Practical SAR Constraints of the Bloch-Siegert B1 Mapping Method at 3T

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Introduction: The Bloch-Siegert shift (BSS) method of B1 mapping was recently described [1] and has many advantages over existing B1 mapping methods, including insensitivity to T1 and the capacity to perform single-slice B1 mapping without degradation from slice profile effects. The major limitation of the BSS method is the high specific absorption rate (SAR) caused by the BSS pulse. The Bloch-Siegert shift pulse used for B1 mapping generates phase which is proportional to the time integral of $B1^2$. The accuracy of the method increases with increasing amplitude of the BSS pulse. Since the SAR of this pulse is also proportional to the time integral of $B1^2$, SAR constraints place limits on the performance of the BSS method in practical settings. To evaluate the constraints on the BSS method imposed by SAR, we investigated the tradeoff between SAR limits and BSS pulse amplitude in a specific implementation of the BSS method, with a variety of RF coils.

Methods: A gradient recalled echo (GRE) sequence incorporating the BSS B1 mapping pulse was implemented on a Siemens Trio 3T (Erlangen, Germany) scanner. We explored the tradeoff between BSS pulse amplitude and sequence TR. Increasing BSS pulse amplitude leads to higher SAR, requiring longer TR to remain within allowable SAR limits. To explore this constraint, we tried several values of BSS pulse amplitude and recorded the shortest TR allowed by the built-in scanner software, which limits SAR to FDA approved levels. Since local SAR depends heavily on the RF coil, we performed this experiment with the body coil of the scanner and with a commercially available single-channel transmit-receive extremity birdcage coil. An 8ms Fermi pulse with K_{BS} of 74.02 rad/G^2 and ω_{RF} of ±4 kHz was used with both coils. The same Fermi pulse elongated to a length of 16ms was also used with the extremity coil.

Results: Figure 1 shows the results of the experiment described above. Higher BSS pulse amplitude requires longer sequence TR to remain within the SAR constraints of the scanner. Sequence TR constraints are higher for the extremity coil than the body coil. Doubling the length of the 8ms pulse to 16ms but leaving B1 amplitude unchanged, as shown in Figure 1, results in an increase in the range of mapped B1 by a factor of the square root of 2 but increases SAR by a factor of 2.

Discussion: The fact that both the BSS phase and SAR are proportional to the time integral of $B1^2$ gives rise to an interesting property of the BSS method: SAR is fixed for a given range of B1 mapping, independent of BSS pulse length. For a given range of flip angle mapping, SAR cannot be decreased by lengthening the BSS pulse. For example, in our experiment if the B1 amplitude of the 16ms BSS pulse had been adjusted downward by the square root of 2, this would give the same range of B1 mapping as the 8ms pulse, with identical SAR as the 8ms pulse.

Although our results are specific to a single implementation of the BSS method, they give some insight into the practical SAR constraints of this method. SAR constraints are least limiting with the body RF coil, because of the fairly homogeneous sensitivity profile of this coil. Smaller coils such as the extremity coil have less homogeneous fields with some "hot spots" that increase local SAR. SAR constraints imposed by the scanner are partly based on information supplied by the coil vendor that takes local SAR including "hot spots" into account. Even using the body coil, our TR constraint appears to be much more limiting than that published by Sacolick et al [1] which describes a similar Fermi pulse used at a TR of 35ms with a B1 strength of 0.2G. Since the publication of reference [1], some modifications have been suggested to reduce SAR for the BSS method [2-4].

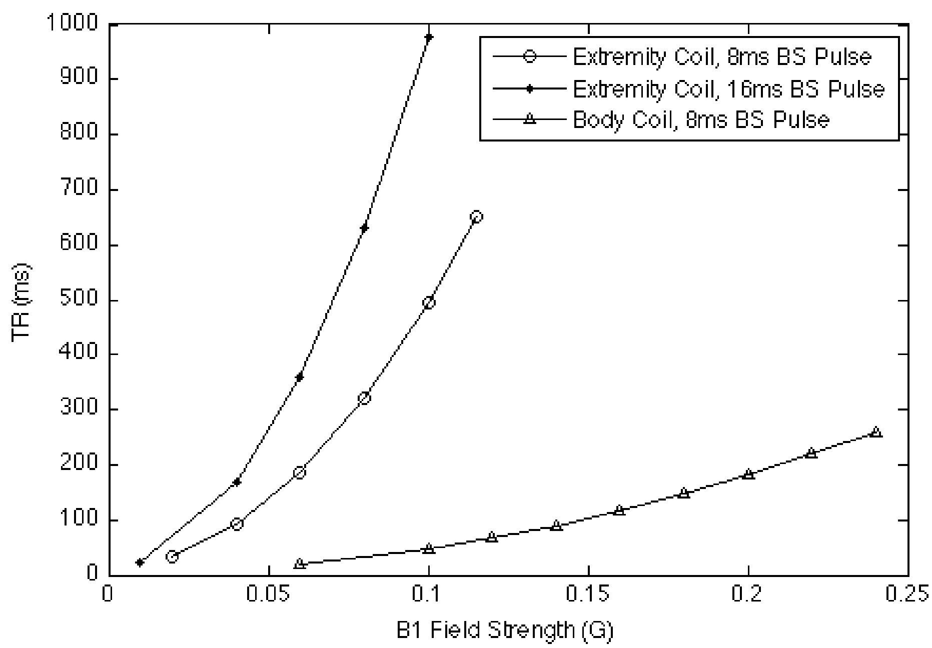

Figure 1: Tradeoff of BSS pulse strength and sequence TR imposed by SAR constraints

One prominent use of B1 mapping is in parallel excitation. Common parallel excitation scenarios include high field strength (7T and above) and an array of local coils with inhomogeneous sensitivity profiles. These factors will likely further increase the SAR constraints on the BSS method beyond the levels demonstrated in our experiment, which was performed at 3T with fairly homogeneous volume coils.

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References:

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