mL/100 g/min; $p = 0.186$).
The correlation between global maxSI and positron emission tomography data was non-significant at rest and borderline significant at stress ($r = 0.265$, $p = 0.382$ and $r = 0.601$, $p = 0.050$, respectively).
Quantified MP may be useful in patients for detection of ischemia.

1. Introduction

Tikhonov's theorem of deconvolution, named after the Russian mathematician Andrey Nikolayevich Tikhonov for functional analysis of dynamic images, can be used for quantification of myocardial perfusion and has been used with success in brain perfusion imaging [1]. In patients with ischemia either due to epicardial or microvascular disease, the measurement of myocardial perfusion is important (Fig. 1). The accurate and high spatial resolution of cardiac magnetic resonance (CMR) imaging is a potential alternative to the established gold standard positron emission tomography (PET) for absolute quantification of myocardial perfusion [2].

Abbreviations and Acronyms: AHA, American Heart Association; AMI, acute myocardial infarction; BMI, body mass index; BP, blood pressure; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CCS, Canadian Cardiovascular Society; CMR, cardiac magnetic resonance; ECG, electrocardiography; HR, heart rate; ICA, invasive coronary angiography; LAD, left anterior descending artery; LCX, left circumflex artery; Δ MBF, Δ myocardial blood flow; maxSI, baseline corrected maximal signal intensity; MP, myocardial perfusion; MPR, myocardial perfusion reserve; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; PET, positron emission tomography; RCA, right coronary artery; RPP, rate pressure product.

* Corresponding author at: Department of Cardiology & Cardiac Catheterization Laboratory 2014, The Heart Centre, Rigshospitalet University Hospital Copenhagen, Blegdamsvej 9, 2100 Copenhagen Ø, Denmark.
E-mail address: abbas.ali.qayyum@regionh.dk (A.A. Qayyum).

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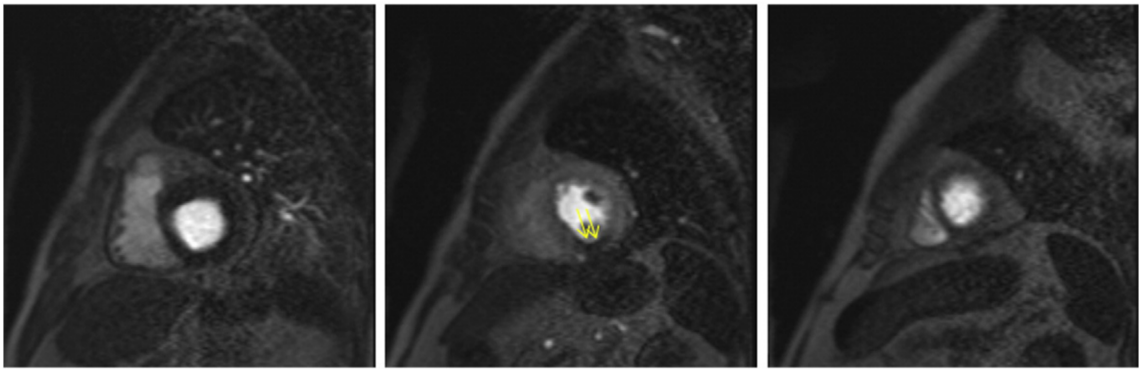

Fig. 1. CMR first-pass perfusion images. Basal, mid, and apical short axis images during first pass perfusion of a patient with ischemia in the inferior wall of the left mid ventricle. The ischemic region appears dark (arrows) and corresponds to a stenotic right coronary artery.

Previously good correlation has been shown between quantified myocardial perfusion estimated by model-free deconvolution with Tikhonov's method and PET in patients with known coronary artery diseases (CAD) [3].

Abnormal stress CMR is able to predict cardiac events in patients with known or suspected CAD [4;5] even after revascularization [6].

In a meta-analysis of 14 studies including 12,178 patients with known or suspected CAD, stress myocardial perfusion imaging with CMR has demonstrated a high negative predictive value for subsequent cardiac events [7] and short term prognosis has been shown to be good in patients with normal stress CMR perfusion imaging [8]. In the selection of patients for coronary angiography, CMR perfusion imaging may also be a help full tool [9].

CMR perfusion imaging may be superior to the widely clinical used single photon emission computed tomography in the detection for CAD [10;11] and thus earlier detection of CMR measured ischemia may be possible leading to earlier intervention against cardiac risk factors and to restore myocardial perfusion. However, absolute quantification of myocardial perfusion using CMR has yet to be established in clinical practice.

The aim of this study was to compare absolute quantified myocardial perfusion with semi-quantitative measured myocardial perfusion using CMR on a global and vessel territorial level in patients with known CAD. Moreover, absolute and semi-quantitative measured myocardial perfusion was used to distinguish between ischemic and non-ischemic myocardium.

2. Material and methods

2.1. Patient population

The study was approved by the National Ethical Committee (02-268856) and performed in accordance to the guidelines for medical research in the Declaration of Helsinki [12].

Into the study, 29 patients were enrolled, all having at least one significant coronary artery stenosis without collateral vessels visualized on invasive coronary angiogram (ICA). Due to the CAD, the patients had moderate to severe angina or angina equivalent dyspnea (Canadian Cardiovascular Society (CCS) class ≥ II or New York Heart Association (NYHA) class ≥ II) despite optimal medical therapy. All patients gave written informed consent.

2.2. Protocol

All patients were instructed to omit caffeine-containing products for 24 h and to abstain from long-acting nitrates for at least 18 h before the examination. ECG, blood pressure, heart rate, and clinical condition were monitored throughout the examination.

2.3. Cardiac magnetic resonance imaging

CMR imaging was performed with the patient placed head-first supine position in a clinical MAGNETOM Avanto 1.5-Tesla scanner (Siemens, Erlangen, Germany). Two 18- and 20-gauge intravenous catheters were inserted in left and right antecubital veins for administration of the contrast and the stress agent, respectively using separate power injectors. A 6-channel chest coil combined with back surface coils were used for imaging.

Briefly, scout images were obtained first. Thereafter short-axis cine images covering the entire heart from basis to apex were acquired.

Three short-axis slices (basal, mid-ventricular, and apical) were obtained for rest myocardial perfusion during the first-pass of gadolinium, using an ECG-gated, end-expiratory breath hold, single-shot hybrid gradient-echo saturation recovery TurboFlash sequence (echo-time, 1.14 ms; repetition time, 190.92 ms; inversion time, 95 ms; flip angle, 12°; field of view, 360 × 360 mm; matrix, 192 × 125; GRAPPA acceleration factor, 2; slice thickness, 8 mm). Gadolinium (Gadovist; Bayer Schering Pharma, Berlin, Germany) was administrated as a bolus of 0.1 mmol/kg body weight at a rate of 5 mL/s, followed by 15 mL of saline at the same rate. Fifty dynamic frame acquisitions of the three slices were acquired with a frame rate of one per heartbeat.

After rest perfusion, late gadolinium enhancement images were acquired as breath-hold, ECG-gated, inversion recovery fast gradient-echo images 10 to 20 min later. Inversion time was set to best nulling the myocardium (250–380 ms) with a total of 0.1 mmol/kg body weight of gadolinium and images were acquired covering the entire length of the left ventricle.

At least 25 min after the first injection of contrast, stress perfusion images were acquired. The same settings and image position as for rest perfusion images were used. After 2.5 min of adenosine infusion at 140 μg/kg/min, a bolus of 0.1 mmol/kg gadolinium followed by 15 mL saline was given and the images acquired. Immediately after the image acquisition, the adenosine infusion was terminated [13].

2.4. Quantitative CMR analysis

Rest and stress myocardial perfusion images were quantitatively analyzed using our own developed software programmed in Matlab (MathWorks, Natick, MA, USA). According to 17-segment American Heart Association (AHA) model [14], the myocardium was divided into 16 segments (minus the apical segment) and based on this the vessel territories were defined. The *endo*- and epi-cardial borders of the myocardium were manually traced on all 50 frames for each slice at rest and stress. Arterial input function was obtained as a function of time with a region of interest drawn on basal slice in left ventricle on all frames for rest and stress. For each myocardial segment, MR signal was obtained as a function of time and converted to relative signal