Improving the Arterial Input Function in Dynamic Contrast Enhanced MRI by fitting the signal in the complex plane

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Target audience Physicists and clinicians working on DCE data analysis

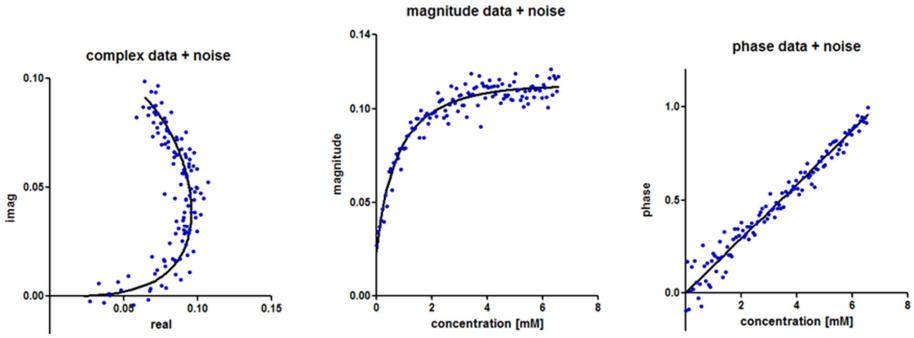


Fig. 1. *Influence of noise on concentration determination. Although the complex noise is equal over the complete signal, the error it causes when using magnitude data is larger at higher concentrations. The error in phase data is larger at smaller concentrations*

Purpose Acquiring an accurate arterial input function (AIF) is essential in dynamic contrast-enhanced (DCE) MRI analysis; the AIF serves as the input for models that estimate tissue properties. Determining patient specific AIFs using MR magnitude data faces challenges due to experimental difficulties such as inflow, B_1 non-uniformity and saturation effects. By using the phase of the MR data, most of these difficulties can be overcome and an attractive linear relationship between contrast agent (CA) concentration and phase shift is obtained[1-3]. However, at low CA concentrations the relatively low amplitude of the signal causes high noise levels in the phase resulting in wrong estimation of the baseline and the tail of the AIF. Magnitude data provides a more reliable estimation at these low CA concentrations, but at high CA concentrations where T_2^* effects dominate the signal, estimation based on magnitude is highly affected by physiological and/or thermal noise (see Figure 1). Recent work by Brynolfsson et al.[4] pointed out the use of magnitude and phase simultaneously for CA concentration estimation using a statistical modelling approach on simulated data. Here we demonstrate that fitting the enhancement data in the complex plane, originally proposed by van Osch et al[5]. for Dynamic Susceptibility Contrast enhanced MRI, can also be used in DCE AIF estimation to mitigate noise and bias that arise from solely using phase or magnitude data. The technique is applied to 3T DCE-MRI data of 3 prostate cancer patients.

Materials and methods The DCE-MRI exams were performed on a 3T MR scanner (Achieva, Philips Healthcare), using a 3D spoiled gradient echo sequence (20 transverse slices, slice thickness 5.0 mm, TR/TE 160, FOV 40 cm, flip angle 8º, 120 dynamics at 2.4 s time interval). In each patient 0.1 mL/kg gadobutrol was injected (1.0 M Gadovist, 1 or 2 mL/s, followed by a saline flush)[3]. For the AIF determination vascular voxels of the femoral arteries were selected. The complex AIF signal S was fit to the following model[6]:

$$\frac{S(C(t))}{S_0} = \frac{\left(1-e^{-TR(R_{10}+r_1C(t))}\right)}{\left(1-e^{-TR\cdot R_{10}}\right)} \cdot \frac{1-cos(\alpha)e^{-TR\cdot R_{10}}}{1-cos(\alpha)e^{-TR(R_{10}+r_1C(t))}} \cdot e^{-TE(r_2C(t))} \cdot e^{i(F\omega_0\chi_m TE\, C(t)+\varphi_0)}$$

where $C(t)$, r_1/r_2 and χ_m are the concentration at time point t, the relaxivities and the molar susceptibility of gadobutrol respectively. R_{10} is the longitudinal relaxivity of blood, F is a geometry factor of the artery, ω_0 is the resonance frequency of protons, α is the flip angle, φ_0 is an offset phase, TR equals the repetition time and TE the echo time. All variables were assumed to be equal to literature and sequence values, so only $C(t)$, φ_0 and α had to be fit. DCE-CT data of the same patients was used as a gold standard.

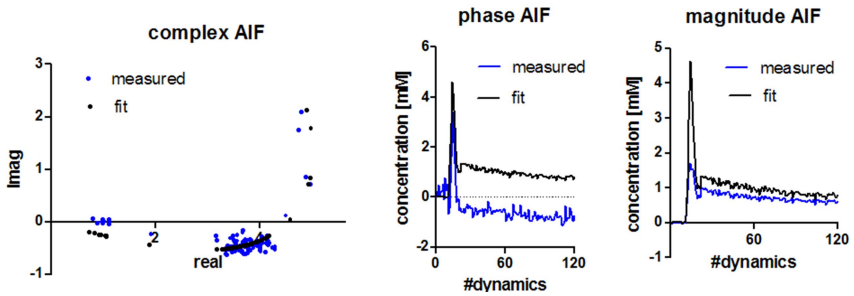
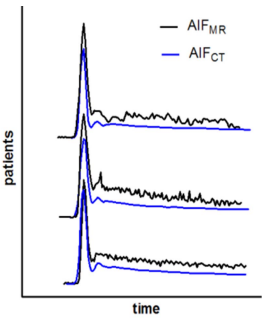


Fig. 2. *On the left a complex fit through measured data. The center graph and right graph shows the phase AIF and magnitude AIF as they were measured compared to the fit. Note the saturation effect in the magnitude data and the large error in phase and for low concentrations as baseline.*

Results and discussion Figure 2 shows the AIFs obtained using only magnitude or phase and when the complex signal is used. The applied fit strongly improved the shape of the AIFs, now showing a clear first pass peak, recirculation and a slowly decreasing tail. Although the model is still affected by inflow and B_1 inhomogeneities, their effects are regularized by also taking the phase into account. In Figure 3 we compare the complex fit AIFs from DCE MRI to the AIFs from DCE CT for the same patients.



← ***Fig.3.*** *The AIF concentrations found by DCE-CT and DCE-MR of three patients*

Conclusion By modeling the complex signal from DCE-MRI, AIFs can be greatly improved, making it a more stable input for DCE models. The correction method will be tested on a larger group of patients to confirm its applicability and confirm the resulting absolute concentrations.

References 1) Akbudak E. et al, MRM 1996; 36:809-815. 2) Garpebring A. et al, Magn Reson Mater Phy 2011; 24:233-245 3) Korporaal J.G. et al, MRM 2011; 66:1267-1274. 4) Brynolfsson et al. Magn Reson Med. 2014 Oct 16. 5) Van Osch et al. Magn Reson Med. 2001; 45:477–485. 6)Schabel et al. Phys. Med. Biol. 2008;53:2345–2373.