Navigator Based Free Breathing Diffusion Tensor MRI of the Human Heart *In Vivo*

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Introduction

Diffusion tensor MRI (DTI) provides a non-invasive approach for the depiction of the myocardial fibre architecture [1-5]. *In vivo* DTI of the heart remains extremely challenging due to cardiac and respiratory motion. Several techniques have been used to compensate for respiratory motion: multiple breath-holds (>36 per patient), synchronised breathing and retrospective navigators based on image cross-correlation [2-5]. The purpose of this work was to implement a novel modification of a prospective navigator technique to allow free breathing *in vivo* DTI of the heart to be performed and, thereby in the future, allow the technique to be broadly applied in patients with cardiovascular disease.

Materials and Methods

The diffusion weighted (DW) STEAM single shot EPI sequence was implemented on a clinical scanner (3T, MAGNETOM Skyra, Siemens AG, Germany) [7]. This sequence runs over two heart beats and makes the assumption that the heart is in the same position at both diffusion encoding times (mid systole) on consecutive cardiac cycles. In order to minimize the length of the single shot EPI readout, parallel imaging with external reference lines and zonal excitation was implemented, such that the first two 90º RF pulses were set perpendicular to the third 90º RF pulse, so that only spins lying in the intersection of both planes contributed to the echo formation [8]. Crossed slice prospective diaphragm navigators were applied before and after the STEAM module. The navigator accept/reject algorithm was modified to prevent bulk respiratory motion artifacts in the diffusion encoded images such that only scans that were within the acceptance window (±2.5mm) would be accepted, but added one extra restriction that the first and second heartbeat that would create an image needed to be within 1mm of each other. A biofeedback mechanism was implemented to increase scanning efficiency. The navigator signal was displayed inside the scanner room, allowing volunteers to adapt their breathing pattern and target the navigator acceptance window. 11 volunteers were scanned twice, on different days, to perform reproducibility analysis. In each scanning session both breath-hold (BH) and navigated free breathing (FB) data sets were acquired. Protocol parameters: 6 diffusion encoding directions, b=350s/mm^2, TR=900-1100ms (for RR intervals=700-1000ms), TE=23ms, BW=2442Hz/pixel, fat saturation, spatial resolution=2.7×2.7×8mm^3, 3 slices, 8-10 averages. FA and MD were calculated in 4 segments of the left ventricle (LV) and the right ventricle (RV). Reproducibility of MD and FA was determined for both BH and FB techniques as the mean±SD of the signed differences between day 1 and day 2. To compare both techniques, the mean±SD of the signed differences between BH and FB were calculated for day 1.

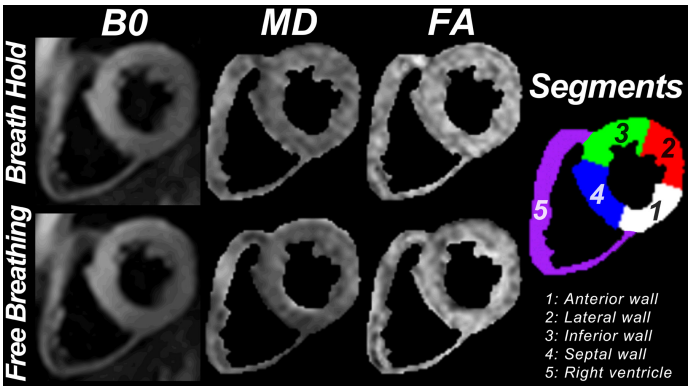

Figure 1. *Example b0 image (averaged), MD and FA maps for BH and FB.*

Results

An averaged b0 image, MD and FA maps are shown in Figure 1. Bland Altman analysis showed good reproducibility of both BH and FB techniques (MD_{BH}: 0.001±0.04, MD_{FB}: 0.01±0.03; FA_{BH}: -0.01±0.04, FA_{FB}: -0.02±0.05). Figure 2 shows plots of the mean ± SD of the MD and FA values of all the regions of the heart (LV + RV) plotted for BH and FB and for day 1 and day 2. No significant differences are seen between the BH and FB techniques for FA (0.006 ± 0.042), while for MD there is a small systematic difference (-0.03 ± 0.03) which requires further investigation. On average, scan duration with the BH approach was 14.4±1.5min and 17.1± 4.2min with the FB approach.

Discussion

The FB approach improved volunteer comfort without a major increase in scan duration. We show here for the first time that a free-breathing navigator based approach to cardiac DTI produces high quality *in vivo* images. The ability to perform free breathing DTI will be critical if the use of DTI is to be extended to patients with cardiovascular disease and limited breath-hold capacity. It also paves the way for a free-breathing 3D technique that achieves isotropic voxel coverage of the heart in clinically feasible acquisition times in order to produce continuous 3-dimensional tractograms of myocardial fibre architecture *in vivo*. This could prove to be a powerful tool to characterise the structural remodelling and fibre disarray patterns of diseases such as myocardial infarction and cardiomyopathies, improving the capability of cardiac MRI for diagnosis and therapy follow-up.

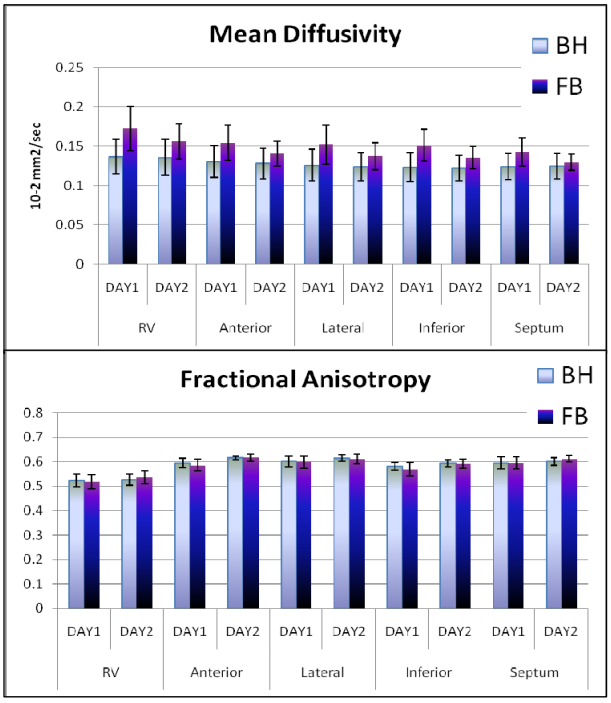

Figure 2. *Bar plots: MD and FA values of the two different days for BH and FB.*

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