# Arterial Input Functions in Dynamic Contrast-Enhanced MRI: Magnitude Versus Phase

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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 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 (CA) over time is calculated. The two approaches to calculate concentration curves based on the complex MR signal are either magnitude- or phase-based. However, the concentration-amplitude relation demonstrates a ceiling effect when the $T_1$ becomes so short that total recovery of longitudinal magnetization occurs. Additionally, $T_2^*$-effects are neglected in this approach, which could potentially lead to underestimations of the first pass of the CA. The phase-based approach is not sensitive to ceiling or $T_2^*$-effects and it has been proposed that this method therefore shows a better depiction of the first pass of CA (Cron, MRI, 2005, 23(5)). However, phase-drift is a well-known problem of MRI-scanners that could make the estimation of the steady-state baseline less reliable (Fig. 1). The phase-based approach can be used in combination with a partial volume correction method to largely eliminate the static contribution of non-enhancing tissue (deBruin, ISMRM2010 #1721_376). The partial volume correction method focuses on the upslope of the phase enhancement curve. In this region there is no influence of the CA leaking in the vessel wall or reaching the tissue directly outside the artery. A feature of this method is that the partial volume correction is performed on the complex MR signal and results in partial volume corrected curves that can be used in either the magnitude or the phase-based approaches. In this work we examine the advantages and disadvantages of phase- and magnitude-based AIFs.

**METHODS & MATERIALS** 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 to acquire a sagittal set of knee images: 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$^{-1}$, 0.2 ml kg$^{-1}$), followed by a saline flush (MedRad injector). Both magnitude- and phase-based methods assume a linear relationship between either enhancement of magnitude or change in phase of the MR signal and the concentration of CA. To compare the different methods, ROIs are drawn in different parts of the popliteal artery in 9 patient datasets and AIFs are calculated with and without partial volume correction, and with or without phase drift compensation (using phase from a reference ROI in the image without CA, see Fig. 1).

**RESULTS** Fig. 2 shows a typical example of AIFs calculated according to phase (AIFp) and magnitude (AIFm). Fig. 3. shows that drift compensation (DC) has no influence on the peak height of the first pass, with (p=0.1) or without (p=0.15) partial volume correction (PVC). Drift compensation is required to correct obvious errors in the tail of the phase, such as negative concentration estimates. Fig. 4 shows that partial volume correction has no influence on the behavior in the tail of the AIF. The AIFm calculated PVC is slightly higher than the AIFm without correction.

**DISCUSSION** We have showed that neither phase-based nor magnitude based approaches provide a complete solution for AIF estimation. The first pass is better modeled using phase, and the steady-state is better modeled using magnitude. This suggests that a hybrid of phase- and magnitude-based AIF methods in DCE-MRI is necessary for robust concentration curve estimation.
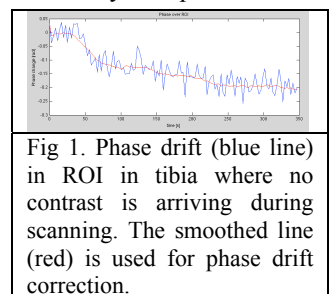


Fig 1. Phase drift (blue line) in ROI in tibia where no contrast is arriving during scanning. The smoothed line (red) is used for phase drift correction.
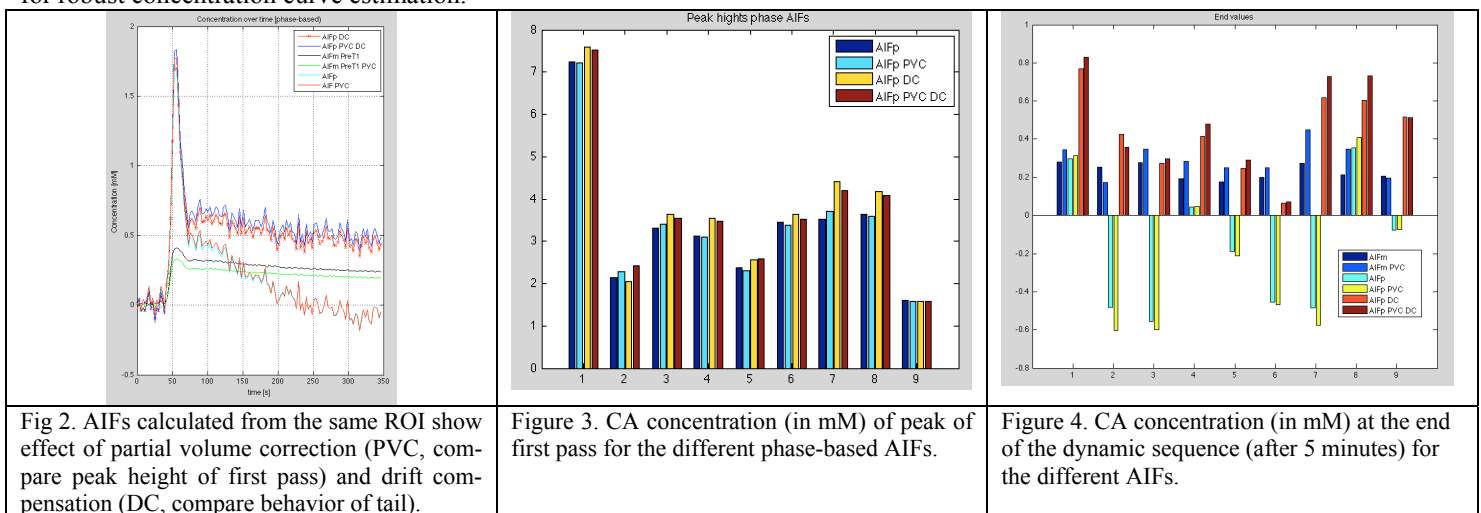


Fig 2. AIFs calculated from the same ROI show effect of partial volume correction (PVC, compare peak height of first pass) and drift compensation (DC, compare behavior of tail).
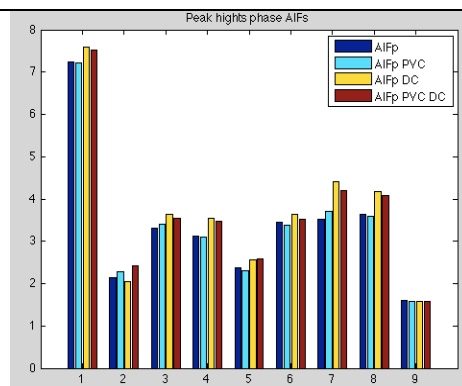


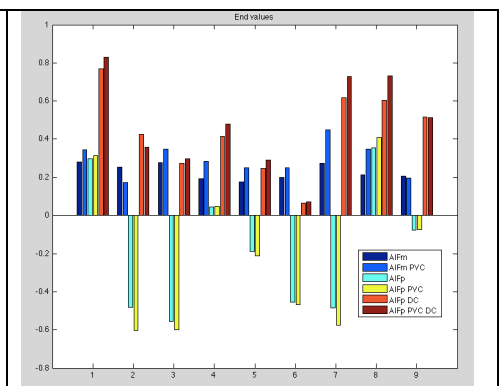Figure 3. CA concentration (in mM) of peak of first pass for the different phase-based AIFs.



Figure 4. CA concentration (in mM) at the end of the dynamic sequence (after 5 minutes) for the different AIFs.