Balanced SSFP cardiac imaging at 7T

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Introduction: At 1.5 T balanced steady-state free precession, bSSFP, sequences are the method of choice for cardiac imaging. Balanced SSFP sequences are known to be demanding in terms of gradient performance, RF power, and static field shimming. The latter two challenges become more problematic with increasing field strength. As such, unoptimized attempts to use bSSFP sequences for 7T cardiac imaging are usually unsuccessful. However, with the proper adjustments of both the B_1^+ and B_0 fields, cardiac imaging using bSSFP can be successfully implemented at 7T.

Materials & Methods: Volunteers were imaged in a Siemens 7T system in accordance with an IRB approved protocol. A sixteen-channel stripline TEM transceiver array [1] was powered by 16 individual RF amplifiers (CPC, Hauppauge, NY). Power deposition was monitored per channel. Wireless vector cardiogram gating was used. To optimize transmit efficiency over the heart, B_1^+ shimming was preformed [2,3]. Relative B_0 maps were calculated from a breath-held multislice 2D dual gradient echo image set and least squares B_0 solutions for 2nd order shims were calculated over the whole heart. Single-slice breath-held bSSFP retrogated cine images were collected with TR/TE = 2.8/1.4 ms, 1.76x1.76x8 mm, ~40° flip and a GRAPPA reduction factor equal to 2.

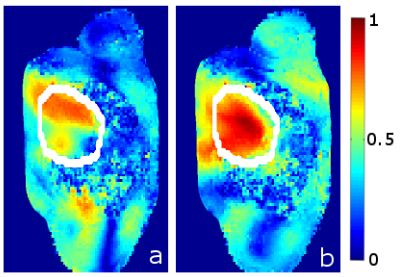

Figure 1: Transmit RF efficiency before (a) and after B_1^+ shimming.

Results & Discussion:

B_1^+ management: Figure 1 demonstrates the improvement in relative transmit efficiency that a personalized B_1^+ shim can make. Starting from a transmit phase distribution calculated for another individual (Fig 1a), the B_1^+ transmit fields were estimated from low-flip angle calibration images and a new shim was calculated (Fig 1b) [2,3]. Over most of the B_1^+ shimming ROI, the relative transmit efficiency is near optimum. It is important to efficiently excite the region of interest to keep power deposition manageable. In addition, parallel imaging serves to reduce the total power deposition. The maximum achievable flip angle is limited by SAR, and thus SAR constraints will limit the SNR achieved by bSSFP sequences.

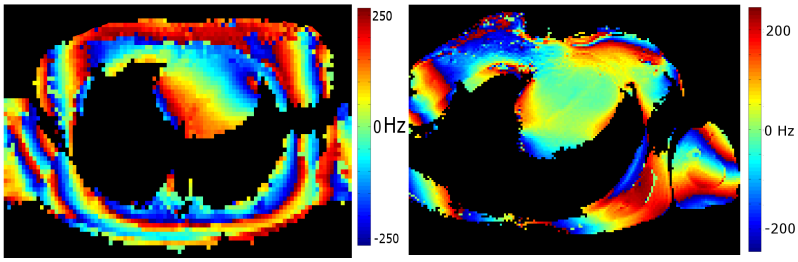

Figure 2: Relative frequency maps for 7T cardiac imaging for an un-shimmed transverse slice (a) and a shimmed 4-chamber view (b).

B_0: Noeske [4] reported the frequency distribution over the unshimmed left ventricle to be ±130 Hz at 3T. Assuming linear dependence with field strength, the frequency range should be ±300 Hz at 7T. A B_0 map of a single transverse slice with standard starting shims (Fig 2a) shows this expected variation. After a least squares B_0 solution using a 2nd order shim set (Fig 2b), most of the heart is homogeneous, but near the boundaries large frequency shifts can occur. Because of this, a frequency scout bSSFP is necessary to adjust the center frequency to ensure banding artifacts avoid flowing blood. A four-chamber bSSFP cine is shown in Figure 3. A B_0 map of the same slice is shown in Figure 2b. Banding artifacts were avoided in the areas of interest. In the short-axis view (Fig 4a), a banding artifact is present, but restricted to posterior myocardium.

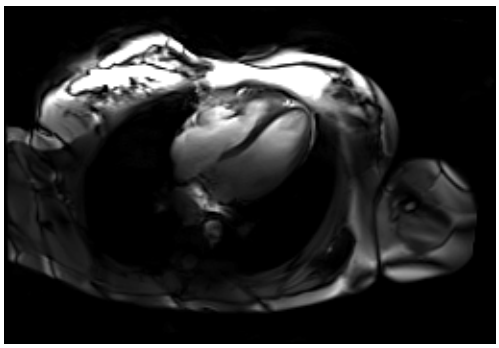
Figure 3: 7T 4-chamber bSSFP cine

Lee [5] has noted that a least squares B_0 shim solution is sub-optimal for bSSFP imaging because it optimizes homogeneity for the majority of the volume at the expense of local outliers that may have large excursions. A B_0 shim solution that minimizes frequency extremes over an ROI may reduce banding artifacts further.

The quality of GRE cine improves markedly with field strength, increasing its utility at 7T. But, for the special cases where bSSFP sequences are required, this demonstrates it is achievable at 7T.


Figure 4: 7T short-axis bSSFP cine.

Conclusion: Balanced SSFP images are at 7T are possible with close attention B_0 and B_1^+ field adjustments. The flip angle will be limited by the SAR, so B_1^+ shimming is necessary to maximize flip angle per watt over selected regions. Balanced SSFP banding artifacts can be managed in 7T cardiac cine.

References: [1] Snyder C et al. ISMRM 2007, 164. [2] Van de Moortele PF Magn Reson Med. 2005;54(6):1503-18. [3] Metzger G, ISMRM 2010. [4] Noeske R, Magn Reson Med. 2000;44(6):978. [5] Lee, J Magn Reson Med. 2009;61(6):1500-6.

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