Correction for T1-Nonlinearity in Myocardial Signal Intensity Improves First-Pass Perfusion Quantification

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INTRODUCTION

The nonlinear T1 saturation recovery in first-pass contrast-enhanced MR myocardial perfusion imaging is an important issue which affects quantification of myocardial blood flow. Despite many efforts focused on improving the linearity of the LV blood pool signal intensity, relatively little work has been published with regard to nonlinearity in the myocardium.

PURPOSE

We hypothesize that 1) T1-nonlinearity is significant in the myocardium and it will affect both semi and fully quantitative perfusion estimates, 2) this nonlinearity will affect a long saturation recovery delay more than a short one, 3) a nonlinear correction of the myocardial signal intensity will improve quantitative perfusion estimates, 4) semiquantitative perfusion indices underestimate perfusion independent of T1-nonlinearity.

METHODS

Ten normal volunteers went through 40 dual-bolus (Gd-DTPA 0.005 and 0.1 mmol/kg) perfusion studies on a 1.5T Siemens Espree scanner to cover the interplay of rest vs. stress states and short vs. long saturation recovery delays (TD 70 and TD150 ms) for quantitative perfusion estimates. Rest perfusion was performed 4 hours after the dipyridamole (0.56 mg/kg over 4 minutes) stress study. TD70 and TD150 studies were acquired on separate days. A look-up-table (LUT) for signal intensity versus T1 magnetization was calculated based on the following imaging parameters: 90° prep, 25° readout, TR 7.5ms, TE 1.48ms, 8mm slice, acquisition matrix 128x80, FOV 360x270. The T1 value was converted to the contrast concentration using the equation $1/T1 = 1/T1init + \gamma \cdot [Gd]$ (T1init: 850ms, γ: 4.5L/mmol). The time-signal intensity curves were analyzed on 6 sectors of a mid ventricular slice.
Semiquantitative perfusion indices of intensity upslope (SLP) and contrast enhancement ratio (CER) were measured. Fully quantitative myocardial blood flow (MBF) was estimated using a Fermi model constrained deconvolution. All perfusion estimates were compared before and after the LUT correction and correlated against the MBF of the LUT corrected TD70.

RESULTS

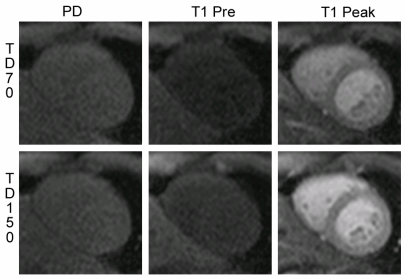

Figure 1. Example images show that the T1-weighted images of TD150 study has visually better SNR than the TD70 (window and level the same). The proton density reference image used the same parameters and thus similar SNR.

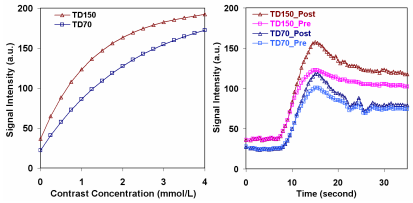

Figure 2. (a) Example of look-up-table (LUT) used to correct myocardial signal intensity in a normal volunteer. The nonlinearity was more severe for TD150 than TD70. (b) Comparison of time intensity curves before and after the LUT correction revealed more severe signal intensity distortion for TD150 than the TD70, particularly at the time period near the peak myocardial contrast concentration (from 12 to 20 seconds along the time axis).

Figure-1 shows example of TD70 and TD150 images from a normal volunteer. The TD150 images showed higher signal intensity than the corresponding TD70 ones. Figure-2 shows the relationship between myocardial signal intensity and contrast concentration for TD70 and TD150. Raw time-signal intensity plot shows the LUT correction has the largest effect near peak contrast enhancement. Table-1 summarizes the results of fully quantitative MBF and semiquantitative CER and SLP before and after the LUT correction. Both fully quantitative and semiquantitative measurements were significantly improved after the LUT correction for the stress perfusion but to a lesser extent for the rest study. The degree of correction required for TD150 was higher than TD70 due to more severe nonlinearity. Figure-3 shows semiquantitative SLP and CER still underestimated vasodilated MBF even after the LUT correction. The effects of underestimation were of similar magnitude for TD70 and TD150.

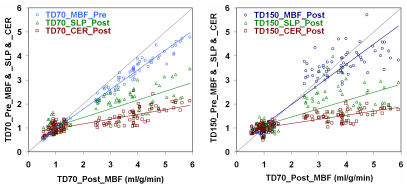

Figure 3. Semiquantitative perfusion measures of SLP and CER underestimated vasodilated MBF despite the myocardial signal intensity correction. For this inter-study comparison, the MBF estimate of TD150 correlated well with TD70 after the LUT correction (R^2=0.87). The correlations were worse for CER and SLP. All perfusion estimates were compared with the TD70 MBF estimate after the LUT correction. The dashed line indicates the expected line of identity for perfusion indices that would increase proportionately with the change in MBF from rest to stress.

N=10	Rest			Stress		
mean	pre	post	%	pre	post	%
TD70 MBF	**0.95**	**1.00**	**4.8%**	**3.34**	**3.89**	**16.3%**
TD70 SLP	0.36	0.38	6.1%	0.75	0.80	11.9%
TD70 CER	1.69	1.78	5.5%	2.43	2.70	11.2%
TD150 MBF	**0.91**	**0.97**	**6.8%**	**2.92**	**3.72**	**27.1%**
TD150 SLP	0.35	0.40	14.5%	0.71	0.88	24.1%
TD150 CER	1.51	1.71	13.2%	2.13	2.60	22.4%

MBF: ml/g/min, SLP and CER: a.u., %: percent of correction

Table 1. Magnitude of corrections on perfusion measurements at rest, stress, and perfusion reserve. All rest perfusion measures needed smaller corrections compared with the corresponding stress measures. All TD70 perfusion estimates required smaller corrections than the corresponding TD150 ones (all p<0.01).

CONCLUSIONS

The effect of T1-nonlinearity between myocardial signal intensity and contrast concentration significantly affects perfusion quantification. This nonlinearity leads to underestimation of all quantitative perfusion measures studied. The effects are more severe for TD150 than TD70. A LUT correction based on acquisition specific relaxivity models of signal intensity versus contrast concentration can correct the signal intensity curves for perfusion quantification. However, semiquantitative perfusion indices still underestimated vasodilated blood flow despite correction of the T1 nonlinearity.