Partial Volume Correction of Arterial Input Functions in T1-Weighted Dynamic Contrast-Enhanced MRI

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INTRODUCTION

Pharmacokinetic Analysis (PKA) using Dynamic Contrast-Enhanced MRI (DCE-MRI) requires good estimates of the Arterial Input Function (AIF). In DCE-MRI a Gd-based contrast agent is injected and the bolus passage is monitored over time. A region of interest (ROI) is outlined in an artery, and the concentration of the contrast agent over time is calculated. However, in many cases the ROI suffers from partial volume effects, i.e., the ROI signal is a mixture of blood and surrounding tissue. To correct for consequent errors in the estimated AIF in T_2^*-weighted MR, it has previously been proposed to estimate the contribution of the surrounding tissue by fitting of the MR signal in the complex plane (van Osch, MRM(45)3 477-85, 2001). In this work a similar approach is adopted for T_1-weighted DCE-MRI.

METHODS & MATERIALS

For an artery oriented parallel to the main magnetic field, signal changes due to the presence of contrast agent are confined to the intravascular compartment and the signal from surrounding tissue is therefore constant during the intra-arterial contrast agent passage. The total signal in the ROI can be modeled by Eq.1. The partial volume correction method is based on iterative estimation of the complex, static tissue contribution by fitting a signal model to the dynamic ROI signal (Eqs 2-5, ξ_m is the molar susceptibility, equal to 0.32 10^{-3} L/mol). For a given estimate of the $S_{surroundings}$, M_0 can be estimated from the pre-bolus signal. Subsequently, the concentration time curved is estimated from the phase of (S_{ROI}-$S_{surroundings}$) and the expected amplitude is calculated from Eq. 2. Finally, the sum-of-squares difference between the actual data and the model is calculated, and the estimation of $S_{surroundings}$ is updated (Nelder-Mead simplex method). MR scanning is performed on a 3T system (Philips Achieva, Philips Health Care, Best, The Netherlands) using a multi-channel dedicated knee coil and a spoiled gradient echo sequence: TR/TE=5.4/3.3 ms, θ=10 degrees, 108x108 matrix, 0.78x0.78 mm pixel size, 5 mm thickness). Gd is administered intravenously (Dotarem, Guerbet, The Netherlands, 0.5 mmol ml^{-1}, r_1=3.4 Lmmol^{-1} s^{-1}), followed by a saline flush (using a MedRad power injector).

1) $$S_{roi}(t) = S_{blood}(t) + S_{surroundings}$$

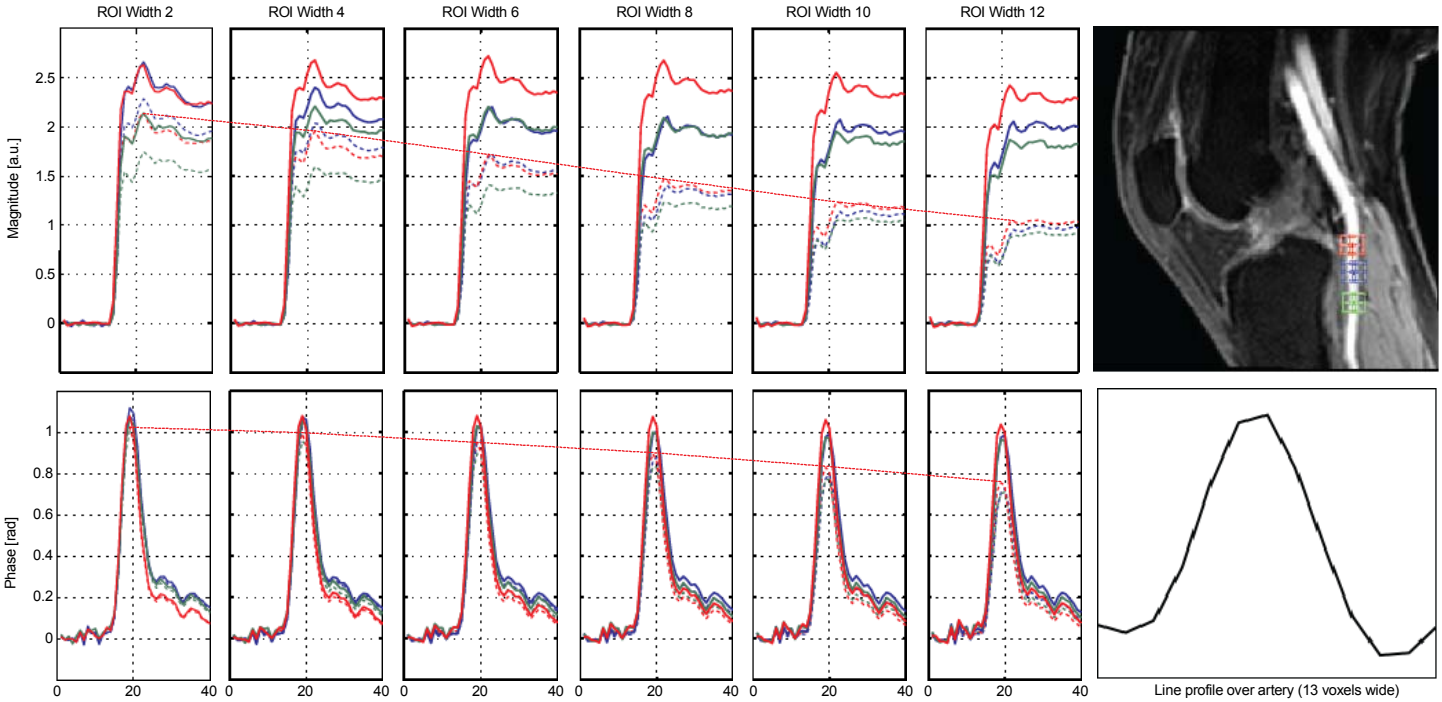
2) $$S([Gd]) = \frac{M_0 \sin(\vartheta)\left(1-\exp\left(-\frac{TR}{T_1([Gd])}\right)\right)}{1-\cos(\vartheta)\exp\left(-\frac{TR}{T_1([Gd])}\right)} \exp\left(-TE\Delta R_2^*([Gd])\right)$$

3) $$T_1([Gd]) = \frac{1}{[Gd]r_1 + R_1(0)}$$

4) $$\Delta R_2^*([Gd]) = 2.3\ 10^6\ [\mathrm{Gd}]^2 + 1.5\ 10^4\ [\mathrm{Gd}]$$

5) $$\Delta\varphi([Gd]) = \frac{1}{3} TE\,\omega_0 \xi_m [Gd]$$

RESULTS



The figure above shows the magnitude and phase of the measured MR signal in 3 ROI locations. The ROIs are increased in width (2, 4, 6, 8, 10, and 12 voxels wide) to increase the partial volume effect over the artery (at the measured locations the artery is 10 voxels wide). The dash-dotted lines show the uncorrected measurements, the thick lines show the corrected magnitude and phase over the same ROIs. The dotted red line shows the decrease in magnitude and phase as a function of the increasing ROI widths for the red ROI.

DISCUSSION

Without correction, partial volume effects lead to an underestimation of the first bolus passage of the AIF. After correction, the AIFs of all ROIs have the same scaling. Even for small ROIs that are positioned completely inside the artery there is still a benefit of applying this correction technique (see third column). Even for the smallest ROI (20% of the artery diameter), appreciable improvements in consistency of the AIF measurement is obtained. For the widest ROIs there is a small decrease in the corrected signal, which can most probably be attributed to contrast agent passage through the surrounding tissue, which is not included in the model. Finally, it should be noted that the phase provides much better depiction of the first passage than the amplitude of the MR signal (in agreement with literature, G. Cron MRM(23) 619–627, 2005). In conclusion, this study proposes a partial volume correction method that improves the robustness and precision of the AIF measurement in DCE-MRI. The only requirement of the method is that the artery is running parallel to the main magnetic field.