B_0 SHIMMING FURTHER IMPROVES HUMAN CARDIAC ^{31}P-MRS AT 7 TESLA

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PURPOSE: Human cardiac ^{31}P MR spectroscopy (^{31}P-MRS) gives unique insight into the metabolic state of the heart by measuring high-energy phosphate metabolites.[1] Yet applications have been limited by low signal-to-noise ratios (SNRs) and the need for long scans.

Human cardiac ^{31}P-MRS at 7T was recently shown to give 2.8x the SNR compared to 3T.[2] That study used a 10cm loop ^{1}H coil for localization, but B_0-shimming with the Siemens product 3D volume shimming tools proved challenging due to strong intensity variations across images from the 10cm loop coil. The scanner's default ("tune-up") B_0-shims were therefore used for all subjects and good quality cardiac ^{31}P-MRS data were still obtained.[2]

We present here the first human cardiac 7T ^{31}P spectra with B_0 shimming; we quantify the reduction in spectral linewidth due to shimming in 6 volunteers; and we show that ^{31}P spectra of comparable quality are obtained from scanners in Oxford and Minnesota in preparation for a forthcoming multi-centre study.

Subj.	γB_0 SD over heart / Hz Tune-up	WIP	NEW
1	140	99	64
2	105	79	67
3	101	92	74
4	73	47	45
5	130	74	68
6	119	72	71
Mean	**111**	**77**	**65**

Table 1: Shim performance *in vivo*.

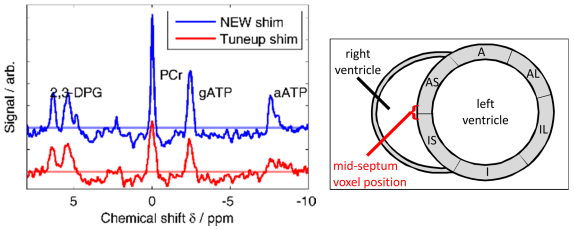

Fig. 1: Spectra from one subject with NEW and tune-up shims in the mid-septum.

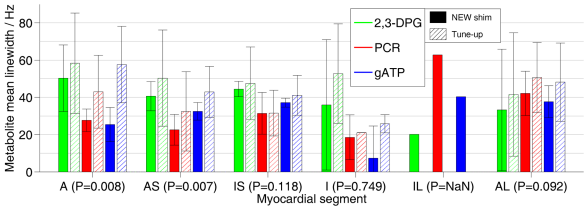

Fig. 2: Linewidths (mean ± inter-subject SD) for voxels in each myocardial segment for the NEW and tune-up shim settings. P values are from a two-tailed, paired t-test on the 3 peaks. Segments follow Fig. 1. Spectral SNR was too low to fit IL *tune-up* data.

METHODS: Normal volunteers (6 males, 24–57y, 73–93kg) were recruited with IRB approval. Scans used the Siemens 7T system in Minnesota. GRE localizers were acquired with a 16-element cardiac TEM array.[3] Several dual-echo GRE 3D B_0 maps were then acquired using the Siemens WIP452B sequence. The first ("tune-up") B_0-map used the scanner's default 1st and 2nd order shims, the second ("WIP") B_0-map followed two iterations of the Siemens WIP452B shim calculation, and the third ("NEW") B_0-map followed two iterations of a customized shim calculation (starting again from the tune-up shim values). In the WIP shim, pixels within a cuboid covering the ventricles were used to optimize the shim, greater attention being paid to higher intensity pixels. In the NEW shim, all pixels with intensity less that in the inferior segments were zeroed, then the magnitudes of all remaining pixels were normalized to 1 but the phases were kept unaltered. Hence, the higher intensity pixels near surface had the same influence as lower intensity pixels in the inferior cardiac segments on the NEW shim solution.

Two sets of ^{31}P spectra were then acquired in 28min each with a 16-element ^{31}P array (Rapid Biomedical), a 3D UTE-CSI sequence, a 16x16x8 matrix and WSVD coil combination (details in Ref. 2). Regions of interest corresponding to the mid-short-axis cardiac segments (Fig. 1) were drawn on the localizers. Voxels centred within each segment were then fitted with a custom Matlab implementation of AMARES[4] and corrected for blood contamination and partial saturation.[2]

RESULTS: Table 1 summarizes the variation in B_0 for each shim solution for each subject. The NEW shim gives 41% less B_0 variation over the heart than the tune-up shim, and the NEW shim gives 16% less B_0 variation than the WIP shim.

Figure 1 illustrates the effect of shimming on spectra in the mid-septum. Across all 6 subjects, the mean mid-septal linewidths were: **43** ± 11 Hz *vs* **71** ± 16 Hz (2,3-DPG, P=0.001), **24** ± 6 Hz *vs* **37** ± 17 Hz (PCr, P=0.07), and **30** ± 6 Hz *vs* **43** ± 11 Hz (γ-ATP, P=0.03) (**mean** ± inter-subject SD for the NEW *vs* tune-up shims). The peak SNRs were: **11** ± 3 *vs* **8** ± 3 (2,3-DPG, P=0.001), **22** ± 6 *vs* **15** ± 3 (PCr, P=0.03), and **14** ± 3 *vs* **10** ± 3 (γ-ATP, P=0.02). The blood- and saturation-corrected PCr/ATP ratios were **1.74** ± 0.25 for the NEW shim *vs* **1.88** ± 0.40 for the tune-up shim (P=0.38) and the PCr/ATP Cramer-Ráo Bounds (CRBs) were **16** ± 4 for the NEW shim *vs* **24** ± 6 for the tune-up shim (P=0.005).

Figure 2 shows the linewidths for all mid-myocardial segments. Shimming significantly reduces the linewidths in the A & AS segments. In some cases, shimming made visible a spectrum in the inferior segments where none could be seen with the tune-up shim.

DISCUSSION and CONCLUSIONS: In the mid-septal voxels, the NEW B_0-shimming procedure significantly improved the linewidths of γ-ATP (by 30%) and 2,3-DPG (by 39%); it improved all metabolite SNRs (by 37–47%) and the PCr/ATP ratio CRB (by 33%); and shimming did not significantly alter the PCr/ATP ratios (as should be the case). In other words, B_0-shimming significantly improves the quality of cardiac ^{31}P spectra at 7T. Furthermore, our NEW shim procedure produced a tighter B_0 distribution over the heart than the WIP shim, showing that the GRE magnitude normalization step mitigates the deleterious effects of image non-uniformity on the Siemens WIP452B shim solutions. Finally, we note that the mean tune-up PCr linewidth (**37** ± 17 Hz) here is comparable to that obtained previously[2] in Oxford (37 ± 11 Hz), showing that this ^{31}P-MRS method is ready for multi-centre studies.

1. Neubauer, NEJM, 2007. 2. Rodgers et al., MRM, 2014. 3. Vaughan et al., MRM, 2009. 4. Purvis et al., Proc. ISMRM 2014, #2885.
Funded by the Wellcome Trust and Royal Society [098436/Z/12/Z], MRC, & NIH P41-EB015894, R01-EB006835, R01-EB007327.