SAR optimised local B_1^+ shimming for cardiac imaging at 3T – a multi-model study

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Target Audience: This work will benefit those interested in using parallel transmission MRI to reduce SAR in cardiac MR

Purpose: Cardiac imaging at high field (3T and above) suffers from image quality issues due to greater B_1^+ inhomogeneities[1] and is frequently limited by SAR, which constrains the speed at which scans can be run without exceeding regulatory limits. Parallel transmission can mitigate these issues by adjusting the complex drive applied on each channel of the system in order to increase B_1^+ homogeneity and/or reduce SAR. We have shown previously using simulated data[2] that at 3T with 8-channel parallel transmission, local SAR can be reduced by up to 75% whilst significantly improving B_1^+ homogeneity in the heart relative to a single channel excitation. Eight channels outperformed two channels, for which clinical data is available[1]. Here we extend our work to include in vivo data and compare results between a larger and smaller volunteer, using approximately corresponding SAR models.

Methods: Data were acquired from two male subjects (75kg and 110kg) on a 3T Philips Achieva MRI scanner with 8-channel body transmit coil[3] and 6-channel cardiac receive coil. In vivo B_1^+ maps were measured using the DREAM method[4] (8° flip angle, 60° STEAM angle, TE=2.3ms, TR=5ms), using linear combinations of the channels in order to increase SNR[5]. Maps for all channels were obtained in a single breath hold with local SAR < 1W/kg. DREAM is sensitive to flow[6], which leads to unreliable maps in the blood pool. In this study, the blood pool was masked out (although nulling the blood signal is another option[6]).

To produce the SAR models, EM field simulations were performed using the Finite Integration Technique of CST Microwave Studio (CST AG, Darmstadt, Germany) with all post-processing and SAR calculations performed in Matlab. The NORMAN voxel model[7] was used in the simulations. Its native size (1.76m tall, 73kg) matched the smaller volunteer and it was scaled[8] in the AP and LR directions to match the larger subject (1.76m, estimated weight 108kg), giving two models overall. The E-fields were used to calculate SAR Q-matrices, which were compressed into a set of VOPs[9] for a 1% overestimate of SAR. SAR penalised B_1^+ shimming was performed with a magnitude least squares[10] optimisation for the heart region (see fig 3) using a range of regularisation parameters for both the matched and the incorrect models. SAR values were calculated for a T1 weighted, TFE, cardiac CINE sequence. Results were compared to the nominal quadrature mode of the scanner in which the 8 channels are driven in a predetermined phased combination that emulates a standard single channel coil.

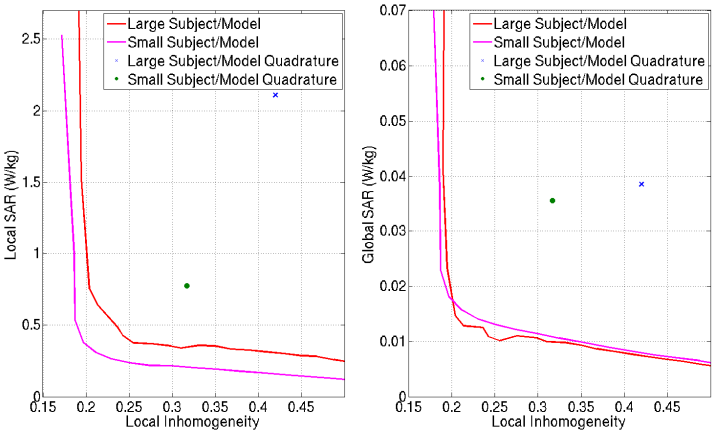

Fig. 1: L-curves plotted for both subjects along with the quadrature excitation points – local SAR (left) global SAR (right)

	Small Subject		Large Subject	
	Matched Model	Incorrect Model	Matched Model	Incorrect Model
Local SAR (W/kg	0.307	0.396	0.486	0.453
Global SAR (W/kg)	0.0157	0.0130	0.0125	0.0159

Table 1: Local and global SAR values for an optimal shim for the large and small subject calculated using the matched model and using the other, incorrect model for each

Results and Discussion: Fig. 1 shows shimming solutions for each subject using their matched model: in all cases it is possible to significantly reduce SAR and increase B_1^+ homogeneity compared to the quadrature mode. Operating at the heal of the L-curve reduces SAR by ~70% and ~60% for the larger and smaller subjects respectively. The local SAR reduction for the large model is particularly dramatic, bringing it from over 2W/kg down to around the same level as that for the optimised small model SAR. The change in maximum local SAR magnitude and location after shimming for the small model can be seen in Fig. 2. The improvement in flip angle distribution for both subjects is shown in Fig. 3. Improved homogeneity translated into more uniform T1 weighted images. Swapping the models over and repeating the calculations leads to incorrect global and local SAR values (Table 1), clearly showing the need for using an appropriate SAR model to optimise shimming and hence maximise imaging improvements.

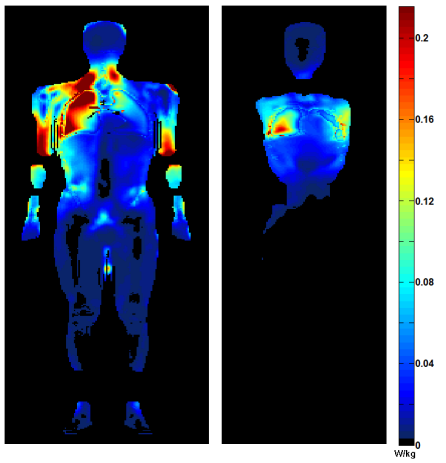

Fig. 2: Coronal slices depicting maximum local SAR for the quadrature mode (left) and shimmed (right) for the small model

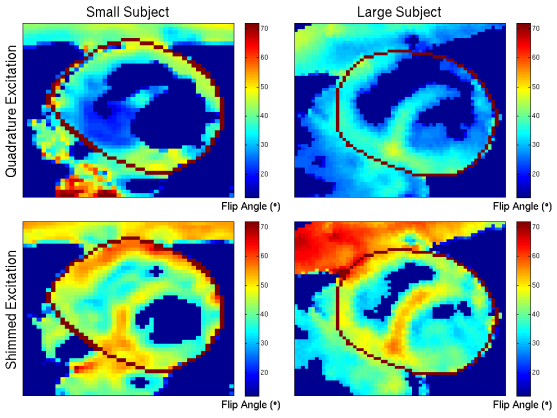

Fig. 3: In vivo B_1^+ maps in a short axis slice through the heart for both subjects with a quadrature and optimally shimmed excitation. Low SNR regions have been masked and ROI used for shimming is shown

Conclusion: We have demonstrated the ability to significantly reduce SAR whilst simultaneously improving B_1^+ homogeneity for cardiac MRI by using 8-channel parallel transmission at 3T. Furthermore we have shown the importance of using the correct SAR model to optimise scanning and ensure that safety limits are adhered to.

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