An In-vivo Image Intensity Correction Method for High Field Systems

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Introduction and Purpose

As the field strength increases, the wavelength in the body becomes comparable to the body size, and severe transmit field (B1) distortions are observed. This is also known as dielectric effect. Although the removal of receive-field inhomogeneity is quite straightforward [1], a clinically applicable method for the B1 field correction has not been proposed yet. In ref [2], a B1 mapping method was proposed optimized for brain imaging at the expense of long in-vivo B1 mapping scan. In ref [3], we proposed a cal-scan technique to remove both receive and transmit field distortions using a combined reference scanning method. Although this method was performing well overall, the B1 mapping method was sensitive to large T1 differences in the tissue, especially in abdominal imaging. In this work we further improved the B1 mapping technique to reduce the sensitivity of the B1 mapping to tissue T1. The reference scan time is still within reasonable limits for routine clinical use for brain, body, and breast imaging. Phantom and volunteer scans performed to test the efficiency and robustness of the technique. All volunteers passed the regulatory/consent guidelines.

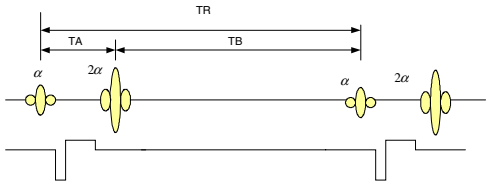

Fig 1: Modified FGRE (RF and read-out only) to desensitize the B1 map to T1 variation in the tissue. α acquisition is shown only. For 2α, the order of the pulses is reversed.

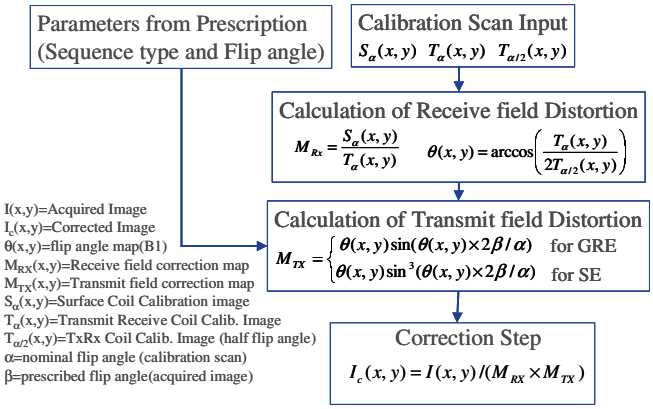

Fig2: Flowchart of the calibration scan acquisition and correction algorithm

Theory and Methods

In the cal-scan, first two sets of images are acquired with 60° flip angle using the surface coil (intended to be used for the clinical scan) and the body coil transmit/receive, respectively. The 3rd set is acquired again with the body coil transmit/receive but using 30° flip angle. The 1st and 2nd sets are used to calculate the receive-field correction map, whereas the 2nd and 3rd set of images are used to calculate flip-angle distribution using the double-angle method [4] . Given the flip angle prescribed and the sequence type, we can approximately calculate the intensity distortion due to any flip angle. Using the receive-field correction and the flip-angle maps, we can correct for both receive sensitivity- and transmit field-induced intensity distortions in the clinical images. Now let's look at how we reduce the sensitivity of flip-angle map to T1 variations in the tissue: Double-angle method is based on acquiring two images (I_1, and I_2) with two different flip angles; α and 2α. From the ratio I_2/I_1, it is possible to calculate the spatial distribution of α(r) as $\alpha(r)=\arccos\left[I_2(r)\big/2I_1(r)\right]$. However, this only holds true if the relaxation effects can be ignored (i.e., TR is set to a large value). If the relaxation terms are included in the calculation, the image ratio becomes:

$$\frac{I_2}{I_1}=2\cdot\frac{1-E1\cos(\alpha)}{1-E1\cos(2\alpha)}\cos(\alpha) \quad \text{where} \quad E1=\exp(-TR/T1)$$

From this eq., it is no longer possible to extract $\alpha(\vec{r})$ directly unless we set TR to a very long value, or choose a very small flip angle. (In the latter, the SNR would be low, and B1 calculation accuracy would be jeopardized.) By using the compensated double-angle-method (Fig 1), the ratio becomes

$$\frac{I_2}{I_1}=2\left\{\frac{(1-EB)+(1-EA)\cdot EB\cdot\cos(2\alpha)}{(1-EB)+(1-EA)\cdot EB\cdot\cos(\alpha)}\right\}\cos(\alpha) \quad \text{where} \quad EA=\exp(-TA/T1), \text{and} \quad EB=\exp(-TB/T1).$$

In this expression T1 dependency is minimized if TA is much less than T1. During the calibration scan three sets of images are acquired with breath hold. Total acquisition time is 18sec for all 3 sets. Once the in-vivo B1 map is acquired, a local 2nd order polynomial fitting algorithm is used to smooth the map and fill in the background of the map. Then the total correction map is applied to the clinical image set to be corrected.

Results

Fig 3a-d shows 4 sample image sets. These images were acquired using GRE (27cm dia 14mM NiCl-doped phantom), T2-FSE, T1-FSE, and SE sequences, respectively. In all test cases we observed considerable improvement in the image uniformity. Especially in the breast imaging, dielectric effect becomes nuisance creating right-left shading. The method was also tested on a SiOil phantom (i.e., in the absence of dielectric effect) and verified that it does not introduce any other artifacts.

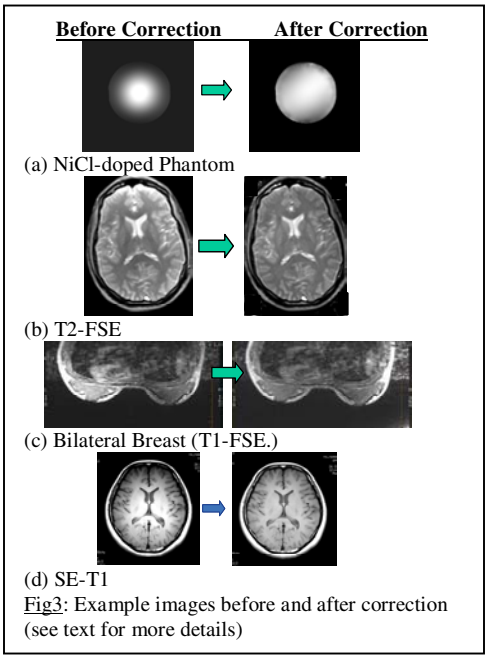

Fig3: Example images before and after correction (see text for more details)

Conclusion

We improved the accuracy of the reference imaging method proposed in [3] to correct for both receive and transmit field distortions (dielectric resonance-induced) in a clinical scan at high field. Although in this study we used a 3T system, higher field strengths and other hybrid pulse sequence types will benefit from this correction technique as long as an approximate flip angle-intensity relationship can be derived. Currently further human volunteer scans are in progress to prove the robustness of the technique.

References:

1. Murakami et al. MRM 35:585-590 (1996).
2. Wang et al, MRM 53:408-417 (2005).
3. Guclu et al, ISMRM 2005, abs#846.
4. Strollberger R and Wach P. MRM 35:246-251 (1996).