Introduction

An interesting method for $B_1^+$ mapping based on the Bloch-Siegert (BLS) shift was recently presented (1,2) for gradient echo (FLASH) and Spin Echo (SE) sequences. This method uses off-resonant pulses before signal acquisition to encode the $B_1^+$ information into the signal phase. Fast $B_1^+$ mapping is possible since the repetition time has only minor influence on the quality of the phase information. In the present study, the use of BLS $B_1^+$ mapping was extended to CPMG-based Turbo-Spin-Echo (BLS-CPMG-TSE) imaging. For fast $B_1^+$ mapping phantom as well as in vivo 2D and 3D experiments were performed to evaluate the proposed method.

Theory

To encode the $B_1^+$ information into the signal phase, an initial off-resonant BLS pulse was applied between the 90° and the first 180° pulse (Fig.1a). To fulfill CPMG conditions in a TSE experiment, the same phase conditions must be present before every refocusing pulse (3). Therefore, a BLS pulse was introduced after each refocusing pulse with the same off-resonance as the initial BLS pulse. Furthermore, the power of these subsequent BLS pulses was increased to $\sqrt{2}$ times the power of the first pulse (Fig.1a/b). This was done in order to restore CPMG conditions since the phase shift introduced by the BLS pulse is proportional to the square of the $B_1$ field (1,2).

Materials and Methods

BLS sequences were implemented on a 7T small animal scanner. All BLS experiments contained standard Gaussian-shaped off-resonant pulses. The BLS pulse duration (BS$_{\text{off}}$) was set to 1ms. For all BLS experiments, two acquisitions with $\omega_{\text{off}} + 16$kHz and $\omega_{\text{off}} - 16$kHz were performed. All $B_1^+$ maps were calculated using the equations given in (1). For 2D multi-slice ex vivo TSE experiments, the FOV included the total volume of the coil (Parameters: TE/TR = 10/30000ms; MTX = 128x128; FOV = 30x30mm$^2$; slices = 30; ST = 2mm). Linear and centric encoding as well as three different turbofactors (TF = 8, 16, 32) were used. For comparison, a multi-slice BLS-SE experiment with TR = 3750ms was performed as described in (1). For in vivo experiments, one mouse was anesthetized with 1.5% isoflurane in a 2 L/min oxygen atmosphere. 3D TSE experiments were performed using the same BLS parameters as in the ex vivo experiments (Parameters: TR = 1000ms; FOV = (15x30x30mm); MTX = 15x128x128; TF = 8, 16, 32). For comparison, SE experiments were performed. The animal experiments were performed in accordance with institutional guidelines and approved by Bavarian state authorities.

Results

Fig.2 shows the phantom experiment results. The $B_1^+$ values obtained from the BLS-SE experiment were in close agreement with the results from the BLS-CPMG-TSE sequence. Fig.3 shows good agreement between in vivo $B_1^+$ maps calculated from data obtained with a 3D BLS-SE sequence (Fig.3a) and a 3D BLS-CPMG-TSE sequence (Fig.3b).

Discussion and Conclusion

Using BLS-CPMG-TSE sequences decreased measurement time compared to BLS-Spin Echo was possible. This enabled fast acquisition of $B_1^+$ information. Furthermore, applying BLS-based spin-echo techniques minimized the influence of $T_2^*$ effects, which are critical for gradient echo-based BLS methods at high field strengths. TSE-based $B_1^+$ methods enable fast $B_1^+$ mapping although they intrinsically have high specific absorption rates (SAR). Thus, this technique is especially applicable for phantom and animal studies at high field strengths.

References


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