Quantitative Evaluation of Regional RF shimming on a Wide Aperture Dual-Channel Multi-Transmit 3.0T: Implications for cardiac MRI

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Introduction: At 3.0T and higher field strengths, the wavelength of the radio-frequency (RF) excitation becomes comparable to or smaller than the size of the human body. As a result, B_1 field is non-uniform across the slice, and is an important cause of artifacts and degradation of image quality. Unlike Bo inhomogeneities, the loss of contrast experienced due to B1 inhomogeneity is irrecoverable, and is a problem that needs to be addressed during the excitation process. Recently multiport parallel RF transmission systems have been proposed as a means for improving B1 homogeneity [1-3]. The purpose of this study is to quantitatively evaluate the performance of a dual channel multi-transmit system to RF shim a region of interest, in a series of subjects.

Materials and Methods: Subjects: Eleven normal subjects (8 male, 49 ± 16 yrs) were imaged on a wide-aperture 3.0T Ingenia (Philips Healthcare). All data acquisition was VCG gated. A combination of 16 channels from the table-top integrated digital posterior coil and 16 channels from the digital anterior coil were used for signal reception. A two channel multi-transmit system with independent RF control was used for excitation. All subjects provided written informed consent.

MRI Acquisition: B_1 maps of the axial plane across the heart were generated using a saturation-recovery, dual flip angle method described previously [4-6]. The acquisition parameters were: TR/TE = 1000/5.7 ms; Nominal flip angle = 30°/60°; acquired voxel size = 5*10*10 mm^3; and readout EPI factor: 11. Based on the acquired complex B_1 map, the amplitude and phase settings of the two transmit channels were set independently to minimize the B_1 variation within the prescribed volume of interest (Volume shim). The B_1 maps were then acquired with and without volume RF shimming for direct comparison (Figure 1).

Data Analysis: On the B_1 maps generated with and without volume RF shim settings, ROIs circumscribing the heart were drawn using a custom built software (MATLAB™, The MathWorks, Natick, MA). The B_1 maps were scaled as a percent of the prescibed flip angle. The following metrics were used for quantitative evaluation of RF homogeneity: 1) The ratio of standard deviation (σ) to mean (μ)of the pixels within the ROI, where a lower ratio corresponds to more uniformity. 2) The fraction of the total number of pixels that fall within a specific percent of the mean. A higher count at a given threshold corresponds to a more uniform B_1 field distribution.

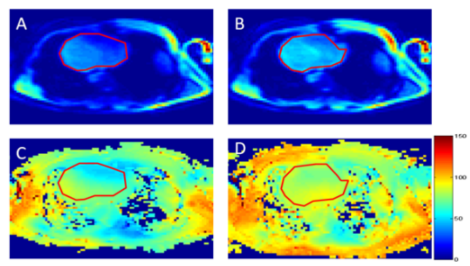

Figure 1: Representative magnitude images (A and B), and B_1 maps (C and D). Images A and C are without volume RF shimming while B and D are with volume RF shimming. ROI selected is shown in red in all images.

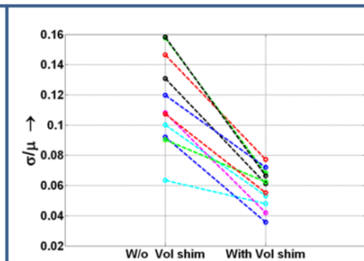

Figure 2: Plot showing the σ/μ variation of the flip angle distribution across the ROI. An average drop of 48 ± 12 is seen, corresponding to a more uniform B_1 map in the case of a volume RF shim.

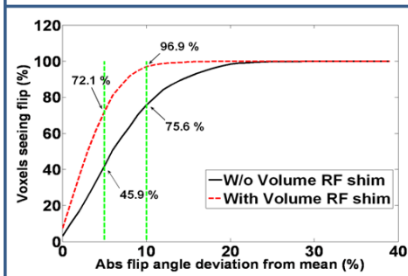

Figure 3: Plot showing the mean number of voxels in the selected ROI that falls within a given flip angle from the mean. Volume RF shim performs better with 96.9 % of voxels in the ROI falling within ± 10 % of the mean flip.

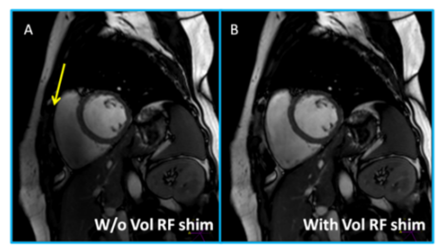

Figure 4: Representative image of a short axis balanced FFE image. The B_1 field inhomogeneity can be seen when volume RF shimming is not used (arrow), which is reduced using volume RF shimming (B)

Results: The σ/μ ratio revealed better RF homogeneity in each subject with subject-specific volume shimming (Figure 2). The average σ/μ for the 11 subjects improved from 0.116 ± 0.03 without patient adaptive RF shimming to 0.058 ± 0.01 for patient adaptive volume shimming ($p < 0.0001$, paired Student's t-test). This reduction corresponded to a mean increase in B_1 homogeneity of 48 ± 12% with volume RF shimming. The total number of voxels that lie within a fraction of the mean flip angle was also evaluated (Figure 3). With volume RF shimming, 97% of the voxels lie within ± 10% of the mean flip angle across the ROI compared to only 76 % of the voxels without. Also, the mean value of the B_1 map from volume RF shimming was closer to the prescribed flip angle (i.e., 100 %) - 85.7 ± 11.5% with volume RF shimming vs. 79.2 ± 12.7% without ($p < 0.005$). A representative image demonstrating the benefit of volume RF shimming using a multi-transmit system is shown in Figure 4. Note the substantial shading artifact seen near the anterior chest wall and RV without volume RF shimming.

Conclusions: The results from the study show the following: (a) At 3.0T even across a small region as the heart, effective flip angles can be in excess of 20% of the prescribed flip angle in over 25% of the pixels without RF shimming,; (b) Patient specific, volume RF shimming using a two-channel multi-transmit system is effective in both reducing the flip angle variation over a prescribed region of interest, e.g., heart, as well as help attain a flip angle that is closer to the prescribed flip angle. B_1 shimming is an important component to be considered in all quantitative magnetic resonance imaging.

References: 1.Roschmann, *Med. Phys*, 14(6), 1987; 2. U.Katscher et al., *NMR in Biomed*,19, 393-400, 2006. 3. Sung et al., *JMRI*, 27:643-648. 4. Cunningham et al., *MRM,* 55:1326-1333; 5) M.Schar, *MRM,* 63:419-426. 6) Harvey P.R., et al *Proc. ISMRM* 2010, 1486.