Curvilinear Myocardial Signal Response to Gadolinium Results in Underestimation of Absolute Myocardial Perfusion by Magnetic Resonance First-Pass Imaging

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BACKGROUND

Absolute myocardial blood flow can be measured from magnetic resonance first-pass perfusion images by model-based deconvolution of the arterial input and myocardial time-intensity curves. The advantages of this technique include enhanced accuracy over semi-quantitative methods and the ability to detect impaired vasodilator reserve even in the absence of a normal reference segment. In order to apply deconvolution to first-pass time-intensity curves, one must assume a linear relationship between signal intensity and gadolinium concentration both in the blood pool and the myocardium. Dual bolus and dual echo strategies have been developed to deal with the known alinearity of the blood pool. However, linearity in the myocardium has not been rigorously investigated.

PURPOSE

We sought to test the linearity of the relationship between gadolinium concentration and signal intensity change in the myocardium and evaluate its effect on absolute myocardial blood flow calculations.

METHODS

All imaging was performed in a 1.5 T clinical MR scanner (Siemens Sonata). First-pass studies utilized a saturation recovery echo planar imaging pulse sequence with parallel acquisition. Typical imaging parameters were: field of view 300 mm x 131 mm; matrix size 192 x 67, slice thickness 8 mm; voxel size 1.6 x 2.0 x 8.0; TR/TE 7.4/1.42 ms; flip angle 25^o; saturation delay 80 ms, EPI factor 4; parallel imaging (TSENSE) acceleration rate 2; bandwidth 1370 Hz/Px.

Phantom Studies:

We calculated the peak myocardial Gd-DTPA concentration expected from a 0.1 mmol/kg injection and prepared 50 ml polypropylene tubes containing Gd-DTPA mixed in normal saline at varying concentrations spanning this expected range. First-pass imaging was performed on the tubes. For each region of interest maximum contrast enhancement (MCE) was measured and normalized to baseline.

Animal Studies:

First pass studies were performed in four purpose-bred hounds, chronically instrumented with a variable hydraulic occluder and Doppler flowmeter around the left circumflex coronary artery as well as left atrial, right atrial, and aortic catheters. Incremental dosages of Gd-DTPA mixed in equal bolus volumes were administered by power injector at a rate of 4 cc/s via the right antecubital vein. Sequential injections were separated by 15 minutes to allow for contrast washout. Studies were performed at rest, during mild vasodilation, maximal vasodilation, and maximal vasodilation with stenosis. Three additional first-pass studies were performed using a dual bolus infusion (bolus #1 0.005 mmol/kg, bolus #2 0.05 mmol/kg) to allow calculation of regional blood flow by deconvolution. Fluorescent microspheres were injected during each examination to allow quantification of myocardial blood flow.

RESULTS

The phantom studies demonstrated a curvilinear relationship between normalized maximal contrast enhancement (MCE) and Gd-DTPA over the full range of concentrations (figure 1). Animal studies demonstrated a similar curvilinear relationship between normalized MCE and contrast dose. In the animal studies, alinearity was apparent even at contrast doses as low as 0.025 mmol/kg. The curvilinear relationship appeared steeper for flow above 2.5 ml/min/g as compared to flow less than 2.5 ml/min/g (figure 2). There was a decrease in the relative signal difference between high flow and low flow studies at increasing doses, suggesting a greater saturation effect at high flow.

Figure 1. Phantom Studies

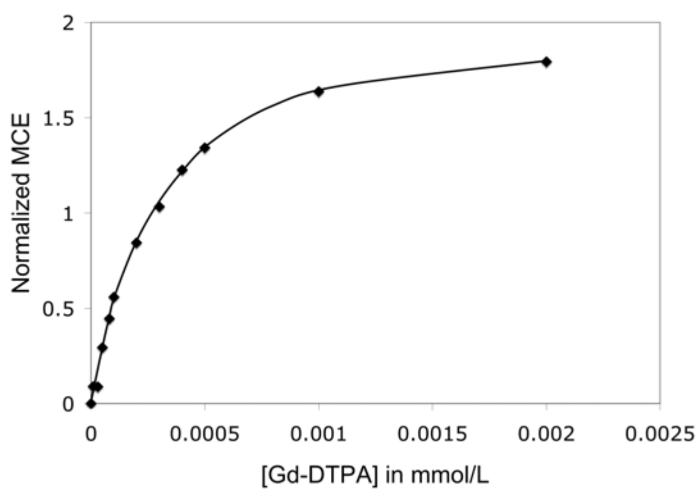
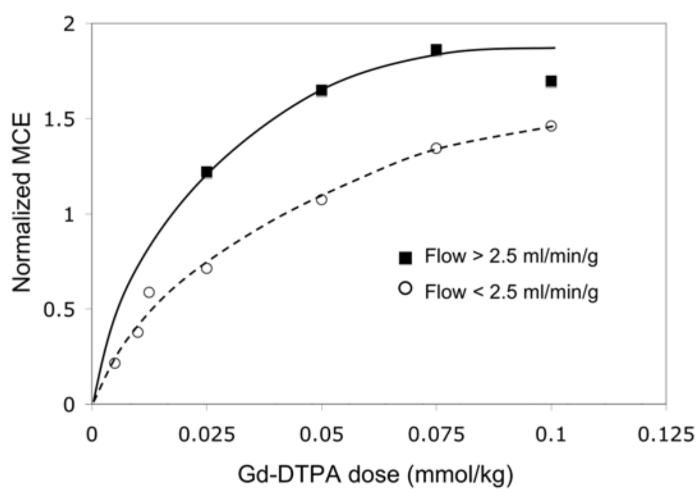


Figure 2. Animal Studies



Despite good correlation, absolute flow values derived from Fermi function deconvolution of time-intensity curves underestimated microsphere blood flow by almost 50% ($y = 0.53x - 0.01$, $r^2 = 0.74$).

CONCLUSIONS

The relationship between signal intensity and gadolinium concentration in the myocardium is not linear over the dose range utilized in first-pass perfusion imaging. Correcting for the alinearity in the blood pool by dual bolus and dual echo techiniques while ignoring alinearity in the myocardium may result in significant underestimation of absolute blood flow by model based deconvolution.