COMPARISON OF ADC AND FA IN EPI- AND SSFP-BASED STIMULATED ECHO DIFFUSION OF THE HUMAN MYOCARDIUM

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Target audience: Physicists with an interest in cardiac diffusion techniques.

Purpose: Cardiac diffusion imaging is a promising technique to probe the microarchitecture of the myocardium in disease. Most existing methods rely on EPI to sample diffusion-prepared magnetisation, which necessitates a very short read out to avoid gross distortion, particularly at 3T. SSFP provides high SNR and undistorted images and has been used extensively in myocardial tissue characterisation. The aim of this study was to compare the ADC and FA measured using a stimulated echo diffusion-prepared SSFP method and stimulated echo EPI cardiac diffusion, and to estimate the reproducibility and SNR of the ADC and FA from the two sequences.

Methods: Two stimulated echo cardiac diffusion sequences were implemented on a 3T TIM Trio (Siemens, Erlangen, Germany) with ECG gating and a 32-channel cardiac coil, one with an EPI readout over a reduced field-of-view[1], the other using an unbalanced SSFP readout[2] following a 90° tip-up pulse. The unbalancing is required to avoid signal loss from the phase change that occurs due to bulk motion between the two diffusion gradients[3]. Sequence schematics are shown in Fig 1. Both sequences had voxel sizes of 2.7x2.7x8mm^3, reference b-value 20 s/mm^2, and b=350 s/mm^2 in six directions, and external GRAPPA reference lines (R=2). Other parameters for EPI: TR/TE=2RR/22ms, bandwidth=2442Hz/px, matrix size 128x48; for SSFP: TR/TE=2.5/1.3ms, α=112°, bandwidth=1021Hz/px, matrix size=96x96. The EPI sequence required an extra two heartbeats to acquire phase correction lines, while the SSFP sequence had a longer recovery time of 2RR intervals between diffusion preparations due to the signal saturation during the longer readout. During a sixteen-heartbeat breathhold, the EPI sequence gave a reference image and 5 diffusion-encoding directions, while the SSFP sequence gave a reference image and 3 diffusion directions. Three healthy volunteers were scanned with both sequences in a single scanning session. A mid-ventricular slice was selected and two sets of six breathholds of each sequence were acquired at end systole, giving two 5-average sets of EPI data and two 3-average sets of SSFP data. These data were processed in MATLAB (Mathworks, Natick, MA) to produce apparent diffusion coefficient (ADC), fractional anisotropy (FA) and helix angle (HA) maps. Myocardial ROIs were drawn around the left ventricle and mean ADC and FA over the slice for each repeat of the two sequences was calculated. Reproducibility was assessed by calculating the mean intrasubject coefficient of variance (CoV) for each sequence, and a paired t-test[4] was used to test whether the sequences measure the same ADC and FA. The SNR was measured using a principal-components-based multiple image method[5].

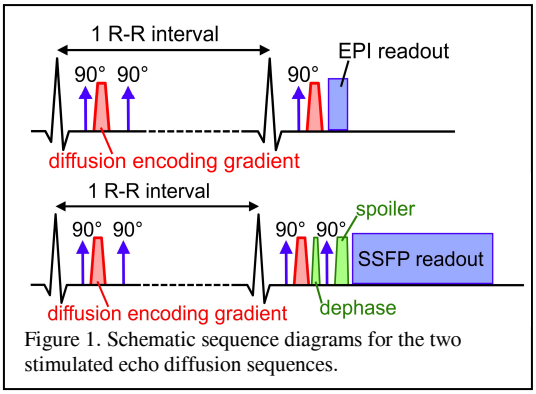

Figure 1. Schematic sequence diagrams for the two stimulated echo diffusion sequences.

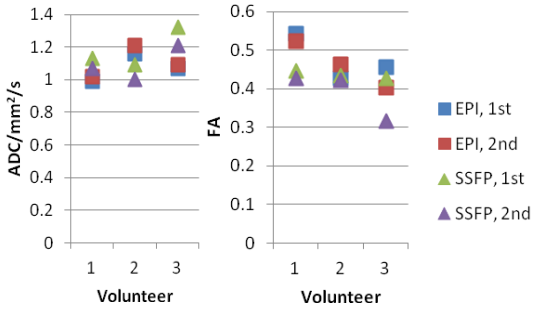

Figure 2. ADC and FA measurements from the two sets of six breathholds for each sequence. Mean±SD
ADC with EPI: 1.09±0.09mm^2/s (intrasubject CoV 3%);
SSFP: 1.14±0.11mm^2/s (CoV 6%).
FA: EPI: 0.47±0.06 (CoV 3%); SSFP: 0.041±0.04 (CoV 5%).

Results: The data are shown and described in Fig 2. The diffusion metrics from the two sequences are very similar and the t-test showed no statistically significant differences between the two sequences (ADC p=0.7, FA p=0.2). The EPI sequence shows better reproducibility than the SSFP sequence. Example ADC, FA and helix angle maps calculated from all data in one subject are shown in Fig 3, along with example reference and diffusion-weighted images. The average diffusion-weighted SNR over all subjects in the septum was 30 with EPI and 21 with SSFP.

Discussion: While SSFP readouts are inherently high-SNR, the necessity of unbalancing involves losing an additional 50% of the signal, which is reflected in the lower SNR of this method. However, the unbalancing substantially reduces the T1-weighting seen in other diffusion-prepared SSFP methods[6]. The lower number of averages in the SSFP sequence due to the longer recovery time between images also contributes to the lower reproducibility of this method. There is also some blurring in the SSFP images due to the longer readout, such that the helix angle map using SSFP looks less ordered than with EPI. However, the overall agreement of the two methods is promising.

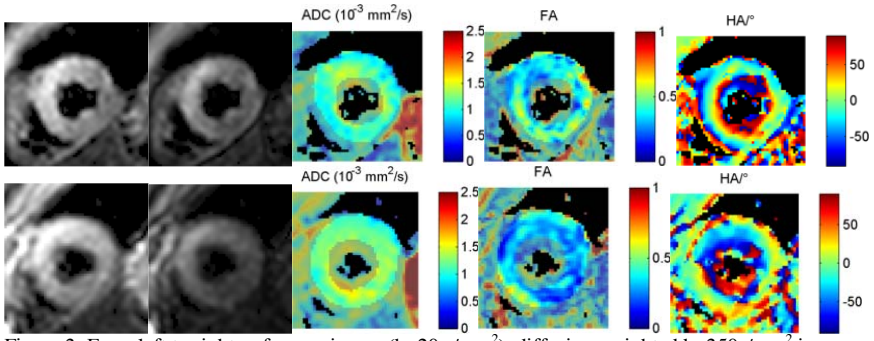

Figure 3. From left to right: reference image (b=20 s/mm^2), diffusion-weighted b=350s/mm^2 image, and ADC, FA and HA maps from the EPI (top row) and SSFP (bottom row) sequence for subject 3.

Conclusion: Stimulated echo cardiac diffusion EPI and diffusion-prepared SSFP yield very similar ADC and FA in the left ventricular myocardium, although the reproducibility of the SSFP method does not seem to be superior to EPI in an equal-time comparison.

References:1 Nielles-Vallespin S et al. *MRM* **70** 454 (2013). 2 Tunnicliffe EM et al. *JCMR* **15(S1)** P1 (2013). 3 Alsop DC *MRM* **38** 527 (1997). 4 Altman DG & Bland JM *Lancet* **327** 307 (1986). 5 Ding Y et al. *MRM* **63** 782 (2010). 6 Jeong EK et al. *MRM* **50** 821 (2003).