ACCELERATED HUMAN CARDIAC DIFFUSION TENSOR IMAGING USING SIMULTANEOUS MULTI-SLICE IMAGING

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Target. Researchers interested in cardiac microstructure and fast MRI.

Purpose. Remodeling of cardiac fibre structure contributes to impaired cardiac function, as well as alterations in electrophysiology, leading to development of life-threatening arrhythmias and sudden cardiac death [1]. Diffusion tensor imaging (DTI) allows non-invasive detection of fibre structure in vivo, but inherently low SNR leads to long scan times, ultimately limiting the patient population which can benefit from such exams. In this abstract, we investigate the feasibility of using a blipped CAIPI acquisition [2] and simultaneous multi-slice (SMS) acceleration to accelerate human DTI of the heart.

Methods. Pulse sequence. A breath-held cardiac-gated single-shot EPI STEAM sequence [3] was modified to include multiband excitation and CAIPI blips (Siemens 3T Trio, TE 13 ms, TR 2 RRs, matrix 128x42, partial Fourier 5/8, FOV 360x180 mm^2, through-plane slice thk 8 mm / gap 20 mm, phase-encode slab thk 120 mm, in-plane res. 2.8x2.8 mm^2, EPI BW 2448 Hz/pixel). The multiband excitation pulse was constructed by summing phase-modulated waveforms exciting single slices (SLR algorithm, TBW 4, thk. 8 mm, PW 4 ms, $10^{-3}/10^{-2}$ passband/stopband ripple, $B_{1,max}$ = 0.006 mT). Controlled aliasing was used to introduce a FOV/3 inter-slice shift to reduce g-factor noise amplification. Data acquisition. Healthy male volunteers were scanned (n=6, ages 28-45 y). The scan protocol involved 7 breath-holds (BHs) for cardiac localizers, single-slice diffusion data (15 BHs = 3 basal, 9 mid, 3 apical), and multiband diffusion data (9 BHs). One BH was used to obtain reference data for multiband reconstruction. This protocol enables a comparison based on equivalent total scan time between multiband and single-slice acquisitions. The diffusion encoded BHs lasted a total of 16 RRs (2: EPI phase correction, 2: b=20 s/mm^2, 12: 6x b=350 s/mm^2 images). Image reconstruction. Following phase correction (Nyquist ghost removal, off-centre correction, and blipped CAIPI phase correction by image entropy minimization [4]), split slice-GRAPPA [5] was used to unalias the multiband images. In this method, kernel weights w_i are fitted which jointly match the reference data and minimize signal from neighbouring slices ($w_i = \underset{w_i}{\operatorname{argmin}} \|S_i - [A_i]w_i\|_2 + \lambda \sum_{j \neq i} \|[A_j]w_i\|_2$). We set λ = 1 and used a kernel size of 11x5 k-space points. POCS was used for partial Fourier reconstruction. SNR performance was characterized using the pseudo-multiple replica method [6]. ADC, FA, and helix angle (HA) maps were measured [7].

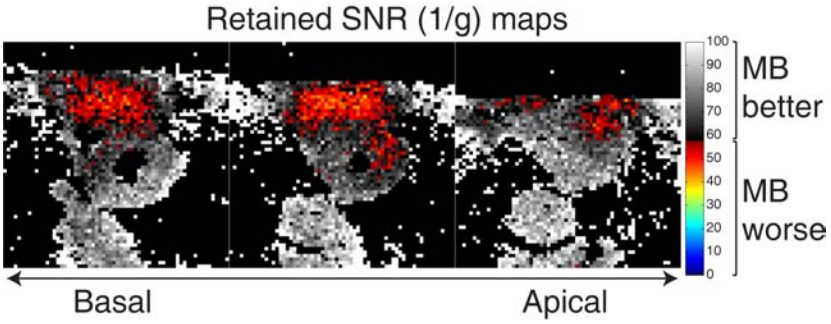

Figure 1. Retained SNR for SMS with a FOV/3 inter-slice image shift produced by controlled aliasing. The colour scale changes from coloured to grayscale at 57% ($1/\sqrt{3}$), the conventional SNR penalty from a 3x scan time reduction. The images are cropped to 180x180 mm^2.

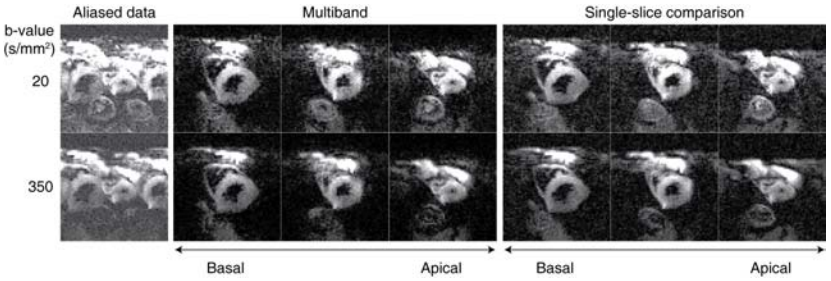

Figure 2. Diffusion-weighted images of the heart using multiband reconstruction and single-slice acquisition. The images are cropped to 180x180 mm^2, and the phase encode direction is from right to left.

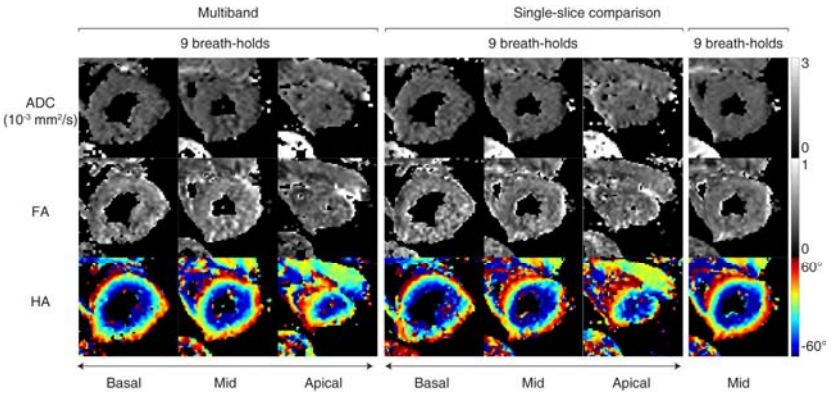

Figure 3. Comparison of in vivo diffusion parameters in the human heart (ADC: apparent diffusion coefficient, FA: fractional anisotropy, HA: helix angle) using multiband (9 BHs / 3 slices), single-slice (9 BHs / 3 slices), and single-slice (9 BHs / 1 slice) acquisitions.

Results and Discussion. Fig. 1 shows retained SNR maps for a FOV/3 inter-slice image shift. The average retained SNR figure over the LV is 71% ± 4%, higher than the standard 57% SNR penalty with a 3x scan time reduction, indicating an SNR benefit when using MB acceleration. Fig. 2 shows diffusion-encoded cardiac images using MB and reference acquisitions. Fig. 3 compares DTI parameters measured using MB and time-equivalent single-slice acquisitions. The maps are visually similar, and no significant difference was detected between the three acquisitions (Fig. 3, $p > 0.05$). The shim volume and centre frequency were kept constant for all scans to maintain the same B_0 image distortion and shifts.

Conclusion. The feasibility of accelerating cardiac DTI using a blipped CAIPI SMS scan by three-fold was demonstrated. The new sequence is anticipated to improve quantitative measurements of cardiac microstructure by reducing the number of breath-holds required for the scan, making it practical to incorporate diffusion tensor measurements within a comprehensive clinical exam.

References. [1] Kawara et al., Circ 2001; 104(25):3069-3075. [2] Setsompop K et al., MRM 2012;67(5):1210-1224. [3] Edelman RR et al., MRM 1994;32(3):423-428. [4] Lau AZ et al, ISMRM 2014 (submitted), [5] Cauley SF et al., MRM 2013. [6] Robson PM et al., MRM 2008; 60(4):895-907. [7] Holmes AA et al., MRM 2000;44(1):157-161.