High B1 efficiency with uniform image contrast in 3D FFE and TSE at 7T.

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Introduction

In high field clinical MRI the B_1 field is limited and non-uniform and RF power deposition is high. Surface coils can improve the B_1 efficiency and reduce the SAR, however severe non-uniform B_1 fields will remain, resulting in non uniform contrast in FFE sequences or even signal cancelation in TSE. This non-uniformity is however mostly present in one spatial dimension, particularly when quadrature surface coils are used[1,2]. Since practically all MRI sequences consist of a spatial selective excitation in one dimension, we propose to apply a RF pulse which uses the slab selection for compensating the inhomogeneous B_1 field. Therefore a combination of the quadrature surface coil and the compensating RF pulse can provide a relatively uniform flip angle with high B_1 strength and low SAR, thereby enabling uniform and highly efficient TSE and strong T1 weighting in FFE, which is shown in the human breast at 7T.

Methods

The B_1 field was measured in the human breast (Fig 1) and used to calculate the desired spatial profile for slab selective excitation or refocusing (Fig. 2). To demonstrate its versatility, the pulse was designed as a chemical shift selective pulse (using a binomial 1-2-1 pulse) requiring ultra short pulse-lengths for water or lipid suppression (Fig 3). The spatial properties were first tested in a uniform B_1 field, using an oil phantom and a head coil. For in vivo measurements in the human breast the surface coil was used. A 3D FFE with and without lipid suppression was applied with a flip angle of 20 degrees and a T_R of 5 ms as well as 1 degree to estimate the flip angle dependence. Also a 3D TSE with the compensating pulse was obtained with the surface coil in a phantom and healthy volunteer.

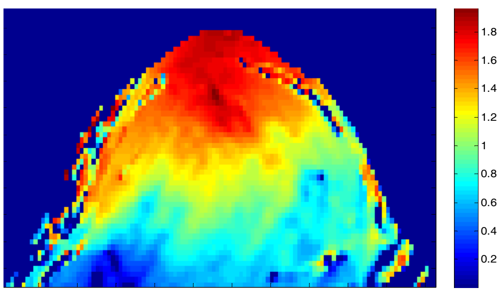

Fig 1. Relative B1 map obtained from the human breast in vivo with the quadrature surface coil. Note the strong, but predominantly in one dimension, non uniformity in B1 field. However, when driven with 2kW, the B1 field in the center (green) is 50µT, while RF power deposition is only 0.6W/kg/µT².

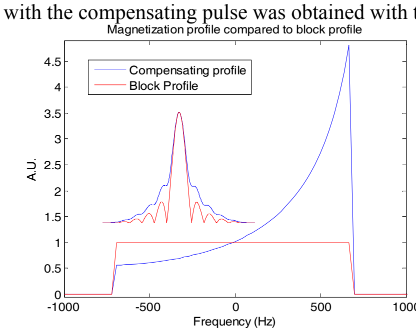

Fig 2. Frequency profile of the B1 compensated RF pulse (1/B1(Anterior-Posterior)) in blue compared to a conventional profile (red) with the time domain of these RF pulses plotted in the inset.

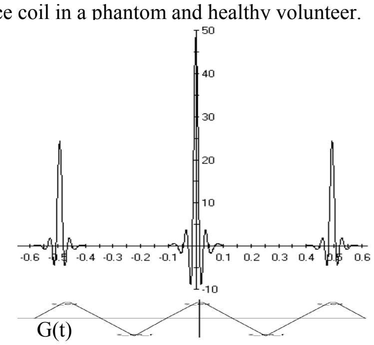

Fig 3. Three 1D spatially compensated 200 µs RF pulses applied as water or lipid selective uniform excitation at a 20 degree flip angle.

Results

For the FFE sequences the B_1 strength in the center of the breast was 50 µT, using only 2kW input power. This enabled the use of flip angles of 20 degrees defined by 3 times 9-lobes in the 200 µs time frame of the binomial pulse. Considering the low RF power deposition, very strong T_1 weighting could be obtained, optimal for contrast enhanced MRI. However due to the non-uniform flip angle, the contrast is spatially dependent. With the newly designed uniform excitation pulse, the same sequences can be applied at the same bandwidth, pulse duration and B_1 strength, hence providing uniform contrast even in the presence of non-uniform B_1 fields (Fig.4). For the TSE sequence the B_1 strength in the center of the breast was reduced to 25 µT. A conventional TSE shows black bands, corresponding to incorrect flip angles, which are caused by the inhomogeneous B_1 field. However the compensating pulse creates a homogeneous flip angle over the entire field of view as shown in a phantom and in a breast of a healthy volunteer (Fig.5).

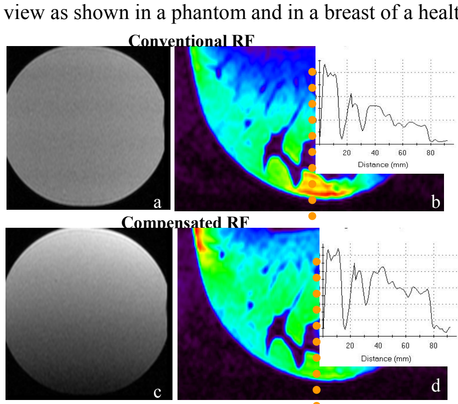

Fig 5: Effects of the slab selective RF pulse profile, showing reversed intensities in a uniform field (a, c) and corrected flip angle when applied with the surface coil in the breast (b, d: lipid selective excitation). The residual signal decay reflects the receiver profile.

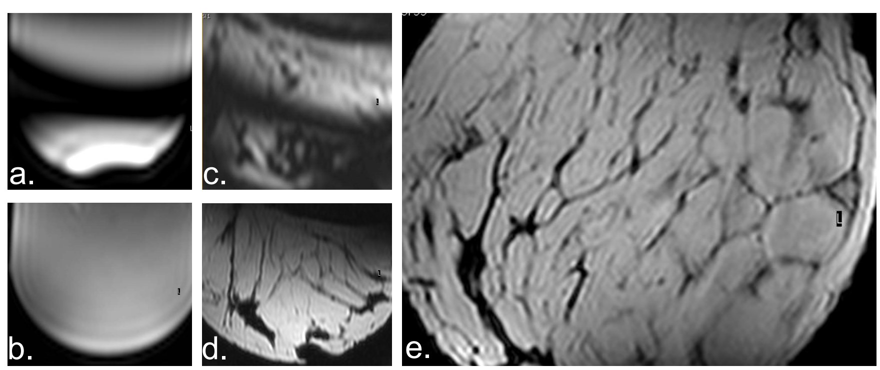

Figure 6: TSE results obtained with conventional pulses (a,c) and with 1D compensated RF pulses (b,d,e) in a phantom (a,b) and a breast of a healthy volunteer (transverse:c,d, coronal:e) using a surface coil transceiver. Note the typical inversion bands obtained with a conventional TSE, while uniform contrast is maintained using the compensated pulses (3D, FOV=100x125x105, TR=4s, turbo factor=124, scantime = 6:44 minutes).

Conclusion and discussion

Applying RF pulses which compensate for the inhomogeneous B_1 field in the dominant dimension of a surface coil, uniform flip angles can be obtained highly efficiently at very low SAR. Therefore strong T1 weighting can be obtained in FFE and high turbo factors in TSE within SAR guidelines, while pulse durations can remain short as was shown in the human breast at 7T.

References

[1] Klomp et al. MRM52:2006. [2].Korteweg et al. Invest.Radiol46:2011.