Correction of the kinetic parameters of human tissue considering RF-field inhomogeneities

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Introduction: Dynamic contrast-enhanced (DCE) MRI provides an exciting opportunity to study kinetic parameters of human tissues [1, 2]. The quantification of these parameters relies on the deconvolution with the arterial input function (AIF), which can be determined from the signal changes in a major artery. But for field strength above 1.5 T RF-field inhomogeneities occur which produce considerable intensity variations and the estimation of the AIF based on signal changes fails. The objective of this work is (a) correction of the influence of B_1 inhomogeneities using a pulse sequence originally proposed for optimizing flip angles during scanner preparation [3], (b) calculation of the temporal T_1 relaxation by means of an additional reference scan [4], (c) calculation of the time course of the contrast agent concentration, (d) determination and evaluation of the AIF obtained in the left and right arteria iliaca communis and (e) estimation of K^{trans} and V_e for selected regions in the musculus gluteus maximus using a generalized kinetic model [2]. All results were calculated with and without the correction of the B_1 inhomogeneities and were checked against each other.

Methods: For the correction of the data with respect to the B_1 inhomogeneitis a special STEAM sequence [3] was used which measures the actual flip angle distribution. Using equation (1) the temporal T_1 relaxation can be calculated from the reference and the DCE images. SI_R, $SI_D(t)$ and T_R are the signal intensity of the reference scan, the signal intensity of the dynamic scan at the time point t and the repetition time of the DCE scan respectively. α_D and α_P are the nominal and the corrected flip angles of the dynamic and the reference scan respectively. The contrast agent concentration C(t) can be calculated with equation (2) using a relaxivity r_1 of 3.7 L $mmol^{-1}$ s^{-1}. The Tofts-model described in (3) was used for the estimation of the kinetic parameters K^{trans} and V_e. $C_T(t)$ is the time-dependent tracer concentration in the tissue and $C_A(\tau)$ represents the AIF and is the time-dependent tracer concentration in arterial whole blood. Hct represents the hematocrit, V_e is the volume of extravascular extracellular space per unit volume of tissue and K^{trans} is the volume transfer constant between blood plasma and V_e. This model was fitted to the dynamic concentration data in order to obtain values for the two free parameters K^{trans} and V_e. For the statistical analysis of the kinetic parameters the mean value and the deviation of the mean values using two comparable AIFs (left and right arteria iliaca communis) are calculated for 4 different regions of interest in the left and right musculus gluteus maximus. All results were calculated with and without the correction of the B_1 inhomogeneities and were checked against each other. The measurements were performed for a group of 9 subjects using a 3.0 T MRI scanner (Magnetom Tim Trio, Siemens Medical, Germany).

$$T_1(t) = -\frac{T_R}{\ln\left(\frac{SI_R\cdot\sin(\alpha_D) - SI_D(t)\cdot\sin(\alpha_R)}{SI_R\cdot\sin(\alpha_D) - SI_D(t)\cdot\sin(\alpha_R)\cdot\cos(\alpha_D)}\right)} \quad (1)$$

$$C(t) = \left(\frac{1}{T_1(t)} - \frac{1}{T_{10}}\right)\cdot\frac{1}{r_1} \quad (2)$$

$$C_T(t) = K^{trans}\cdot\int_0^{t_M}\frac{C_A(\tau)}{(1-Hct)}\cdot e^{-\frac{K^{trans}}{V_e}(t-\tau)}\,d\tau \quad (3)$$

Results: Fig.1 (a) shows the DCE scan for a selected slice. The depicted regions are used for the calculation of the required parameters and for the evaluation of the results with and without correction of the flip angle. The regions AIF_R and AIF_L are used to calculate the AIF. Region 1-4 are in the space of one muscle tissue in order to point out the deviations of T_1, concentrations and kinetic parameters within one selected tissue region. Fig.1 (b) shows the flip angle image for a selected slice. Fig.1 (c) and (d) show the comparison of the left and right AIF for a selected subject and the comparison of the maximum values of the left to the right AIF for all 9 subjects obtained with (red, magenta) and without (blue, cyan) B_1 correction.

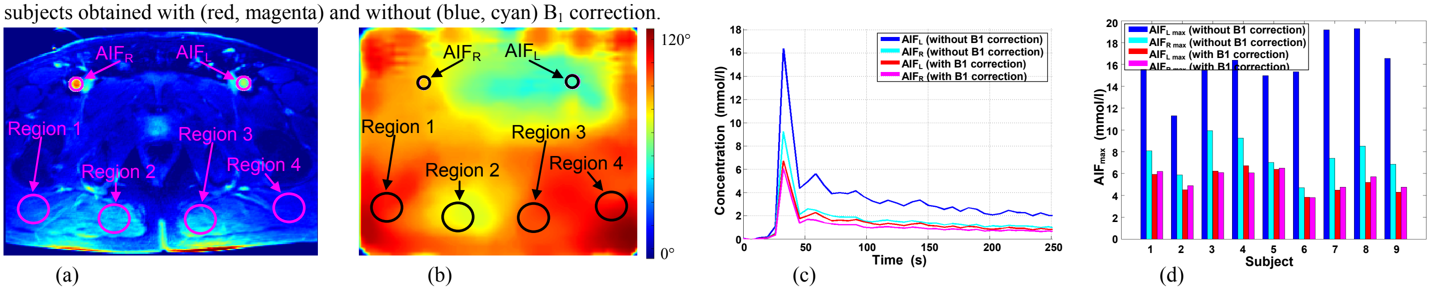

Fig. 1: (a) Perfusion scan with the respective regions, (b) Flip angle image, (c) left and right AIF, (d) maximum values of the AIF

Fig.2 (a) and (b) show the comparison of the mean value of K^{trans} and V_e for a selected subject. The magenta and red bar represent the values obtained with the right and left AIF with B_1 correction and the cyan and blue bar represents the values obtained without B_1 correction. Fig. 2 (c) and (d) show the comparison of the absolute deviation of K^{trans} and V_e with respect to the right and left AIF for all subjects. The bars colored from red to magenta represent the values obtained for regions 1 - 4 with B_1 correction and the bars colored from blue to cyan represent the values obtained without B_1 correction.

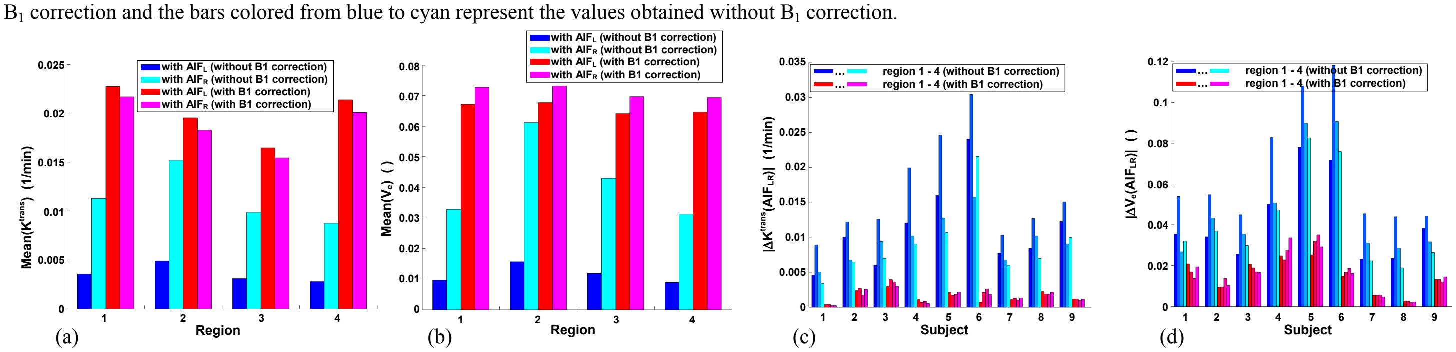

Fig. 2: (a) mean value of K^{trans}, (b) mean value of V_e, (c) absolute deviation of K^{trans}, (d) absolute deviation of V_e

Discussion: The determination of the AIF and of the kinetic parameters depends strongly on the inhomogeneities of the RF-field. An essential improvement can be achieved if the dynamic data are corrected accordingly. The absolute difference of K^{trans} and V_e obtained with the AIF in the left and right arteria iliaca communis can be improved by a factor up to 33 when using the correction procedure.

References: [1] S.M. Galbraith, NMR Biomed., 15, 132-142 (2002), [2] P.S. Tofts, J. Magn. Reson. Imaging, 10, 223-232 (1999), [3] W.H. Perman, Magn. Reson. Med. 9, 16-24 (1989), [4] K. Hittmair, Magn. Reson. Med. 31, 567-571 (1994)