Hybrid Excitation and Bloch-Siegert Encoding Pulses for short-TE 3D $|B_1^+|$ mapping

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Target Audience

Imaging scientists interested in $|B_1^+|$ mapping techniques, sequence development and pulse design.

Purpose:

Recently, a $|B_1^+|$ field mapping method based on the Bloch-Siegert (BS) shift has been proposed [1], which uses a high-amplitude RF pulse played with a frequency offset far from resonance to impart a phase shift in the MR signal that is approximately proportional to $|B_1^+|^2$. The method has received significant attention for its ease of implementation and robustness to relaxation effects. It is also accurate and sensitive over a relatively wide range of $|B_1^+|$ and inhomogeneities in the main (B_0) field. However, the minimum echo time (TE) of this sequence is at minimum several milliseconds, due to the need to accommodate the off-resonance pulse and gradient crushers, between the excitation pulse and readout. We introduce a new hybrid excitation and off-resonance B_1^+-encoding pulse that enables BS B_1^+ mapping with a much shorter TE, enabling mapping of short-T_2 species.

Theory:

A conventional gradient echo (GRE) BS sequence [1] (Fig. 1a) comprises an excitation pulse, followed by a frequency-modulated B_1^+-encoding pulse that is surrounded by crusher gradients to eliminate on-resonance excitation produced by the encoding pulse. To achieve a shorter TE, it is desirable to omit the crushers and combine the excitation and B_1^+-encoding pulses. In this work we capitalize on the fact that the amplitudes of our previously-described optimized frequency-modulated (green) B_1^+-encoding pulse are constant [3], so that when a hard pulse is also used for excitation in a non-selective 3D sequence, the excitation (EX) and BS pulses may be combined to achieve a shorter TE (Fig. 1b). Furthermore, the crusher gradients can be omitted because we need not approximate the effect of the BS pulse as applying a pure phase shift to previously-excited magnetization; instead, we generate a lookup table based on Bloch simulations of the *entire* hybrid pulse on a grid of B_1^+-Δf_0 grid, which is used to calculate B_1^+ from the phase difference between two BS acquisitions with opposite frequency shifts, and a Δf_0 map.

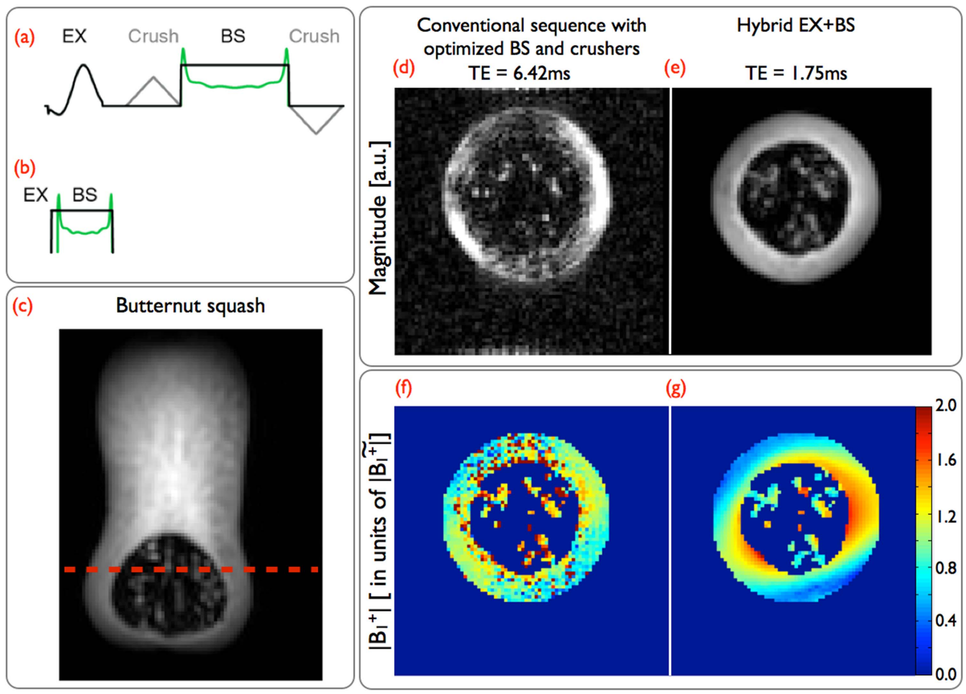

Fig.1: (a) A conventional Bloch-Siegert mapping GRE sequence (a) with an excitation (EX) pulse followed by set of bipolar crusher gradients (gray) and an optimized Bloch-Siegert encoding pulse (amplitude in black; frequency modulation in green). (b) A hybrid sequence of EX and BS pulses. (d,e) BS image magnitude and (f,g) calculated $|B_1^+|$ (in units of median $|B_1^+|$) for each sequence in one slice of the butternut squash (c, slice indicated by the dashed red line).

Methods

2 ms and 0.5 ms BS B_1^+-encoding pulses were designed as in [2,3] over a $|B_1^+|$ range of 0.3-20 μT and bandwidths ±600Hz (2 ms pulse) and ±250 Hz (0.5 ms pulse), with nominal amplitude 15 μT. The hybrid sequence (Fig. 1b) was implemented, so that the 15 degree flip EX block (0.1 ms duration) directly precedes and is continuous with the 0.5 ms BS B_1^+-encoding pulse. The 2 ms pulse was implemented in a conventional GRE BS sequence with a 15 degree flip EX pulse. A 3D B_1^+-mapping experiment was performed using both sequences on a butternut squash (c) on a 7T Philips Achieva scanner (Philips Healthcare, Cleveland, Ohio, USA). The repetition times (TRs) were 300 ms conventional/87 ms hybrid and the TE's were set to the minimum possible in each case, where were 6.42 ms conventional/1.75 ms hybrid. Other scan parameters were: FOV 150x150x201 mm, and resolution 1.9x1.9x3 mm; a Δf_0 map was also collected. Finally for each acquisition lookup tables were used to calculate $|B_1^+|$ from the BS phase shifts and Δf_0 maps.

Results

The results of the mapping techniques are shown in Fig. 1 (d-g). The magnitude images obtained with a conventional sequence with an optimized BS waveform and a hybrid technique are shown in (Fig. 1d) and (Fig. 1e) correspondingly. The $|B_1^+|$ maps are shown on the normalized color scale in (Fig. 1f) and (Fig. 1g). Due to the short T_2 of the squash, the $|B_1^+|$ map of the conventional sequence has very low SNR, and the magnitude appears is only a bit above the background noise level. In contrast, the SNR of the $|B_1^+|$ maps and magnitude images from the hybrid sequence appears much higher.

Discussion and Conclusion

In the presented experiments, a 2DFT acquisition was used; using a partial Fourier or center-out radial acquisition, the TE could be reduced to just over 0.5 ms. While magnitude-based B_1^+ mapping methods such as double-angle [4] and AFI [5] can easily be applied with very short echo times, they typically suffer from low dynamic range and sensitivity to errors from T_1 relaxation, which the BS method does not. Thus, the proposed pulses should enable B_1^+ mapping in short-T_2 species with higher dynamic range and less sensitivity to T_1 errors than is currently possible.

References

[1] Sacolick et al., MRM 63: 1315 (2010); [2] Jankiewicz et al. 2012 ISMRM, p. 3362.; [3] Jankiewicz et al., *in press*, J Magn Reson, 2012. [4] Insko et al., J Magn Reson A 103:82, 1993. [5] Yarnykh, MRM 57:192, 2007.