Fast B1 inhomogeneity correction in bSSFP imaging using transient-state signal

Min-Oh Kim[1] and Dong-Hyun Kim[1]
[1]*Electrical and electronic engineering, Yonsei University, Seoul, Seoul, Korea*

Target audience: Researchers interested in B1 correction in bSSFP imaging

Purpose: $B1^+$ inhomogeneity induces spatially varying signal modulations in bSSFP, therefore requiring correction to make the images more reliable. Several $B1^+$ mapping methods using steady-state free precession (SSFP) signal were proposed[1,2], however, these methods require relatively long acquisition time compared to the fast balanced SSFP (bSSFP) sequence. Here, an extremely fast B1 mapping method is proposed which corrects B1 inhomogeneity induced image modulation in bSSFP imaging using early transient-state signal.

Methods: A conventional bSSFP sequence is modified (Fig.1a) which consists of 4 blocks (preparation, I_1 for 2α image, I_2 for α image, and bSSFP image). We introduce an α pulse for preparing B1 mapping, two opposite-phase 3α pulses for double angle acquisition (I_1 and I_2), a β_p pulse for imaging preparation and β_{im} pulses for conventional bSSFP imaging. Figure 1b shows the magnetization changes according to each sequence block. For fast B1 mapping, two assumptions are made, 1) B1 varies slowly in spatial domain; a low resolution image can represent B1 map, and 2) T1 and T2 relaxations are negligible if TR << T1, T2; $B1^+$ dominates overall signal in early-stage of bSSFP. Under these assumptions, the I_1 and I_2 signals are acquired using single-shot low resolution spiral technique and $B1^+$ map can be calculated from these two data set in a similar manner to the double angle method (DAM)[3]. The conventional bSSFP image can be acquired following a bridge β_p pulse (= α + β_{im} /2) and β_{im} pulses. Thus, total scan time increment due to the B1 mapping is negligible compared to the conventional bSSFP acquisition (2xTR addition). Furthermore, FAs can be flexibly chosen for B1 mapping and imaging because FAs for B1 mapping (α) and imaging (β_{im}) are applied separately with the bridge FA (β_p). Various T1s, T2s and FAs were tested in simulation to estimate the assumption error due to tissue relaxation. Simulation parameters were TR/TE= 5.0/2.5 ms, FA= 1~60°, T1=1~5000ms and T2=1~500ms. The mapping accuracy was calculated by the difference between input and estimated B1 values. Experiments were performed on a 3T scanner (Tim Trio, Siemens Medical Solutions, Erlangen, Germany) using a cylindrical water phantom and *in vivo* brain with TR/TE= 5.0/2.5 ms, α = 50°, β_{im} = 30° (β_p = α + β_{im}/2= 65°), FOV = 256mm, slice-thickness= 5mm, B1 matrix = 12x12, bSSFP matrix = 128x128. The acquired bSSFP images were corrected using the measured B1 information.

Results: According to the simulation results (Fig.2), B1 estimation error mainly depends on T2 and FA because T1 is much longer than TR. High FA is preferred for reducing the estimation error because the inverse cosine procedure in DAM is less sensitive to noise with high FA. Furthermore, long relaxation parameters are efficient to reduce the estimation error due to the assumption which neglects T1 and T2 relaxation. Figure 3 and 4 show the experiment results on the cylindrical phantom and invivo brain. The spiral-acquired low resolution images for B1 mapping are masked and interpolated to the same size of bSSFP image. The B1-induced intensity inhomogeneity is corrected using the estimated B1 map in both phantom and *in vivo* experiments. In *in vivo* experiment results, relaxation parameter dependency of each tissue is negligible using short TR imaging and smeared-out due to spiral low resolution imaging.

Discussion and conclusion: As shown in phantom and *in vivo* experiment results, this technique can alleviate the B1 inhomogeneity induced artifact. For this approach to be usable, two assumptions were required because short T1 and T2 spins increase estimation errors since the signal level does not depend on B1 alone anymore in this case. The dependence on B_0 inhomogeneity should be taken into consideration due to the banding artifact inherent in bSSFP. We have shown a very fast B1 mapping which uses the transient-state signal with flip angle variation in early stage of bSSFP acquisition. The proposed method can be involved in bSSFP protocol as a concept of $B1^+$ pre-scan for intensity correction.

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References: [1]. Ganter C, et al., MRM. 2013; 70:1515-23, [2]. Yarnykh VL. MRM. 2007;57:192-200, [3]. Stollberger R, et al., MRM. 1996;35:246-251

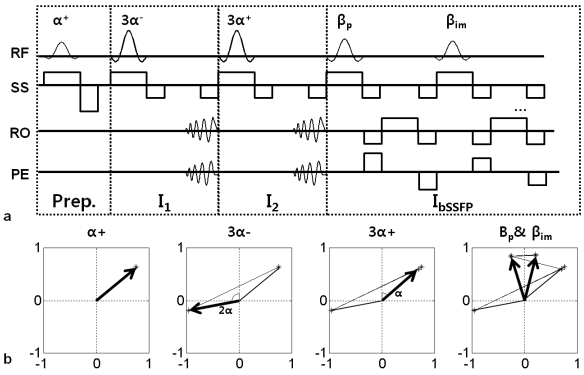

Figure 1.(a) The proposed pulse sequence diagram and (b) the magnetization diagram of each blocks (T1 = 500ms, T2= 80ms, TR = 5ms, α = 50°, β = 30°)

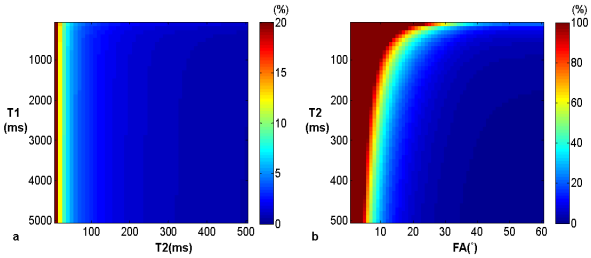

Figure 2. B1 estimation errors related to (a) T1 and T2 relaxations (FA = 50°), and (b) T2 relaxation and FAs. (TR = 5ms). Estimation error highly depends on T2 and FA rather than T1.

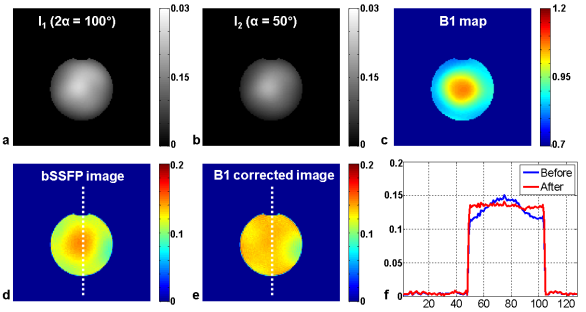

Figure 3. Phantom experiment results. The acquired (a) I_1, (b) I_2 images, and (c) the estimated B1 map are shown. The acquired conventional bSSFP image (d) is corrected using (c) and thus intensity variation due to B1 inhomogeneity is corrected in (e). Their line profiles along dotted lines are shown in (f). Inhomogeneous intensity at the right side of the phantom is due to the low receiver sensitivity at that region.

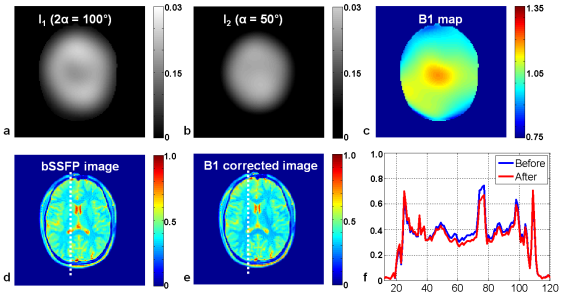

Figure 4. Invivo experiment results. The images are presented as the same notation of the phantom results in figure 3.