RF Non-uniformity over the Whole Heart at 3T

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Introduction: Accurate knowledge of the transmitted radiofrequency field (B1+) is essential for MR image-based quantitation (e.g. first-pass perfusion imaging), signal-to-noise and contrast-to-noise optimization, and the design of new pulse sequences. Variations of 40-100% over the heart at 3T have been reported in the literature [1,2,3]. In-vivo measurement of B1+ variations across the heart have been limited by the lack of time-efficient methods for B1+ mapping, which should be volumetric and be performed within a breath-hold. Cunningham *et al.* recently developed the saturated double angle method (SDAM), which allows the use of repetition times much shorter than T1, and with accuracy demonstrated in phantoms and in-vivo [3]. In this work, we have optimized SDAM for B1+ measurement across the entire heart in a single breathhold and performed an analysis of repeatability and profile variation.

Methods: Figure 1 illustrates the timing of the multi-slice cardiac-gated SDAM acquisition. This sequence was tested in eight healthy volunteers and two cardiac patients. Six short-axis slices spanning the LV were acquired in a breath-hold period of 16 R-R intervals to generate flip angle maps. Full images were acquired with prescribed flip angles of α and 2α (α = 60˚). The measurement was repeated 5-10 times in separate breath-holds in each subject. Regions-of-interest (ROIs) containing the LV were manually segmented from each slice. For each subject, flip angle variation was calculated as $(\alpha_{max}-\alpha_{min})/\alpha_{max}$ and the standard deviation (SD) of the repeated measurements was used as a indicator of overall repeatability. After observing predominantly unidirectional patterns of flip angle variation over the LV in short-axis slices, a profile analysis was performed to determine the accuracy of unidirectional approximations to the B1+ profile. The primary direction of variation was found by exhaustive search, and selection of the direction with minimum mean square error (MMSE) of the 1D approximation.

Experiments were performed on two GE Signa EXCITE 3.0 T systems using the body coil for RF transmission and 8-channel phased array for signal reception. The acquisition parameters were: 2.6 ms sinc RF pulse, TE = 2 ms, FOV = 30 cm, 2.2 mm in-plane resolution, and 5 mm slice thickness. During reconstruction, a Hamming window was applied to k-space data to increase SNR while reducing the in-plane spatial resolution to 5 mm.

Results: Representative flip angle maps from one healthy volunteer are shown in Figure 2. For a prescribed flip angle of 60˚ and using the scanner's auto-prescan function to calibrate RF transmission, the observed flip angles across the LV myocardium ranged from 32˚ to 64˚. After 10 repeated measurements, the SDs of the pixel-by-pixel flip angle measurements for all six slices were less than 1.7˚. The relative errors between the true (2D) and unidirectional (1D) approximation were less than 1.4%.

Considering data from all ten subjects (see Table 1):

- The amount of B1+ variation was **31% to 66%** over the entire LV volume and **23% to 47%** over the LV in individual short-axis slices.
- The SD of flip angle measurements (averaged over all 6 slices) in the LV was less than **1.4**˚, indicating repeatability of the measurement method.
- The pattern of B1+ variation was primarily unidirectional in short-axis slices for both 3T scanners. Relative approximation error was ≤ **3%** in all subjects, and ≤ **1.5%** in eight of the subjects.

Discussion: There is substantial B1+ variation over the heart at 3 Tesla using body-coil transmission. Because of this, rapid B1+ mapping may become an important part of pre-scan calibration prior to actual imaging (similar to field map acquisition). Ill effects from B1+ variation can then be mitigated by tuning RF pulse amplitudes based on knowledge of the B1+ field, and by designing tailored RF pulses that compensate for the known variation over an ROI [4].

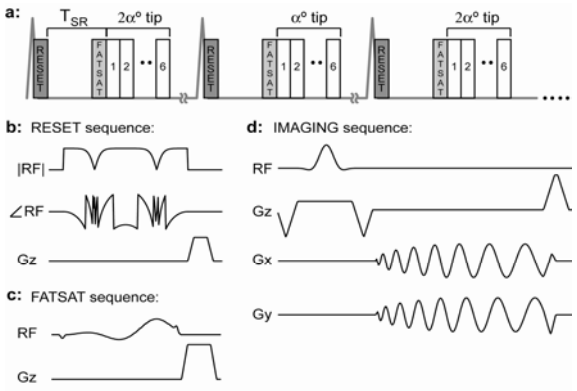

Figure 1: Multi-slice cardiac B1+ mapping acquisition. Acquisitions are (a) cardiac gated and consist of a longitudinal magnetization reset, delay (T_{SR}), contrast preparation, and multislice acquisitions (6 slices shown). (b) RESET: 8 ms BIR-4 saturation pulse and a dephaser. (c) FATSAT: 8 ms fat-selective saturation pulse and a dephaser. (d) IMAGING: slice-selective excitation, 5.9 ms spiral readout, and a dephaser.

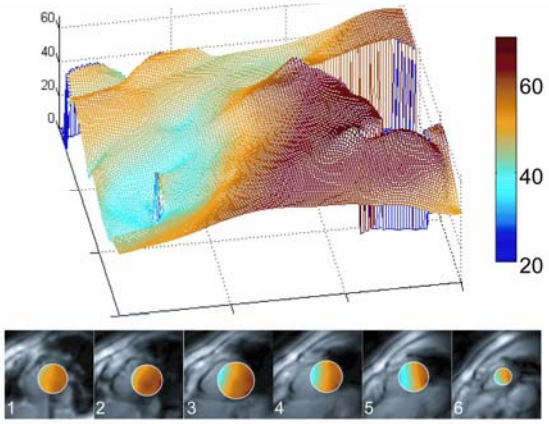

Figure 2: Cardiac B1+ maps from a healthy volunteer at 3T. (Top) Mesh plot depicting the flip angle variation in a mid-short axis slice (slice #3) and (Bottom) flip angle profiles in all six slices. Note that the variation is strong and primarily unidirectional across the left ventricle in all slices.

	SD	α_{min}- α_{max}	Variation	Unidirectional Approx. Error
Subject 1	0.8˚	32˚ – 64˚	50.2 %	1.1 %
Subject 2	0.6˚	34˚ – 64˚	46.0 %	1.5 %
Subject 3	0.9˚	34˚ – 67˚	49.4 %	1.1 %
Subject 4	1.4˚	26˚ – 59˚	55.6 %	2.1 %
Subject 5	0.5˚	45˚ – 66˚	31.3 %	1.1 %
Subject 6	1.0˚	42˚ – 61˚	31.2 %	1.2 %
Subject 7	0.8˚	28˚ – 58˚	52.2 %	1.4 %
Subject 8	1.1˚	34˚ – 67˚	49.0 %	1.4 %
Subject 9	0.6˚	42˚ – 66˚	36.0 %	1.2 %
Subject 10	1.3˚	20˚ – 60˚	65.7 %	3.0 %

Table 1: Repeatability and profile analysis data in ten subjects. The parameters for each subject cover the entire LV (averaged over all 6 slices).

Conclusion: This study has (a) demonstrated a cardiac B1+ measurement protocol that produces reliable B1+ maps over the entire heart in a single breath-hold, (b) found B1+ variation over the LV at 3T using body-coil transmission to be approximately 31 - 66%, and (c) suggested that the variation is primarily along one in-plane axis in short-axis slices.

References: [1] Singerman RW, et al.. JMR 1997; 125:72–83. [2] Greenman RL, et al. JMRI 2003; 17:648-655. [3] Cunningham CH, et al. MRM 2006; 55:1326–1333 [4] Sung K. et. al. ISMRM 2006, p597