First and Second Order Motion Compensated Spin-Echo Diffusion Tensor Imaging of the Human Heart

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Introduction: Stimulated echo acquisition mode (STEAM) [1] imaging has been used to probe myocardial microstructure in-vivo. However, STEAM imaging requires 2 R-R intervals, sophisticated respiratory navigator gating [2] and is subject to myocardial strain [3,4]. Spin-echo (SE) based single-shot diffusion weighted sequences present an appealing alternative [5,6]. In this work the sensitivity to bulk motion of cardiac SE diffusion tensor imaging is addressed by using second order motion compensated diffusion encoding.

Materials and Methods: First and second order motion compensated diffusion encoding gradients were incorporated into a cardiac triggered single-shot SE sequence (Figure 1). Imaging was performed on a 1.5T Philips Achieva system (Philips Healthcare, Best, The Netherlands) equipped with a gradient system delivering 80mT/m@100mT/m/ms per physical axis. Five healthy volunteers were imaged (4 female, age: 21±2years, heart rates: 66±13 beats/min, min/max heart rates: 47/85 beats/min) with navigator-gating during free-breathing (gating window 5mm) with the following parameters: resolution: 2.2×2.2mm^2, slice thickness: 6mm, local-look FOV: 230×98mm^2, TR/TE: 1R-R/83ms. Fat suppression was incorporated by spectral-spatial excitation. Diffusion weighted imaging (DWI) was acquired by encoding along three orthogonal diffusion encoding directions (b=450s/mm^2, 8 averages) at trigger delays ranging from 45ms to peak systole (steps of 10ms). DWI was acquired at basal and apical level where greatest through-plane and rotational motion is expected. The mean diffusivity (MD) and the corresponding standard deviation across the myocardium as well as the volunteers are presented as function of trigger delay and used as measure for the sensitivity to bulk motion.

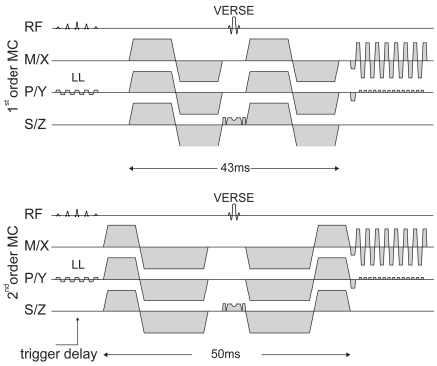

Figure 1 First order motion compensated (top) and second order motion compensated (MC) spin-echo diffusion encoding.

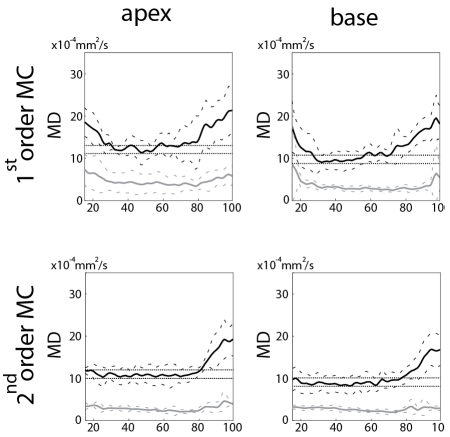

Figure 2 Mean diffusivity (MD) for first and second order motion compensated (MC) diffusion encoding as function of trigger delay. Black lines represent the mean MD across the myocardium and gray the corresponding standard deviation. Solid lines represent the average across volunteers, dashed lines the standard deviation across volunteers. The horizontal dashed lines indicate a range of minimum MD and 2.05×10^{-4}mm^2/s above.

In an additional session DTI data with ten diffusion directions (10 averages/TR: 2R-R) were acquired at 38%/47%/56%/66%/75% peak systole. Imaging slices were positioned at basal and apical level. A local radial, circumferential and longitudinal basis was defined by the slice normal and the shortest distance between the epicardial and endocardial surfaces. Helix angle maps were calculated upon projection of the diffusion tensor's first eigenvector onto the circumferential/longitudinal plane [7]. The local transmural depth was normalized and transmural helix angle histograms are presented.

Results: Second order motion compensated diffusion encoding gradients were 7ms longer in duration compared to first order diffusion encoding gradients. Resulting MD as a function of trigger delay is shown in Figure 2. Second order motion compensated diffusion encoding yielded an applicable trigger delay range of 15-81% (apical) and 15-77% (basal) of peak systole. For first order motion compensation, the corresponding trigger delay windows were only 30-57% (apical) and 27-56% (basal). Figure 3 shows a time series of helix angle maps (mid-ventricular) and the transmural helix angle histograms (apical/mid-ventricular/basal). For first order motion compensation a wider circumferential helix angle distribution is found reflecting patches without transmural change of fiber orientation.

Discussion: Second order motion compensated cardiac SE diffusion encoding significantly decreases the sensitivity to bulk motion compared to first order motion compensation. Thereby cardiac DTI at various time points during the cardiac cycle is possible and hence insights into the dynamic rearrangement of myofiber aggregate during contraction may be obtained.

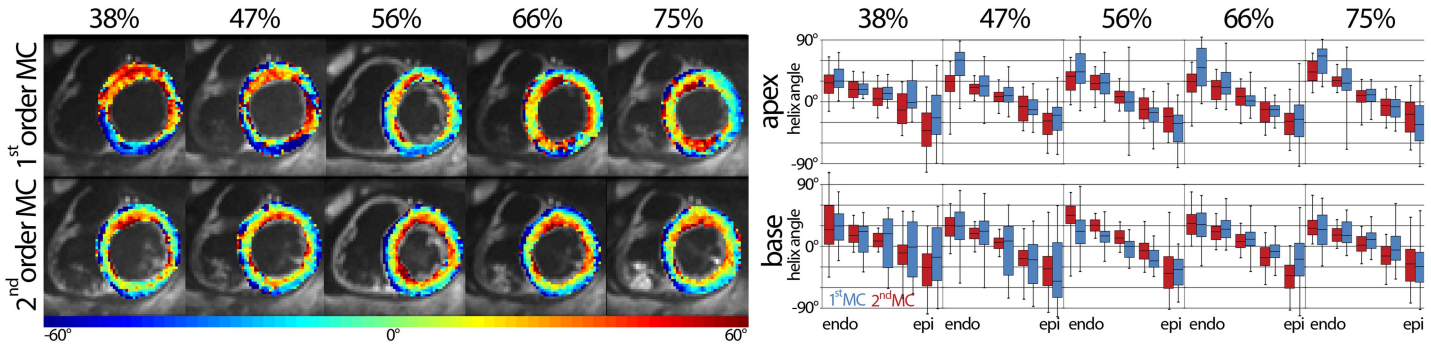

Figure 3 Helix angle maps for first and second order motion compensated (MC) diffusion encoding at basal level(left). Transmural helix angle histograms at basal and apical level are shown on the right. The box corresponds to the 50% percentile and the error bars to 90% percentile of helix angles.

References: [1] Edelman et al., MRM 1994. [2] Nielles-Vallespin et al., MRM 2013. [3] Reese et al., MRM 1995. [4] Stoeck et al., PLoS ONE 2014. [5] Gamper et al., MRM 2007. [6] Nguyen et al., MRM 2013. [7] Scollan et al., AJP 1998.

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