Off-Resonance Effects of Spectrally-Selective Adiabatic Inversion Pulses in Dynamic Contrast-Enhanced Breast Examinations

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Introduction

The analysis of contrast-agent (CA) uptake curves is an essential part of breast MRI examinations [1,2]. Dynamic Contrast-Enhanced (DCE) protocols using spectrally-selective adiabatic fast passage (AFP) inversion pulses for fat suppression can be very effective but, because the effects of this pulse depend on both T1 and resonant frequency, good B_0 field homogeneity is required. Shimming over the breasts can be difficult due to their shape [3] and deformations caused by disease, previous surgery, and radiotherapy markers have a detrimental effect. In this work we investigate whether spectrally-selective inversion pulses affect contrast-agent uptake curves in regions where the water resonant frequency is offset from the central frequency due to B_0 field inhomogeneity.

Materials and Methods

DCE Breast examinations were undertaken at 1.5T (Philips Intera, Best, The Netherlands). Both simulations and experimental work employed the same fast grad-echo sequence, preceded by Inversion recovery fat suppression: TE/TR= 1.8/3.9 ms, Flip Angle= 18º, 60 echoes, radial acquisition, parallel imaging factor=2 (R/L). Fat suppression uses a hyperbolic secant inversion pulse (bandwidth 339 Hz at FWHM and 386 Hz at 99%), centred at 259 Hz below the central frequency, with inversion time 90ms. Data was acquired for a 3D volume 240x216x150mm.

<u>Clinical Breast Examinations</u>: B_0 field inhomogeneity (after shimming) in bilateral breast examinations was evaluated in 5 patients and one volunteer, using phase images (TE_1/TE_2=2.3/4.6ms). The range of T1 values found in breast following CA injection was evaluated using data from the MARIBS breast screening trial [1]. Breast parenchyma linewidth was estimated pre-contrast on four patients with large lesions who were part of a separate study (two-point T2* estimation from TE_1/TE_2=4.6/46 ms). Clinical DCE breast examinations were also scrutinised for evidence of fat suppression failure. All subjects were scanned with the approval of the Local Authority Research Ethics Committee.

<u>Simulation</u>: Image Intensity as a function of T1 (25-1200 ms) was calculated for a range of frequency offsets, ranging from the water central frequency to the CH_2 frequency (3.5 ppm) using the Bloch equations and considering a linear variation in the longitudinal magnetisation within the transition region following an AFP inversion pulse, as shown in Figure 1. The linewidth estimated in breast lesions was used in the simulations.

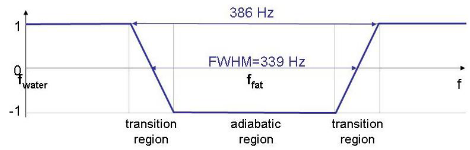

Figure 1 – Function used to model the AFP inversion pulse.

<u>Test Object Imaging</u>: A test object containing solutions of Gd-DOTA (DOTAREM, Guerbet, France) with concentrations from 0.1 to 10 mM was scanned with the clinical breast DCE protocol. The frequency offset of the inversion pulse was shifted in 25 Hz steps, from 359 Hz above the central frequency to zero. The field inhomogeneity over the test object was also measured by phase images (TE_1/TE_2=4.6/6.9 ms) to estimate the frequency offset at the position of each solution. Image intensity was plotted as a function of 1/T1 for different frequency offsets from the nominal water central frequency.

Results

<u>Clinical Data:</u> Typical values for the range of magnetic field values found in breast exams after shimming are 0.5 ppm over the central slices. The range can reach about 2 ppm in slices away from the centre, and the overall range is above 1 ppm in every dataset. In double-dose DCE breast examinations [1] the shortest post-contrast T1 values observed were of the order of 70-80 ms for enhancing lesions and 50 ms for blood vessels. T2* values in non-enhanced breast ranged from 25 ms to 100 ms, and these values were used to estimate linewidth in the simulations of Figure 2.

<u>Simulations and Test Object Data</u>: Simulations show that on resonance the image intensity has an approximately linear relationship with 1/T1 over the range of T1 down to 100 ms (Figure 2a). The linear relationship is preserved for off-resonance frequencies, but with a smaller relative change in image intensity associated with a given CA uptake. Using lower flip angles the linear relationship between image intensity and 1/T1 is not maintained up to 100 ms even on resonance and off-resonance curves are less similar to the on-resonance one (Figure 2b). The experimental results are in agreement with the simulation, and suggest that the actual flip angle may be lower than the nominal 18º (Figure 3).

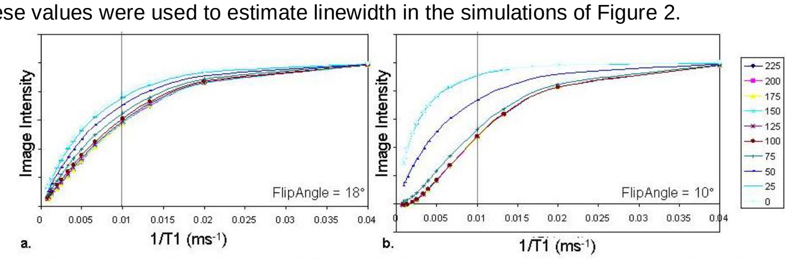

Figure 2 – Image Intensity as a function of 1/T1 for the same parameters used in clinical examinations (a) and for a lower flip angle (b), in arbitrary units. Curves start from the nominal water frequency (0) and progress towards the main fat frequency in steps of 25 Hz. Dotted line indicates T1= 100 ms.

<u>Clinical DCE</u>: Figure 4a shows one area in a DCE examination where water signal was saturated by the inversion pulse. This was confirmed in further examinations of the same patient, which did not show signal drop out on the left breast. In Figure 4b the fat suppression failed in small areas due to field inhomogeneity. Those off resonance effects are common in fat suppressed Breast DCE examinations.

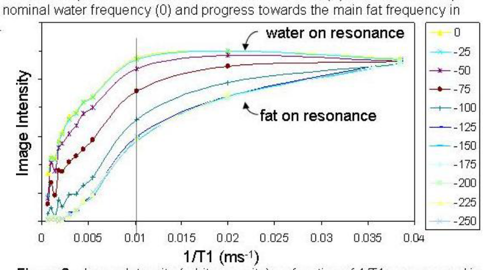

Figure 3 – Image Intensity (arbitrary units) as function of 1/T1 as measured in solutions of concentration up to 10 mM. Curves start from the nominal water frequency (0) and progress towards the main fat frequency in steps of 25 Hz.

Discussion and Conclusions

Results show that the off-resonance behaviour of DCE sequences with AFP inversion pulses for fat suppression differs from the on-resonance performance (1) by affecting the relative change of signal intensity associated with a given contrast uptake and (2) by affecting the shape of the expected contrast uptake curve. In breast examinations, significant field inhomogeneity is observed, and therefore parameters must be chosen to provide an approximately linear relationship between image intensity and concentration not only on resonance, but also off resonance. Our current parameters provide an approximately linear relationship between signal intensity and 1/T1 for the range of T1 values expected in breast lesions in single dose examinations. In addition, in the presence of field inhomogeneity, sequences with spectrally selective AFP inversion recovery are not suitable for quantitative analysis, and comparison between enhancement curves at different locations within the same examination may be affected by spatial changes in the resonant frequency, which may cause variations in the shape of the contrast uptake curve.

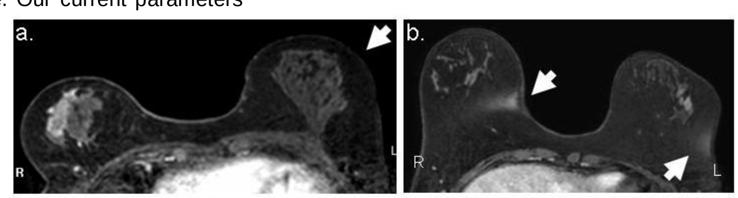

Figure 4 - Post-contrast breast examination showing progressive anterior saturation of water signals on the left breast (a) and localised fat suppression failure (b) attributed to field inhomogeneity.

References: 1. MARIBS Trial, Lancet 365(9473), 1769-1778 (2005). **2.** C Kuhl. Eur. Radiol. 10, 46-58 (2000). **3.** Maril et al. Magn.Reson. in Med. 54:1139-1145 (2005). **Acknowledgement**: We acknowledge Cancer Research UK and NHS funding to the NIHR Biomedical Research Centre.