A novel method for simultaneous 3D mapping of T1, B1 and B0.

S. Zhao[1], and G. J. Parker[1]

[1]ISBE, University of Manchester, Manchester, England, United Kingdom

Introduction: Mapping of T_1, B_1 and B_0 is essential in many MR measurements, such as quantitative magnetization transfer. Usually this can be done by conducting three separate experiments to measure T_1, B_1 and B_0 respectively. Here we report our newly devised method which maps T_1, B_1 and B_0 in a 3D volume simultaneously.

Theory and method: Our method is based on magnetization prepared 3D turbo-FLASH [1]. A diagram of the pulse sequence is shown in Fig.1, where a selective pulse of fixed flip angle followed by a spoiler gradient is used as the initial preparation, after which only the longitudinal magnetization is left. A delay Td is then added before the turbo-FLASH acquisition begins, which employs a centric k-space sampling scheme. A series of such acquisitions are needed, in which the frequency offset of the selective pulse and the delay are varied. Images of such a series are fitted using a signal equation to obtain T_1, B_1 and B_0 as well as M_0, the equilibrium magnetization.

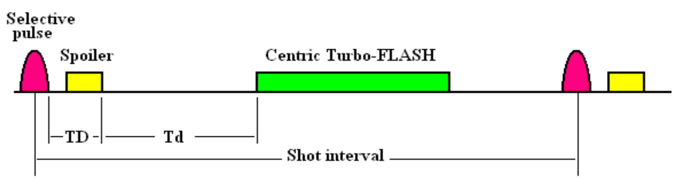

Fig.1. Pulse sequence for T_1, B_1 and B_0 measurement

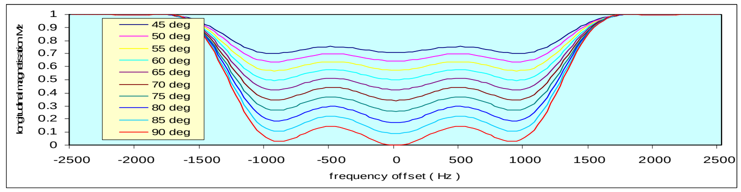

Fig.2. Simulated frequency response function for a 2 ms sinc-Gaussian pulse at zero frequency offset.

The transverse and longitudinal magnetizations after an RF pulse of any shape can be calculated precisely by Bloch simulation, eg. [2]. Fig. 2 shows the longitudinal magnetization after a selective sinc pulse for different flip angles. We call this function as frequency response function (FRF) of the pulse and denote it as $F(\theta, \Delta f)$, which is a function of two parameters: pulse angle θ and frequency offset Δf. The vertical deviation of experiment data with the FRF indicates the B_1 error and horizontal deviation indicates the B_0 error. Considering the T_1 relaxation during TD + Td_i before the turbo-FLASH acquisition, the signal equation for each voxel can be written as $S(\Delta f_i, Td_i, \mathbf{r}) = M_0(\mathbf{r})\ \{ 1 - (1 - F(\lambda(\mathbf{r})\theta, \Delta f_i(\mathbf{r}) - \Delta f_0(\mathbf{r})))\ \exp(- (TD + Td_i) / T_1(\mathbf{r}))\}$, where subscript i denotes each acquisition in the series, θ is the scanner's nominal flip angle and $\lambda\theta$ is the true flip angle at a voxel position, λ being the B_1 efficiency at position **r**, Δf is the frequency offset of the RF and Δf_0 is the B_0 deviation from the nominal B_0. Experimental parameters (Δf_i, Td_i) are varied in the series and the image data S_i will then be fitted to obtain M_0, λ, Δf_0 and T_1.

Experiments: Turbo-FLASH acquisition: FOV: 240x240 mm^2, matrix 128x102, 20 overcontiguous transverse slices of 6.3 mm thickness, FA=5 deg, TR/TE = 3.5/1.37ms, Turbo direction along Y, with centric k-space ordering, multi-shot mode, TFE factor = 64, and shot-interval= 6.0 s. Magnetisation preparation: a 2 ms Sinc shaped pulse of 3 lobes on each side modulated by a Gaussian of SD = 3. A fixed nominal angle of 70 degrees is used for all acquisitions. With $Td_i = 0$, we varied Δf_i as 0, -100, 200, -400, 800, and -1600 hz. Then with $\Delta f_i = 0$, we varied the delay Td_i as 200, 400, 800, 1200, 1600, and 2400 ms. Altogether 12 pairs of (Δf_i, Td_i) have been acquired. Total acquisition time is about 12 minutes.

The frequency response function $F(\theta, \Delta f)$ is calculated as a look-up-table to facilitate the fitting. Ideally we would hope that with a centric k-space acquisition scheme, the T_1 effect would only be seen during the period of TD and Td_i. However, we have observed that T_1 effect extends into the turbo-FLASH acquisition period. In order to account for this effect, we added in the calculation an extra decay Δd into the term of (TD + Td_i) in the signal equation, and we conduct the fitting at each voxel for 5 times with Δd = 10, 12.5, 15, 17.5, and 20 ms, then select the set of results that has the minimum chi-squared value.

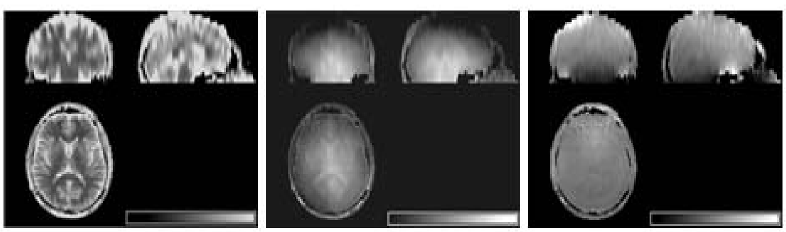

Fig.3. From left to right: orthogonal images of T_1, B_1 and B_0 offset fitted using the signal equation. The display scales are T_1: 0 to 2000 ms, B_1 efficiency: 07 to 1.3, and B_0 offset:- 300 to 300 Hz respectively.

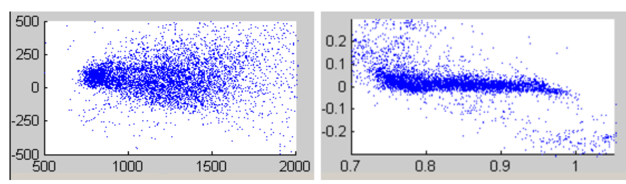

Fig.4. From left to right, Bland-Altman plots of a volunteer's brain T_1 (ms) and B_1 (proportional error) comparisons of our method with Look-Locker method for T_1, and with a previous method for B_1[2]. The horizontal axes are the average of the two methods, the vertical axes the differences.

Results: A set of example images of T_1, B_1 and B_0 in the head are shown in Fig.3. We have compared our result of T_1 with that from Look-Locker method [4], and B_1 from a method [3]. The T_1 and B_1 comparisons show good agreement (Fig.4). Variation in B_0 is as expected around the sinuses.

Conclusion: We have presented a novel method for simultaneously mapping T_1, B_1 and B_0 in 3D based on a magnetization preparation Turbo-FLASH method. This method is easy to conduct, and provides results consistent with alternative independent measurements of T_1 and B_1. We are currently evaluating the B_0 map with alternative methods.

Acknowledgement: We would like to thank Barry Whitnall, Neal Sherrat and David Pollitt for their kind help during the image acquisition.

Reference [1] Haase A, MRM 13, 77-89 (1990) [2] Hargreaves B, http://www-mrsrl.stanford.edu/~brian/blochsim/ [3] Zhao S, Gregory LJ and Parker GJ, ISMRM 2008. [4] Look DC and Locker DR, Rev. Sci. Instr. 41:250-251, (1970).