A Parametric Model for Quantitative Analysis of Contrast-Enhanced First-Pass MR Myocardial Perfusion that Accounts for Gd-DTPA Interstitial Loading

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Introduction: Quantitative analysis of contrast-enhanced first-pass MR myocardial perfusion is useful for the detection of coronary artery disease. Myocardial blood flow (MBF) estimated from both arterial and myocardial time signal intensity curves provides more linear dynamic range for the assessment of myocardial ischemia than using semi-quantitative indices such as upslope and contrast enhancement ratio [1]. However, quantification of myocardial blood flow can be hampered by the interstitium being loaded with the extracellular gadolinium-based contrast agent. Furthermore, the T_1 nonlinearity between signal intensity and gadolinium contrast concentration may lead to systematic errors in quantifying myocardial perfusion [2]. The primary aim of this study was to estimate MBF of first-pass MR perfusion using a simple mathematic model of constrained devolution that accounts for loading of the interstitial space with gadolinium contrast. Compared with conventional logistic functions, such as a Fermi function [3], this model exploits an additional parameter accounting for the distortion of the myocardial time signal intensity curves due to interstitial loading.

Methods: Local hyperemia of MBF in the left anterior descending coronary artery distribution was induced in 7 dogs through intracoronary adenosine infusion. A dual-bolus contrast (Gadolinium-DTPA 0.005 and 0.05 mmol/kg) technique with steady-state free precession imaging (Siemens 1.5T scanner) was used to acquire first-pass myocardial perfusion MR images. Fluorescent microspheres were used to determine the absolute MBF in ml/g/min. Magnetization modeling that considered baseline T1, baseline T2, and parameters specific to the acquisition sequence were used to convert signal intensity to gadolinium concentration. For these specific experiments, we used the following imaging parameters: composite 90° prep, 50° flip, TR 2.7ms, TI 90ms, 8mm slice, acquisition matrix 128x80, FOV 260x179mm, T_{1-myo} 850ms, T_{1-LV} 1200ms, T_{2-myo} 50ms, T_{2-LV} 250ms, γ: 4.5 L/mmol. Time contrast concentration curves were analyzed based on 8 equal-divided transmural sectors of a mid ventricular slice. MBF of each sector was estimated using a model constrained deconvolution based on a logistic impulse response function:

$$h(t) = \frac{F}{1+\exp[-(t-\tau)*k]} + I$$

where F represents the magnitude of the function, t and k describes the temporal delay length and decay rate of $h(t)$ due to dynamic contrast changing. Compare to conventional logistic function such as a Fermi function, an interstitial loading parameter I is considered in this model. This parameter provides a linear offset of the impulse response function from zero during and after the first-pass, which corresponds to the leakage of the extracellular contrast into the interstitial space and the slow clearance relative to the first-pass kinetics. MBF of a time contrast concentration curve was estimated using this model and compared to microsphere absolute MBF value on a sector-by-sector basis.

Results: Animals with successful vasodilation were included where microspheres documented two-fold increases in MBF in hyperrhemic segments relative to remote myocardium (n=7). Average MBF from microsphere measurements were 5.1±1.5 ml/g/min in hyperemic sectors and 1.3±0.7 ml/g/min in control zones. MBF estimated from MR perfusion time-signal intensity curves averaged 5.0±1.7 ml/g/min and 1.5±0.9 ml/g/min for hyperemic and control sectors. After the signal intensity to [Gd] conversion, MBF estimated from time-concentration curves did not change significantly and averaged 5.0 ± 1.7 ml/g/min (p=NS) and 1.4 ± 0.9 ml/g/min (p=NS). For a sector-by-sector based analysis (n=56), MBF estimates from the MR perfusion correlated well with the microsphere absolute MBF (Figure-1). Bland Altman analysis also showed no consistent bias as a function of MBF.

Discussion and Conclusion: The proposed impulse response function with a parameter accounting for interstitial contrast loading takes into account the observation that some gadolinium enters the interstitial space and clears very slowly relative to other first-pass kinetics. Incorporating this term into the deconvolution model allows fitting the time intensity curve beyond the first-pass range and therefore minimizes the manual interaction needed in quantifying myocardial perfusion. Combining the conventional Fermi function with this interstitial loading term provided a robust parametric model for estimating MBF from perfusion MRI using model constrained deconvolution. The results closely correlated with absolute microsphere measurements in a wide range of MBF values. The T1 nonlinearity in a half-dose contrast and steady-state free precession imaging protocol did not significantly affect the results of MBF quantification.

References:
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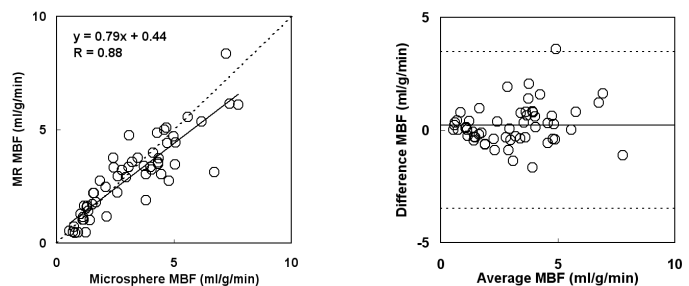3. Jerosch-Herold M, et al. Med Phys, 1998, 25(1):73-84

Figure-1