SCIENTIFIC LETTER

Myocardial perfusion by first pass contrast magnetic resonance: a robust method for quantitative regional assessment of perfusion reserve index

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Heart 2006;92:689–690. doi: 10.1136/hrt.2005.065037

Assessing myocardial perfusion is a key issue in the diagnosis and subsequent treatment of patients with coronary artery disease (CAD).^{1,2} A single magnetic resonance (MR) examination can assess perfusion by monitoring the upslope of the signal change in dependence on the first pass of gadolinium derivatives. We propose a method of evaluating the regional distribution of the perfusion reserve index (PRI), defined as the ratio between stress and resting upslopes. The PRI regional distribution was assessed in patients with and without CAD and a PRI cut off was identified.

METHODS

Thirty two patients (mean (SD) age 65 (10) years, 20 men) underwent MR imaging and quantitative coronary angiography to assess the presence of coronary artery stenoses. The protocol was approved by the institutional ethics committees and informed consent was obtained from all patients.

MR images were acquired with a GE Signa 1.5 T scanner during gadolinium-diethylenetriaminepentaacetic acid (DTPA) infusion (Omniscan, Nycomed Imaging, Roskilde, Denmark) into a cubital vein (0.1 mmol/kg, 5 ml/s) followed by 10 ml of saline flush. A cardiac array coil was used, with fast gradient echo with an echo train readout sequence. For each examination, three 256 × 256 short axis slices (basal, middle, and distal) were acquired in the diastolic phase during an RR interval with a slice thickness of 8 mm. The acquisition was repeated along 60 RR intervals. All the patients were asked to hold their breath as long as they could during the acquisition. The other sequence parameters were field of view 42 cm, one excitation, flip angle 25°, ET 4, repetition time 6.8 seconds, echo time 1.5 ms, acquisition matrix 128 × 92, time for slice 60 ms, and interslice gap 8–12 mm. Dipyridamole was given in accordance with a high dose protocol consisting of a cumulative dose of 0.84 mg/kg in 10 minutes. MR images were acquired at rest and 20 minutes after the end of dipyridamole administration.

MR images were processed by an in-house software tool. For each of the three slices acquired at rest, for examination the operator traced a region of interest that roughly outlined the shape of the heart in one frame in the temporal sequence. All the image frames were automatically registered to correct the misalignments induced by the patient's breathing and motion during the examination. Mutual information maximisation was used for the registration.^{3,4} The left ventricular wall was segmented on the selected frame by a semiautomated procedure, by using anisotropic filtering with application of gradient vector flow snake algorithm.⁵ The contours were then replicated along the image sequence registered in the previous task. Two reference points (the anterior and posterior septal insertions of the right ventricle) were defined. The myocardium was automatically divided into a defined number of sectors, according to a 16 segment model.

For each sector the related residual curves were extracted as the value of the mean signal intensity over time. A reference residual curve was automatically extracted from the centre of the left ventricular cavity and was considered to be representative of the input function. Residual and reference curves were normalised with respect to the precontrast signal intensity. The upslope was evaluated by maximising the first derivative according to a five point sliding window on the rising part of the curve. The normalised upslope was evaluated by dividing the upslope of the myocardium by the upslope of the reference curve. The above procedure was repeated with data acquired during stress. PRI was calculated as the ratio between the resting upslope and the upslope after dipyridamole infusion for each left ventricular segment.

RESULTS

A total of 1008 (504 rest, 504 stress) segments were analysed, excluding 16 segments affected by noise artefacts. The same data set was processed again after one week. The intra-observer variability was low ($p < 0.001$, $r = 0.98$) as was the interobserver variability ($p < 0.001$, $r = 0.91$). The 95% confidence interval in the Bland-Altman analysis was -0.68 to 0.44 , mean deviation -0.11 and -1.65 to 1.31 , mean deviation -0.17 , respectively. The mean processing time for each patient was 15.25 (8.5) minutes.

Sixteen patients had significant CAD (10 single, six multivessel). Of the 504 myocardial segments, 387 (77%, group 1) were supplied by non-stenosed coronaries and 117 (23%, group 2) by coronaries with 75% quantitatively assessed diameter stenosis. PRI was significantly different between the two groups (group 1: 2.95 (1.6) v group 2: 1.78 (0.8), $p < 0.001$). When a cut off < 1.5 for PRI was used, according to the receiver operating characteristic curves, the sensitivity and specificity for the detection of segments of group 2 were 60% and 97%, respectively (fig 1). In the jack knife analysis, the sensitivity ranged from 0 (three stenotic segments were not recognised in one patient) to 100% with a mean of 63%. Specificity ranged from 81–100% with a mean of 98%.

When a PRI below the cut off of 1.5 in at least two contiguous myocardial segments was used as a perfusion positivity criterion for the diagnosis of CAD, receiver operating characteristic curve analysis showed a sensitivity of 88%, specificity of 86%, and diagnostic accuracy of 84%. Sensitivity and specificity for individual coronaries were, respectively, for the left anterior descending artery 72% and 68%, for the circumflex artery 100% and 60%, and for the right coronary artery 85% and 56%.

Abbreviations: CAD, coronary artery disease; DTPA, diethylenetriaminepentaacetic acid; MR, magnetic resonance; PRI, perfusion reserve index

Figure 1 (A) Distribution of perfusion reserve index (PRI) in myocardial segments perfused by stenotic (group 2) and normal coronary arteries (group 1). (B) Receiver operating characteristic (ROC) curve used to identify the PRI cut off.

DISCUSSION

The high robustness of the proposed method is substantiated by the high interobserver and intraobserver reproducibility. The processing time is short enough to allow routine analysis. The image misalignment due to the patient's breathing and motion seems to be effectively corrected by the mutual information approach.⁴ Operator dependence is minimised

because the only inputs required are the selection of the reference image and the rough definition of the left ventricle. Moreover, the PRI regional distribution along the myocardium can be effectively assessed. A comparison with results provided by coronary angiography showed good consistency between the two methods. In particular, a threshold of 1.5 for PRI was established as a discriminating cut off between segments supplied by stenotic and non-stenotic coronaries; this is in good agreement with other studies. When the presence of a PRI below the cut off in at least two contiguous myocardial segments was adopted as a criterion of positivity, the diagnostic accuracy for detecting patients with CAD was 84%.

Some limitation should be recognised in this study. The PRI is merely an indirect index of myocardial perfusion because of the extravascular nature of the gadolinium and the peak clipping effect on the arterial input function assessment. The registration procedure can correct only for rigid misalignment in the image plane and does not correct for through plane motion. Lastly, the detection of correct myocardial borders can be difficult due to a poor signal to noise ratio and presence of artefacts.

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Competing interests: None declared.

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Accepted 18 August 2005

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