The effect of RF field non-uniformity on tracer quantification in DCE MRI of the pelvis at 3 T.

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Introduction

Dynamic Contrast Enhancement (DCE) MRI has become an important imaging modality in the detection of tumors in the pelvic areas such as prostate cancer [1]. The principle is based upon administration of a T_1-shortening contrast agent such as Gadolinium-DTPA which modulates the T_1 relaxation time of tissue. Quantitative monitoring of contrast bolus passage requires accurate T_1 mapping with high temporal and spatial resolution. A popular method is the variable flip angle (VFA) method which is used to measure pre and post contrast T_1 values [2]. A prerequisite for using this method is that the flip angle is known over the region of interest. Otherwise, systematic errors are introduced in the contrast quantification. At 3 Tesla the RF wavelength for muscular and fatty tissue is 0.26 and 0.60 m. respectively. This small wavelength introduces a significant flip angle non-uniformity over the pelvis. The aim of this study was (1) to evaluate the consequences of flip angle deviations for the quantification of the contrast agent concentration for DCE-MRI and (2) and to compensate the VFA method for the flip angle non-uniformity in the pelvis at 3 Tesla. This work was motivated by our finding that at 3 T patients undergoing a DCE exam consistently demonstrated different peak concentrations in their left and right Iliac Externa arteries as shown in Figure 1a, while one expects almost identical concentration curves.

Methods

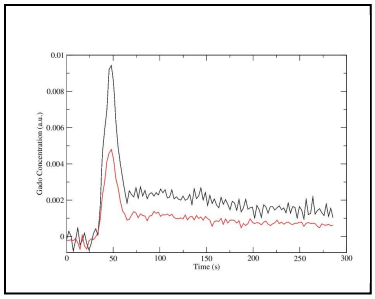
To investigate the sensitivity of the quantification of contrast agent concentration for flip angle errors, we mimicked the VFA method with inclusion of flip angle errors. We calculated pairwise signal intensities for two nominal flip angle settings (10 and 35 degrees) using the signal equation for a spoiled gradient echo sequence. In the signal calculation the nominal flip angle is substituted by the 'true' flip angle which is the nominal flip angle multiplied by a transmit efficiency between 0.5 and 1.1. Also, a 'true' T_1 relaxation is assumed. From the signal pairs we reconstructed the 'measured' T_1 relaxation assuming no flip angle errors. To include the T_1 shortening of the bolus passage this procedure was repeated for several post-contrast 'true' T_1 values in the range of 100 to 1600 ms. We assumed a 'true' pre-contrast T_1 value of 1.6 s. In this way, we can a theoretical curve showing the error in the concentration quantification as a function of the flip angle deviation.

B_1 and T_1 mapping experiments were performed on a 3 Tesla whole body MR scanner (Achieva, Philips Medical Systems, Best, the Netherlands) using a 6 channel cardiac receive coil. The flip angle (B_1) distribution in the pelvis of a male volunteer was mapped by using a multiple 2D spoiled gradient echo sequence (TE=2 ms, NSA=2, flip angle 70°). Two images were acquired in the pulsed steady state for two alternating TR of 20 and 100 ms [2]. The acquired in plane resolution was 4.0 x 3.1 mm^2 using 10 axial slices of 5 mm slice thickness and acquisition time was 4 minutes. A T_1 map of the pelvis was acquired by using a dual flip angle method. Two images were acquired with a multiple 2D spoiled gradient echo sequence for two different flip angles (10 and 35 degrees, TR=21.4 ms, TE= 2ms, NSA=2, 29 dummy excitations). To reach quicker steady state conditions allowing rapid T_1 mapping, two different initial flip angles (33 and 41 respectively) are applied before each measurement [2]. The scanned volume and resolution was identical to the B_1 mapping. With the measured B_1 maps the T_1 map can be corrected for flip angle non-uniformity.

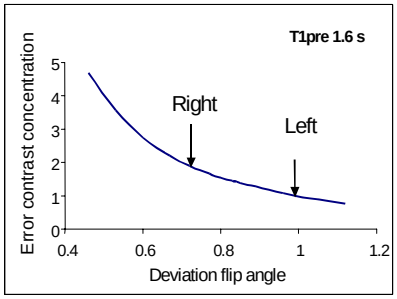
Results & Discussion

Figure 1b shows the error in contrast concentration due to flip angle errors. It illustrates that lower flip angles will lead to a large overestimation of the contrast concentration. Figure 2a shows a flip angle pattern in the human pelvis. The typical diagonal pattern is the result of the wave interference of a circularly polarized RF field with an elliptic geometry [3]. For centrally placed organs such as the prostate, the RF artifact will result in moderate flip angle deviations around 10 to 15%. However, for the right Iliac Externa artery which is a frequently used artery in DCE MRI to measure the arterial input function (AIF) needed for tracer kinetics analysis, these deviations can mount up to 30 to 40%. The exact values depend on the eccentricity of the pelvis, although we observed that the left Iliac Externa artery differs mostly only slightly from the nominal value. Based upon these flip angle differences and our simulations from Figure 1b one expects that the right Iliac Externa will have approximately a factor two higher peak concentrations than in the left Iliac Externa. This might explain the difference in left and right peak concentrations shown in Figure 1a.

To compensate for the flip angle non-uniformity, we have started to compensate the VFA for the spatial varying flip angle. Preliminary results are shown in Figure 2b and c. As can be observed in Figure 2b, the contrast in uncorrected T1 maps is obscured by the flip angle heterogeneity. In Figure 1c the T_1 map is corrected for the flip angle non-uniformity reducing the effect of the flip angle pattern.



1a



1b

Figure 1. a:) Patient example of AIF taken on left (red) and right (black) Iliac Interna. error in b:)Error in quantification as result of flip angle errors. A value of 1 corresponds to no error. A T_1pre of 1.6 corresponds to arterial blood at 3 T.

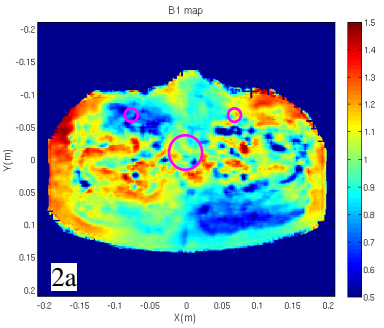
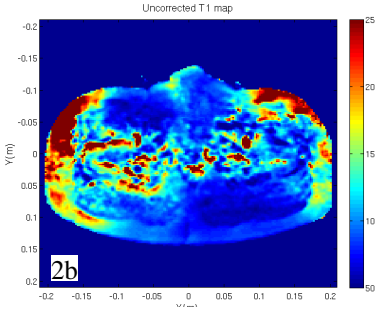
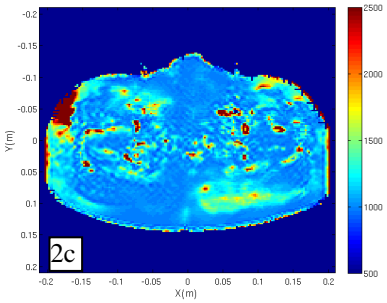


Figure 2. a:). Measured flip angle non-uniformity pattern. The positions of the Iliac Externa and the prostate are marked. b:) The uncorrected T_1 map. and c:) Corrected T1 map





Conclusions

RF field effects at 3 T cause a typical diagonal flip angle pattern in the human pelvis. However, for off center regions deviations are larger. Especially for a reliable determination of the AIF one should be cautious. Depending on the B_0 orientation (here head-toe) the left or right Iliac Externa will be the preferred choice. However, we believe that since also central regions such as the prostate can suffer of flip angle deviations, the quality of the contrast quantification in DCE-MRI can be much improved by including B_1 mapping into the protocol.

References

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3. Van den Berg CA et al. MRM 57:577-86. (2007)