Rapid B_1 Mapping Method Eliminating T_1 Effect by Using Multi Td Sequence

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Introduction

B_1 map is used in many applications of high field MRI like RF shimming (1) or Transmit SENSE (2). Many B_1 mapping methods have been proposed, such as DAM (3), AFI (4), SA2RAGE (5), and Bloch-Siegert method (6). For clinical use of B_1 maps, fast and accurate method is desired. By using Bloch-Siegert method, scan time is 7 sec (6).

In this study, we develop a new fast B_1 mapping method named "multi Td method" its scan time is less than 1 sec. This method is similar approach to Sa2RAGE that uses two images acquired after pre-pulse to calculate B_1 map. But in multi Td method an additional image is acquired before pre-pulse is applied in order to eliminate the effect of T_1 relaxation. So no lookup table is needed in multi Td method contrast to SA2RAGE.

Materials and Methods

[*B_1 map Calculation*] Pulse sequence of Multi Td method is shown in Fig.1. Before pre-pulse is applied, reference images are acquired, and after pre-pulse is applied, two different Td images are acquired using same scan parameters as the reference images. Short-TR, small FA 2D Gradient Echo (GrE) sequence was used as the imaging sequence. Because small FA is used, the saturation effects caused by RF pulses of GrE can be ignored, so signal intensity of the Td_i image (i=1 or 2) is described as eq.1.

$$S_{Td_n} = S_{seq}\left[1-\left\{1-\cos\left(B_1\cdot\alpha\right)\right\}\exp\left(-Td_n/T_1\right)\right] \quad [1]$$

Where α is flip angle of pre-pulse. S_{seq} is signal intensity of the GrE. The signal intensity of the reference image is described as S_{seq} because it is acquired using same scan parameters as Td_i images before pre-pulse is applied. By taking natural logarithm of the ratio of Td_i images and the reference images, the dependency of B_1 and T_1 are completely decomposed and described by linear combination, using matrix notation, eq.2 is obtained. By multiplying inverse of matrix A from left, B_1 is acquired as eq.3.

$$\mathbf{S}=\mathbf{A}\cdot\mathbf{x},\ where/\ \mathbf{S}=\begin{bmatrix}\log\left(1-\frac{S_{Td_1}(\vec{r})}{S_{seq}(\vec{r})}\right)\\ \log\left(1-\frac{S_{Td_2}(\vec{r})}{S_{seq}(\vec{r})}\right)\end{bmatrix},\ \mathbf{A}=\begin{bmatrix}1 & 1\\ 1 & \frac{Td_2}{Td_1}\end{bmatrix},\ \mathbf{x}=\begin{bmatrix}\log\left(1-\cos\left(B_1(\vec{r})\cdot\alpha\right)\right)\\ -\frac{Td_1}{T_1(\vec{r})}\end{bmatrix} \quad [2]$$

$$B_1=\frac{a\cos\left[1-\exp\left(A^{-1}{}_{1i}S_i\right)\right]}{\alpha} \quad [3]$$

[*Monte Carlo simulation*]

The dynamic range of the B_1 map was evaluated by Monte Carlo simulation. The system SNR of 100 and T_1=300 ms was used. The range of actual flip angle was 0°-180° (in 1° steps). The number of calculations for each flip angle was 100.

[*Experiment*]

Multi Td sequence was implemented on 3T whole body MRI system. Torso phantom (300mm×200mm×300mm, T_1=200 ms) and four healthy volunteers (who all gave written consent) were imaged. In volunteer study, pelvis where the effects of respiratory motion is little, were imaged. A QD band-pass TR body coil was used to transmit RF pulses and receive signals. Scan parameters are as follows; TR/TE = 2.5/1 ms, Td_1/Td_2 = 10/500 ms, FA of pre-pulse was 90°, slice thickness=10 mm, FOV=500 mm, and measurement matrix was 64×64. To set Td_1 short, centric k-space reordering was used. Scan time for acquiring all data was 980 msec. For comparison, B_1 maps acquired by the use of DAM were used. The scan parameters of DAM was as follows; TR=5000ms, FA=60°/120°, the scan time was 10min50sec. Cross-correlation was used to compare B_1 maps acquired with DAM and multi Td method.

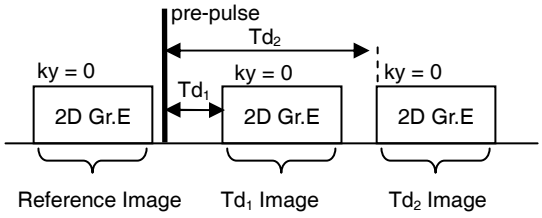

Fig. 1 pulse sequence of multi Td sequence

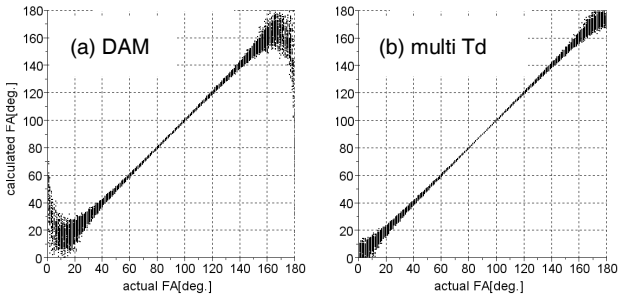

Fig. 2 Dynamic range of B_1 map (a) DAM, and (b) multi Td method

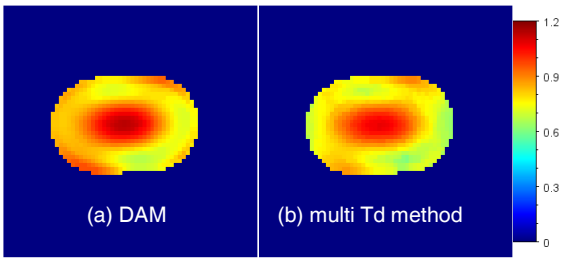

Fig. 3 B_1 maps of Torso phantom

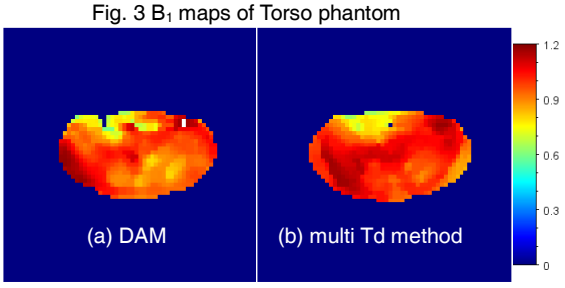

Fig. 4 B_1 maps of volunteer pelvis

Results and Discussions Fig. 2 shows the results of Monte Carlo simulation ((a) is DAM, and (b) is Multi Td method). The x-axis is actual flip angle, and the y-axis is flip angle calculated by the two methods of B_1 mapping. A perfectly accurate method is represented by a diagonal line (i.e., actual flip angle = calculated flip angle). The dynamic range of flip angle calculated by multi Td method is wider than that of DAM. The standard deviations of calculated flip angle by the use of multi Td method were smaller than 5° in all flip angle region due to no approximation for T_1 relaxation is used. So especially for long T_1 region, multi Td method can calculate B_1 map more accurate than other methods that using approximation for T_1 relaxation. The result of phantom imaging and volunteer imaging are shown in Fig.3 and 4. The correlation was 0.992 for Torso phantom, and 0.961 for volunteer pelvis. The average value and standard deviation of B_1 map was 0.82±0.11 (DAM; phantom), 0.80±0.11 (multi Td; phantom), 0.95±0.11 (DAM; volunteer), and 0.95±0.12 (multi Td; volunteer). By using multi Td method, similar B_1 maps to those taken by DAM were acquired in 980 ms.

Conclusions A new fast and accurate B_1 mapping method was developed. By taking reference images, multi Td method can calculate B_1 map analytic, and the dynamic range of flip angle calculation was wide. Due to its short scan time and high accuracy, multi Td method will be effective in clinical use of the applications like RF shimming, Transmit SENSE, and T_1 correction.

References (1) T. S. Ibrahim, et al; MRI 18(2000) 733-742, (3) Insko EK, et al. J Magn Reson Ser A 1993;103:82,
(4) Yarnykh VL, MRM 2007;57:192 (5) Eggenschwiler F, et al, MRM2012;67:1609 (6) L. I. Sacolick, et al; MRM 63; 5, 1315-1322