Quantitative DCE-MRI in Breast with Direct Measurement of AIF using Tofts and ATH models: A Simulation Study

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INTRODUCTION: Quantitative measurement of pharmacokinetic parameters by DCE-MRI in breast is difficult to realize in practice due to the lack of a major artery within field of view in normal breast MRI. Accurate measurement of AIF on the individual-subject basis is critical for absolute quantitative DCE-MRI. In the estimation of those pharmacokinetic parameters by DCE-MRI, many variabilities, such as blood flow and partial volume effects, can produce technical difficulty. The objective of this work is to evaluate the feasibility of quantitative measurement of pharmacokinetic parameters in breast with direct measurement of AIF with an additional surface coil placed at the back of volunteers, and to investigate the impacts of the unreliable AIF on the accuracy of pharmacokinetic parameters obtained from the fittings to both Tofts and adiabatic approximation to the tissue homogeneity (ATH) models. This work is a part of our DCE-MRI projects in both treated and untreated breasts.

METHODS: MRI scans were performed with a whole-body 3T MR scanner (Magnetom Trio; Siemens, Germany) and a seven-channel breast receiver coil including an additional surface coil placing on the back of volunteers for better positioning in direct measurements of AIF from the aorta. The volunteers were imaged axially in the prone position. With a spoiled 3D FLASH dynamic acquisition, we employed a TR=4ms, flip angle (FA)=20°, matrix 128×128, 10 slices, 3-mm slice thickness, and temporal resolution 1.8s per frame. For simulation, the AIF signal curves was generated by using the experimentally-derived functional form (Parker et al. (1)). Various sets of values for (Ktrans,Vp,Ve) and (E,Fρ,PS,Tc) as shown in the figures was used in the simulation of tissue dynamic enhancement curves for Tofts' and ATH models respectively (2,3). We investigated how B1 inhomogeneity (FA errors) effect on the T1 of tissue or on the AIF affected the final pharmacokinetic parameters estimated in different models. All fittings were implemented in Matlab.

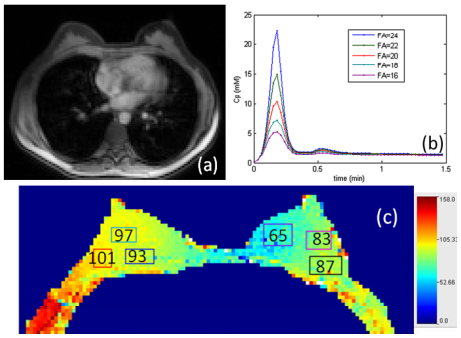

Fig. 1 (a) Representative dynamic image in breast; (b) simulated AIF with different flip angles; (c) Flip angle mapping.

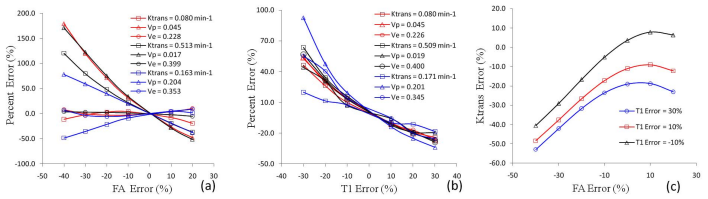

Fig. 2 (a) errors on Ktrans, Vp and Ve vs. FA errors on AIF; (b) errors on Ktrans, Vp and Ve vs. T1 errors on tissue; (c) Ktrans errors vs FA errors on AIF with T1 errors.

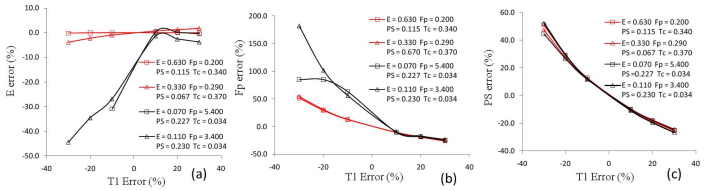

Fig. 3 errors on (a) E, (b) Fρ and (c) PS vs. T1 errors on tissues under different nominal parameters.

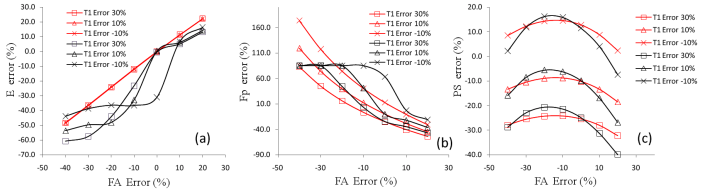

Fig. 4 errors on (a) E, (b) Fρ and (c) PS vs. FA errors on AIF with T1 errors on tissues. Red lines: E=0.630, Fρ=0.200, PS=0.115, Tc=0.340; black lines: E=0.070, Fρ=5.400, PS=0.227, Tc=0.034.

RESULTS: Fig.1a illustrates a representative dynamic image of a volunteer acquired in a temporal resolution of 1.8 sec by 3D FLASH. The usage of additional surface coil greatly enhanced the SNR at the aorta making the direct measure of AIF possible. Fig.1b shows that a small FA error on the aorta could have a significant influence on the initial part of the concentration curve of aorta. The peak concentration of AIF can drop from 14.9mM to 10.4mM as FA changes from 22° to 20°. The resulting FA values in tissue (Fig.1c) could actually in some regions deviate significantly from the nominal 90° in breast. Fig.2a shows the FA errors of AIF imposed a significant influence on the fitted Ktrans, but less on Ve. In some circumstances, 30~40% deviation on FA at AIF produces up to 80~120% offset on the Ktrans. The Vp term is also very sensitive to the deviation of AIF if included in the Tofts' model. Ktrans, Vp and Ve are underestimated or overestimated randomly by AIF errors regardless of the selections of high or low nominal Ktrans in the simulation. On the contrary, in spite of nominal high or low Ktrans assumed, all estimated Ktrans, Vp and Ve have similar pattern of underestimation or overestimation (Figs. 2b and 2c) with respect to the T1 errors of tissue.

Figs.3 and 4 are the simulation results with ATH model. In Fig. 3a~c, the biases of parameters extraction fraction (E), flow (Fρ) and permeability (PS) are evaluated under the T1 error of tissues. For the low flow/long capillary transit time Tc case (Fig3a), the estimated E is insensitive to the T1 errors and gives very small percent errors, but at the high flow/short Tc case it is completely different. Even with the considerations of both T1 and AIF errors (Fig.4a), the bias of E from T1 error is still small in the low flow/long Tc case. Individually, FA errors on AIF significantly affect E values for high or low flow cases (Fig.4a). For both high flow/short Tc and low flow/long Tc cases (Fig. 3c), PS is affected in similar ways by T1 errors. Both T1 errors in tissues and FA errors on AIF greatly affected the accuracy of Fρ (Figs.3b and 4b).

DISCUSSION & CONCLUSION: Results in this work showed FA errors on AIF have a more significant influence on the accuracy of pharmacokinetic parameter estimations than that of T1 errors do in the Tofts' and ATH models. Care should be taken with the parameters fitting by these models when there exists FA errors on T1of tissue or AIF. By using an additional surface coil in the breast DCE-MRI, higher SNR on the aorta makes the direct measure of AIF possible and reliable, but careful calibration of FA errors should be made.

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