Improved Tractography of the Human Heart In Vivo by Motion Correction of Multi-breathold Diffusion Tensor MRI

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Target Audience: Scientists Interested in Diffusion Tensor MRI and motion correction strategies in the heart.

Purpose: Diffusion Tensor MRI (DTI) tractography of the human heart *in vivo* is a viable technique, but requires multiple breatholds per slice to yield adequate SNR.[1] The physiological motion inherent to multiple breathold acquisitions results in a diffusion-encoded volume in which the data vary as a function of both space and time. This may impact the estimation of diffusion based-indices as well as accurate tractography of myofiber architecture. We therefore developed a novel automated motion correction scheme to improve the accuracy of DTI-tractography in the heart.

Methods: DTI of 10 normal volunteers was performed on a 3T clinical scanner (Skyra, Siemens) with the following parameters: 6 diffusion-encoding directions, b=350s/mm^2, fat saturation, TR/TE=1100/23ms, BW=2442Hz/pixel, spatial resolution=2.7x2.7x8mm^3, 8 averages. This required 24 separate breatholds for a 3-slice diffusion-encoded volume. On a chosen reference frame, n radial scanlines starting at the left ventricle (LV) - right ventricle (RV) junction and crossing at the center of the LV cavity were defined as the axes of alignment. Motion was estimated by matching the intensity gradient profiles of corresponding radial scanlines between frames and at all 3 slice levels. A rigid registration defined by a set of translations and rotations was determined between pairs of DTI images, iteratively, until the global minimum of the quadratic error of the intensities was reached. Fiber tracking was performed with a 4th order Runge-Kutta approach as previously described.[2] The signal-noise-ratio SNR_t(r) = MEAN_t(r) / SD_t(r), was calculated at each pixel r with a given number of averages (repetitions) t, with and without motion correction.[3] The tractographic propagation angle (PA) in human hearts (n=5) *ex vivo* was used as the gold-standard, and compared to the PA values obtained *in vivo* before and after motion correction. The PA has shown to be a robust metric of tract coherence and quality.[4]

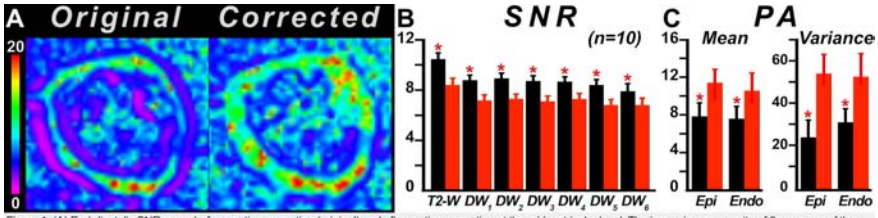

Figure 1. (A) End-diastolic SNR maps before motion correction (original) and after motion correction at the midventricular level. The image is a composite of 8 averages of the diffusion-free component (b=0s/mm2). (B) SNR in the b=0s/mm2 and the diffusion-weighted images is significantly improved (p<0.01, Mann-Whitney) by motion correction (black bars = corrected; red bars = original). (C) Mean PA and PA variance are both significantly reduced by motion correction (p<0.01, Mann-Whitney), particularly at the borders of the myocardium. This indicates that motion correction produces more coherent fiber tracts.

Results: Figure 1A shows SNR maps at end-diastole for the diffusion-free image (b=0s/mm^2). Note the low SNR (purple color) at the LV borders in the SNR map of the uncorrected image, indicating misalignment of the images during averaging. Motion correction, produced an average increase of 24% in the SNR of the diffusion-free image. An average SNR increase of 21% was seen in the diffusion-weighted images (Figure 1B) at end-diastole (p<0.01, Mann-Whitney). Mean PA values were reduced by up to 33%, and PA variance by 35%, after motion correction, indicating more coherent tracts (Figure 1C). The impact of motion correction on PA is shown in Figure 2. In the human hearts imaged *ex vivo* PA averaged 2.4±1.1. The use of motion correction *in vivo* reduced PA from 9.7±6.3 to 5.9±2.9 (p<0.05), so that it more closely resembled PA *ex vivo*. The impact of motion correction on tract coherence was also evident on the tracts color-coded by the helix angle (HA). As shown in Figure 2, the tracts in the subepicardium were substantially more coherent, more closely resembling the tracts in the *ex vivo* hearts, after motion correction.

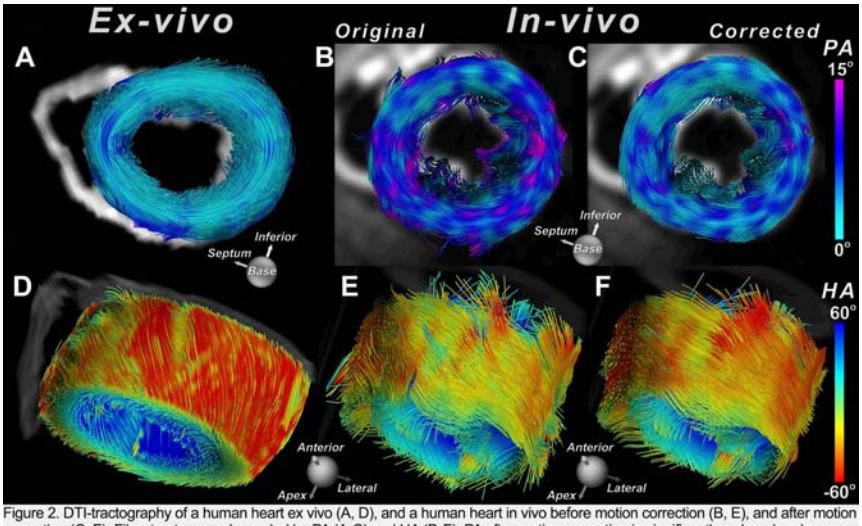

Figure 2. DTI-tractography of a human heart ex vivo (A, D), and a human heart in vivo before motion correction (B, E), and after motion correction (C, F). Fiber tracts are color-coded by PA (A-C) and HA (D-F). PA after motion correction is significantly reduced and more closely resembles ex vivo PA. Likewise, myofiber tracts color-coded by HA reveal that fibers in the subepicardium are significantly more coherent and organized after motion correction. PA = propagation angle. HA = helix angle.

Discussion: Variations in cardiac and respiratory motion can severely affect DTI tractography of the heart *in vivo*, which requires multiple breatholds per slice. Here, we show that motion correction over space and time can significantly diminish the motion displacement produced by multiple breatholds and increase the quality of the resulting tractograms and associated statistics.

Conclusion: Motion correction facilitates the accurate quantification of diffusion based-indices and the performance of high-resolution DTI tractography *in vivo*. This will be particularly important for free breathing navigator-based DTI of the heart.

References: 1) Nielles-Vallespin S *et al.*, MRM 2012; 2) Mekkaoui C *et al.*, JCMR 2012; 3) Reeder SB *et al.*, MRM 2005; 4) Mekkaoui C *et al*., ISMRM12.