A Practical Bookend Technique for Quantitative DCE-MRI Evaluation of the Liver

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Introduction: Accurate T1 measurements are essential in quantitative DCE-MRI. However, these are often time consuming to obtain. It has been previously reported that bookend T1 measurements acquired before and after dynamic imaging would allow conversion of signal intensities into T1 estimates without the errors associated with imperfect slice profile and transmitter coil B1 profile [1]. Previous studies have shown that the variable flip angle method (VFA) is a practical method of calculating accurate T1 [2]. In this study, different combinations of VFA were used to calculate bookend T1 measurements, which were subsequently used to generate Gd-DTPA concentration-time course curves. The aim of this study was to find the optimum combination of flip angles with a minimum number of measurements, which provides accurate quantitative DCE-MRI analyses. Minimising the number of measurements reduces patient imaging time and improves patient comfort, especially when breath-holds are involved in the clinical protocol. T1 measurements were first performed using phantoms and volunteers for technique validation and subsequently applied to clinical studies.

Methods: Measurements were performed on Siemens Avanto 1.5T MR scanner using a phased array body coil. Validation studies of T1 measurements using a 3D VIBE sequence were performed on Eurospin II phantom (T1 range = 221–1547ms) and three volunteers (TR/TE=4.36/1.34ms, interpolated matrix size=256×256, number of slices=12, slice thickness=5mm, NSA=3). T1s were calculated using combinations of 5 flip angles (α=2°, 8°, 12°, 18°, 24°) and 2 flip angles (α=2°, 24°). These flip angles are optimal for the phantom and physiological T1 ranges and the TR employed.

In a clinical abdominal study of a patient with liver metastases, bookend T1 measurement images were acquired pre- and post-injection of Gd-DTPA at α=2°, 8°, 12°, 18° and 24° using a 3D VIBE sequence with the same sequence parameters as in the validation studies. Each navigator-followed bookend measurement was acquired during a breath-hold of approximately 16s. The dynamic part of the study consisted of 40 dynamic measurements acquired every 5.6s (with a 5s gap in between each image) using a 3D VIBE sequence with navigator breath-hold and follow (iv. Magnevist® 0.1mmol/kg body weight, TR/TE=4.36/1.34ms, α=24°, interpolated matrix size=256×256, number of slices=12, slice thickness=5mm, NSA=1). Gradient echo sequence simulations show that there is a linear relationship between acquisition signal intensities and contrast agent concentrations, up to a concentration of ~2.0mmol/kg body weight, using this sequence. Bookend T1s were calculated using three different combinations of VFA which are tabulated in table 1 as A, B and C. These measurements involve ten, four and three breath-holds, respectively, each lasting approximately 16s. Gd-DTPA concentration time courses were generated using calculated bookend T1 measurements [1]. ROIs were drawn around metastases and liver; from which mean native T1s were obtained. The transfer constant (K^{trans}; min^{-1}) was calculated by fitting the Gd-DTPA concentration-time course curve to a bi-compartmental model [3] for each pixel in the whole liver. A single arterial-input was assumed and a generalized vascular input function (VIF) based on published data was used in the modelling procedure [4, 5]

	Pre-contrast T1 calculation	Post-contrast T1 calculation
A	2°, 8°, 12°, 18°, 24° (all acquired pre-contrast)	2°, 8°, 12°, 18°, 24° (all acquired post-contrast)
B	2°, 24° (both acquired pre-contrast)	2°, 24° (both acquired post-contrast)
C	2°, 24° (both acquired pre-contrast)	2° (acquired pre-contrast), 24° (acquired post-contrast)

Table 1: Combinations of flip angles used for bookend T1 calculations. Combinations A, B and C require patients to hold their breath 10, 4 and 3 times respectively.

Results: In the phantom study, phantom T1 and calculated T1 values, using 5 and 2 flip angles were highly correlated (R^2=0.939 and 0.946 respectively). Mean % errors in measured T1 values using 5 and 2 flip angles were 4% and 5% respectively. From the volunteer studies, mean (±SD) liver T1 of 561(±89) and 560(±100ms) were obtained using combinations of 5 and 2 VFA respectively. The liver T1s agree well with literature value [5].

From the patient study of metastatic liver, mean native liver T1 of 607 (±58), 599 (±66) and 602 (±75) ms and mean native metastasis T1 of 1393 (±471), 1257 (±329) and 1336 (±447) ms were calculated from the combinations A, B and C, respectively. K^{trans} maps generated using combinations A and C are shown in figure 1, together with a map showing the correlation of the two K^{trans} maps and their correlation plot (R^2=0.924, p<0.001).

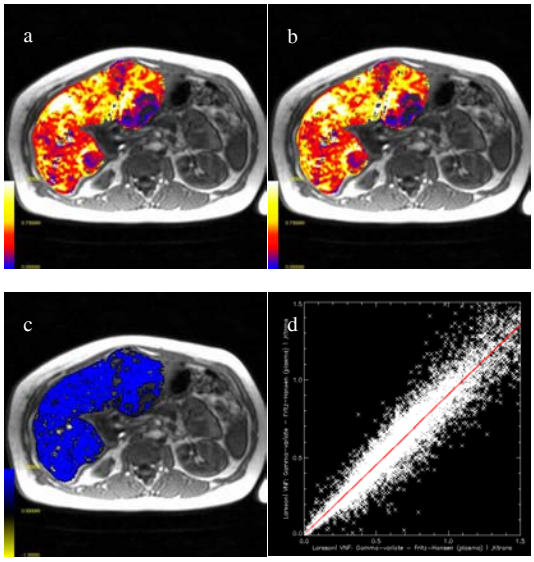

Figure 1: K^{trans} maps calculated using a) 5 flip angles (combination a) and b) 2 flip angles (combination c), c) correlation map between the two (where blue represents high correlation).and d) correlation plot of the K^{trans} values. Dark speckles seen in the maps, in particular the correlation map, are due to signal voids.

Discussions: Results of the validation studies have shown that for the range of T1s present, using 2 flip angles to measure T1 has comparable accuracy to using 5 flip angles. Liver T1s obtained from volunteers agreed with literature value. In the patient study, native T1s measured and contrast agent concentration curves generated using the three different combinations of flip angles agreed with each other. High variations in the metastasis T1 observed demonstrate the heterogeneous nature of metastases. Parametric K^{trans} maps, a conventional DCE-MRI parameter, calculated from the contrast agent concentration curves were also highly correlated.

Results have shown that using ten bookend measurements (i.e. combination A: both pre- and post-contrast 2°, 8°, 12°, 18° and 24° images) has no significant advantage over using just three bookend measurements (i.e. combination C: pre-contrast 2° and 24° and post-contrast 24° images) on the accuracy of bookend T1 measurements or on the subsequent conversion of dynamic signal intensities to Gd-DTPA concentrations. This study has shown that using a T1-weighted gradient echo sequence with a linear relationship between signal intensities and contrast agent concentrations, accurate bookend T1 measurements using VFA can be obtained in just three breath-holds instead of ten breath-holds, considerably decreasing imaging time and improving patient comfort.

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