Fast, Accurate and Precise B_1 Mapping In vivo using the 180° Null Signal

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Introduction

RF field B_1 nonuniformity (NU) is the largest cause of error in the quantitative measurement of clinically-relevant parameters in MR images and spectra.[1] A knowledge of the spatial dependence of the RF field may be used to improve the accuracy and precision of such parameters. Here, we introduce a technique that can deliver a B_1 map covering the whole head in less than 4 minutes without confounding effects from T_1, T_2 and proton density (PD).

Method

The NMR signal from a spoiled gradient echo sequence is given by $S = M_0 [1 - \exp\{-TR/T_1\}] \sin\theta \ / \ [1 - \cos\theta \exp\{-TR/T_1\}]$, where M_0 is the magnetization at thermal equilibrium and θ is the flip angle ($= 2\pi \gamma B_1 \tau$, where τ is the RF pulse duration). When the magnetization undergoes a 180° pulse, the NMR signal is nulled, irrespective of T_1 (Fig. 1).[2] Note that the signal has an approximately linear dependence upon θ in the vicinity of the null-point. B_1 may be determined for each voxel from the nominal (system-calibrated) flip angle that yields a signal null, θ_{null}. By using linear regression θ_{null} can be determined on a pixel-by-pixel basis from a series of images acquired with flip angles in the linear region where $\theta \approx 180°$.

A GE 1.5 T Signa with a birdcage head coil was used for both phantom and *in vivo* studies. The RF field was mapped using the manufacturer's 3D spoiled GRASS (gradient recalled acquisition in the steady state) sequence. The slab-select gradient was removed during the RF pulse to ensure uniform excitation across the volume of interest. The excitation pulse duration was 5 ms and only the amplitude was varied to achieve the desired flip angles. Frequency encoding was conducted along the superior/inferior direction to avoid aliasing from the shoulders and upper body. TR = 33 ms; TE = 6 ms; acquisition matrix size = 128 × 64; 28 slice locations; scan time per flip angle = 70 seconds; voxel dimensions: (3.4 × 3.4 × 5)mm^3. It is possible to construct a B_1 map from only three series of images (*e.g.* with nominal flip angles 140°, 180°, 220°) resulting in an overall scan time of 210 seconds.

The method was validated by manually adjusting the transmitter output by a factor of 1.122 and 0.891 (= ±10 TG units on a GE scanner) and measuring the resulting change in RF field strength from the B_1 maps.

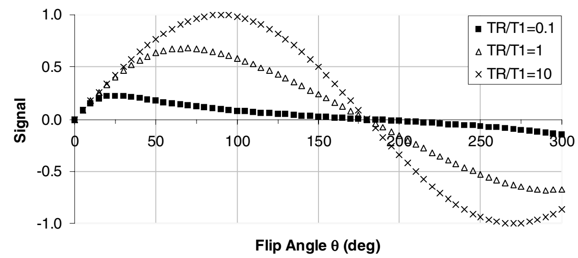

Figure 1
Plot of simulated NMR signal intensity S versus flip angle θ for different TR/T_1 values in a spoiled gradient echo experiment.

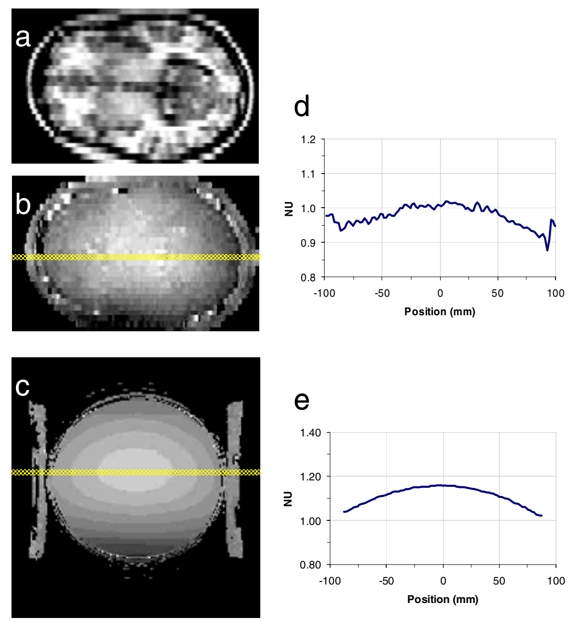

Figure 2
(a) Axial reconstruction from sagittal-plane images of the brain and (b) the corresponding B_1 map. (c) Sagittal slice from the B_1 map of a spherical water phantom, 15 cm in diameter. The intensity either side of the phantom originates from the loading ring. (d) and (e) the transmitter nonuniformity (NU) profiles across the B_1 maps shown in (b) and (c) respectively. The profiles were extracted along the rows marked with the yellow line.

Results

Figure 2a shows an axial reconstruction using sagittal-plane images of the brain. The corresponding B_1 map (Fig. 2b) demonstrates the method can report the RF field strength in spite of variations in PD and T_1 across the brain, even from the CSF-filled ventricles. The nonuniformity profile (Fig. 2d), extracted from the region indicated by the yellow line in Fig. 2b, reveals that B_1 is enhanced at the centre of the head due to the presence of RF standing waves. The B_1 map of a water phantom (Fig. 2c) shows the same effect. Water has a high dielectric constant that results in a much larger RF field at the centre of the phantom. This is clearly shown by the accompanying profile (Fig. 2e).

Validation was completed when the B_1 maps accurately determined (to better than 0.1%) the change in RF field strength due to a manual increase in transmitter output as described above.

Conclusions

This method can accurately and precisely determine a B_1 map covering the entire brain in less than 4 minutes using a pulse sequence available on commercial scanners. Owing to the short scan time of this procedure, it is envisaged that this technique can be incorporated into MR protocols to enable the accurate determination of quantitative MR parameters in the presence of B_1 inhomogeneity.

References

1. Tofts, Quantitative MRI of the brain, Wiley, Ch. 2 (2003)
2. Venkatesan, MRM, 40:592 (1998)