Second order motion compensated cardiac DTI: direct comparison in-vivo and post-mortem

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Introduction: Spin-echo based cardiac diffusion tensor imaging (DTI) [1] is highly sensitive to myocardial strain. When employing first order motion compensated diffusion encoding, imaging during systolic contraction is feasible [2,3], but requires precise planning of the sequence timing [4]. Second order motion compensated diffusion encoding has recently been proposed for small animal imaging [5] to reduce the impact of myocardial strain on the diffusion tensor.
In the present work second order motion compensated DTI was performed in a porcine model in-vivo and compared to post mortem DTI on a clinical MR system.

Materials and Methods: Second order motion compensated diffusion encoding gradients were incorporated into a cardiac triggered single-shot spin-echo sequence (Figure 1). A pig (65kg) was imaged on a 1.5T clinical system (Philips Healthcare, Best, The Netherlands) equipped with a gradient system delivering 80mT/m@100mT/m/ms per physical axis. Six slices distributed along the long axis were acquired during spontaneous free breathing with the following parameters: resolution: 2.2×2.2mm^2, slice thickness: 6mm, reduced FOV [6]: 230×98mm^2, TR/TE: 2R-R/83ms, 10 signal averages. Fat suppression was established by spectral-spatial excitation. Ten diffusion encoding directions with a b-value of 450s/mm^2 were applied. The trigger delay was set to early systole to mimic the contractile state of the heart post-mortem. The pig was euthanized by a potassium injection inside the MR scanner and the protocol was repeated. The animal experiment was performed in adherence to the Swiss law of Animal Protection and approved by the Zurich cantonal veterinary office.
To determine reproducibility the in-vivo as well as the post-mortem acquisition was performed twice. 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 local circumferential/longitudinal plane [7]. The myocardium was segmented in 4 angular and 4 radial segments per slice similar to the procedure proposed in [8] (Figure 2 top).

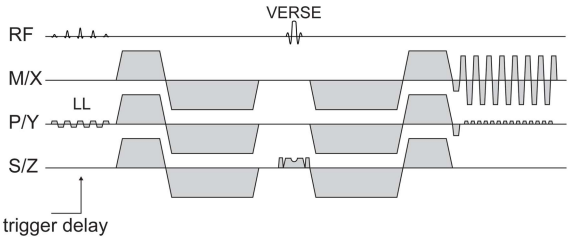

Figure 1 Second order motion compensated diffusion weighted spin echo sequence. A spatial spectral pulse is employed for fat saturation and limits the field of view in phase encoding direction (LL). The Echo pulse duration is shortened by variable rate selective excitation (VERSE)

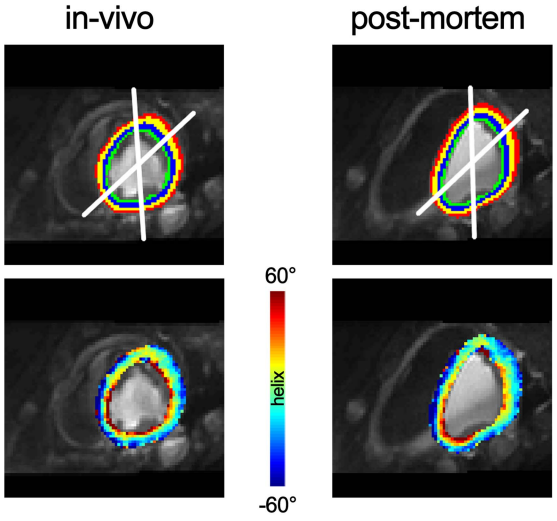

Figure 2 The myocardium was segments into four angular sectors and four transmural layers (top). The left ventricular – right ventricular junctions were used as anchor points. Helix angle maps were calculated upon Tensor reconstruction for the in-vivo and post-mortem case (bottom)

Results: Example in-vivo and post-mortem helix angle maps are shown in Figure 2 (bottom). Sectors were spatially matched and the corresponding correlation analysis for in-vivo vs. post-mortem data as well as for repeated measurements is presented in Figure 3. Root mean squared differences between sectors in-vivo and post-mortem were 14.4°. For comparison of repeated acquisition the root mean squared differences between sectors was 10.8° and 15.2° for in-vivo and post-mortem respectively. Greatest differences were found at apical level at the intersection of the left ventricle and the papillary muscles. Despite significant deformation of the post-mortem heart due to the loss in blood pressure, good agreement between in-vivo and post-mortem data was revealed.

Discussion and Conclusion: Good correlation between in-vivo and post-mortem imaging in the range of measurement reproducibility in-vivo and post-mortem was found proving that bulk motion and strain effects are well suppressed if second order motion compensated diffusion gradients are employed.

References: [1] Gamper et al., MRM 2007. [2] Toussaint et al., MedIA 2013 [3] Sosnovik et al., Circ 2014 [4] Stoeck et al., ISMRM 2011. [5] Welsh et al., ISMRM 2014. [6] Feinberg et al. Radiology 1985. [7] Stoeck et al., PLoSone 2014. [8] Nielles-Vallespin et al., MRM 2013.

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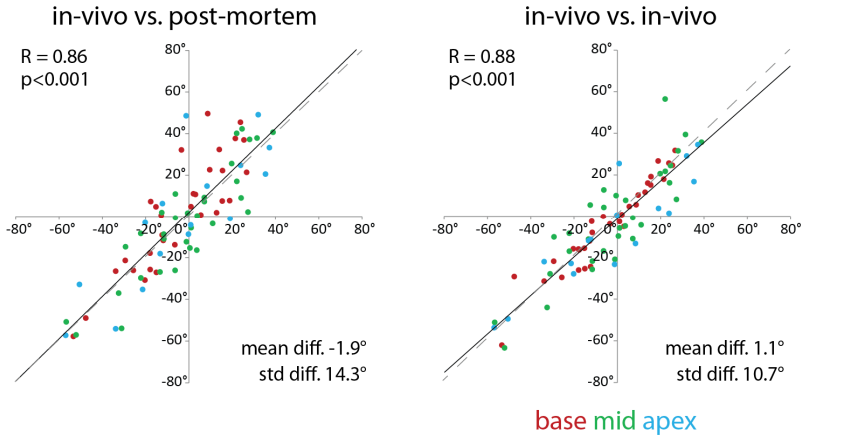

Figure3 Sector wise comparison of the helix angle distribution in-vivo and post mortem as well as for repeated measurements. Color-coding corresponds to the slice position: base (red) mid-ventricular (green) and apex (blue)