Rapid Dixon Estimation of Water and Fat Equilibrium Magnetisation for Breast Density Measurements

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Introduction

Quantitative measurements of water and fat content are desirable for population studies comparing and classifying groups of subjects, and for longitudinal studies. One example is the assessment of breast density, a known risk factor in breast cancer. Dixon methods produce separate fat and water images of high-resolution, within a breath-hold. However, longitudinal changes in image intensity can be attributed to either T1 or proton density changes. The objective of this work is to produce separate proton density maps for fat and water using Dixon fat and water images acquired with 3D spoiled gradient-echoes and two different flip angles, and to optimise the data acquisition parameters.

Methods

Computer Simulations: Monte-Carlo simulations were employed to determine the best pair of flip angles to minimise the uncertainty in calculated proton density maps, for each value of the ratio TR/T1 (Matlab, Cambridge, UK and IDL 7.1, Boulder, USA). Rician noise was added to the signal intensity calculated as a function of flip angle, employing noise levels consistent with experimental values. The lowest standard deviation identifies the optimal set of two flip angles. In addition, the effect of flip angle errors was evaluated, as this is a known problem in quantitative dynamic contrast enhanced (DCE) studies.
Test Objects: Images were acquired at 1.5T with fast spoiled 3D gradient-echo pulse sequences (TR=4ms), using a test object containing solutions covering a wide range of T1 values with constant proton density. Flip angles from 2^o to 26^o were employed, in 2^o steps. Images acquired with different flip angles were combined in pairs to yield proton density maps [1], and the standard deviation over a homogeneous region of interest of known T1 was used to evaluate the uncertainty in the proton density measurement.
Clinical Examinations: All subjects were examined with approval of the Local Ethics Committee. Knee images were acquired with 3D fast spoiled gradient echoes and flip angles 5^o, 10^o, 15^o and 20^o (TR = 17ms). Test tubes containing solutions with same proton density and different T1s were placed in the field of view. The manufacturer's own software was used to produce fat and water images (Siemens Avanto 1.5T, 3-pt Dixon WIP, Erlangen, Germany). Images were combined in pairs to produce proton density maps, and evaluated. Breast images were also acquired with dual-echo techniques (Philips Intera 1.5T, Eindhoven, Netherlands) and the flip angles calculated to provide the best proton density map, with a view to its use in breast density evaluation. Fat-water separation was processed with in-house software [2]. Fat and water images were combined to produce separate fat and water proton density maps, and corrected for the sensitivity of the breast receiver coil using body coil images as a reference.

Results

Figure 1 shows the two flip angles that optimise the proton density map calculation as a function of TR/T1. These flip angles differ from the optimal flip angles for T1 calculation, used in DCE [1]. For all TR/T1 values within the clinical range, simulations showed that the choice of the lowest flip angle is the most critical. As an example Figure 2 shows isocontours of the standard deviation of the calculated proton density as a function of the flip angles for TR/T1 = 4ms/480ms. The optimal combination is indicated by "+" and there is little variation on the standard deviation with change of the highest flip angle. Figure 3 shows proton density maps calculated for the test object, confirming the simulation results (Figure 3). Only the first row, acquired with flip angle 2^o produces an even proton density map over the entire object. The proton density uncertainty rises sharply for higher values of the lowest flip angle. Test tubes within white boxes in Figure 3 have T1s 290, 400, 480, 860, 1070ms, closest to the range of T1s found in breast. Breast was scanned with flip angles 7^o and 25^o, TR=6.1ms. Figure 4 show fat and water proton density maps (bottom), different from the T1 weighted images of the breast (top). For a range of T1s the overestimation (or underestimation) of proton density as a result of a difference between the nominal flip angles and the actual ones is shown to be approximately linear and independent of T1 (Figure 5). Proton density maps can therefore be corrected by reference to a known proton density object within the field of view.

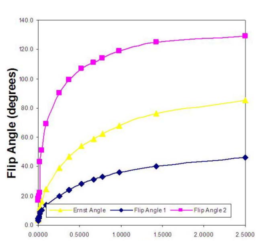

Figure 1

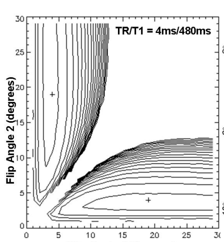

Figure 2

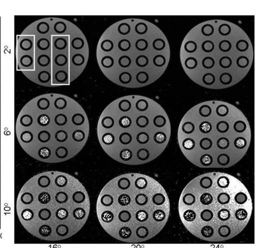

Figure 3

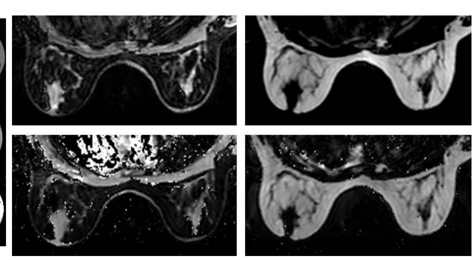
Figure 4- T1W (top) & PD (bottom)

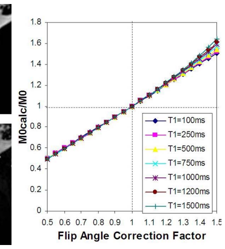

Figure 5

Conclusions

Proton density maps can be reliably generated from two sets of 3D spoiled gradient-echo Dixon images acquired with two optimised flip angles. This technique can account for partial volume effects, and therefore can go beyond assigning each breast pixel to either fat or water components. Classifying breasts in terms of their fat and water proton density can lead to an MR-based investigation of risk factors in breast cancer. Cyclic variations of proton density in breast can also be studied.

References: 1. Wang et al. MRM 5, 399-416 (1987), 2. Schmidt and Fraser JMRI 2008; 27: 1122-1129

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