Quantitative Comparison of B_1^+ Mapping Methods for 7T Human Imagning

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Purpose

Large-scale transmit RF field inhomogeneities are often present in ultra-high field human MR images, so there is considerable interest in using accurate B_1^+ mapping methods for post-acquisition corrections of image intensity as well as for the modeling and design of RF coils and RF pulses. The goal of this study was to compare the accuracy of three widely used B_1^+ / flip angle mapping techniques and the magnitude of systematic errors inherent in these methods.

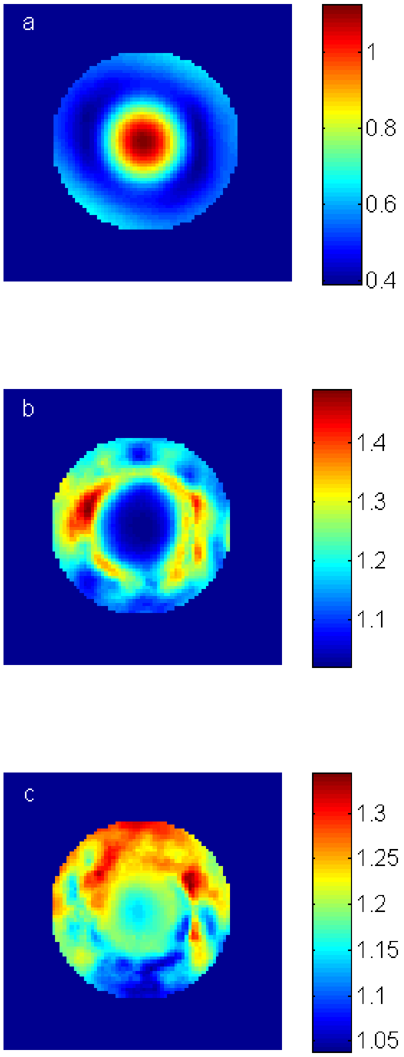

Figure 1: **(a)** B_1^+ map from the fitting of a series of GRE images with nominal flip angles of 10, 30, 50, 70, 90 110, 130, 150, 170, 190, and 210°; **(b)** normalized double-angle flip angle map divided by (a); **(c)** normalized pulsed steady-state flip angle map divided by (a). Assuming the GRE series B_1^+ map to be most accurate, errors of the double-angle technique are in the 50% range with pulsed steady-state errors are in the 35% range. In either case, deviations are significant and should be considered according to the B_1^+ application at hand.

Methods

All data were collected in the transverse plane with an 80 x 80 acquisition matrix using a 17 cm diameter dielectric phantom and a Philips Achieva 7.0T human MR scanner with an eight channel T/R head coil. The three B_1^+ measurement methods chosen for evaluation were a GRE series fitting technique, a double-angle approach, and a pulsed steady state (PSS) protocol, all of which infer the spatial distribution of the B_1^+ field through a measurement of the actual flip angle of the magnetization in a particular voxel.

The first of these methods involves a voxel-by-voxel fitting of the signal from a series of GRE images with different flip angles [1]. Signal intensity in a GRE image can be expressed as $\beta \sin(\lambda \cdot \alpha)$ where α is the flip angle, β represents $M_0 \cdot B_1^-$, and λ is the scale factor by which B_1^+ changes the flip angle from its nominal value. Thus, for a prescribed set of flip angles (10, 30, 50, 70, 90 110, 130, 150, 170, 190, and 210° in this study), a least-squares fitting routine can be used to determine β and λ. The double-angle method evaluated determines actual flip angles through the ratio of signal S_2 from a GRE image with nominal flip angle 2α to an identically acquired signal S_1 from an image with flip angle α [2]: $\alpha_{actual} = \arccos(S_2 \div 2S_1)$. Due to signal to noise considerations, angles of 60° and 120° were chosen for this study. The PSS method similarly involves the ratio of two images, but from interleaved excitation pulses in the steady state. The first pulse and acquisition of S1 occurs during a TR_1 (30 ms) and is immediately followed by an identical second pulse and acquisition occurring during a TR_2 (120 ms). Both excitations are 60° block pulses and are subject to gradient and RF spoiling. Again, the ratio of the two acquired signals can be related to the actual flip angle of the magnetization.

Results and Conclusions

Figure 1a shows the B_1^+ scale factor as obtained from the GRE series fitting. Confidence in the accuracy of this GRE series approach to measuring the effects of B_1^+ on flip angle is founded on the numerous measurement points per voxel (one measurement per flip angle), whereas the subsequent methods discussed rely on only two measurements per voxel. The GRE series method is the only such method found to allow for the successful experimental application of the highly B_1^+ sensitive sparse spokes pulse sequence [2]. Such information supports the use of this method as a metric by which to compare other B_1^+ measurement protocols.

Figure 1b shows the ratio of the flip angle map (normalized to nominal value) from the double-angle method to the B_1^+ scale factor from the GRE series data. At all spatial locations, the flip angle is overestimated by the double-angle method, with some measurements deviating by ~50% from the GRE series values. Figure 1c shows the ratio of the similarly normalized flip angle map from the PSS method to the B_1^+ scale factor from the GRE series data. Agreement here is slightly better with deviations up to ~35%, but again there is a significant systematic overestimation of flip angles at all spatial locations.

While double-angle and PSS methods may be useful for applications which require only qualitative information about the distribution of the B_1^+ field and may have the respective advantages of simple implementation and fast acquisition over a 3D volume, the results of this study suggest that these techniques may suffer from significant systematic errors when implemented at 7T. When accurate quantitative B_1^+ measurements at ultra-high field are needed, researchers are urged to take into consideration the inherent variations among the available measurement techniques.

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References

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