Trigger Delay Scout Sequence for Multi-phase Cardiac Diffusion Tensor Imaging

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Introduction

Myocardial microstructure critically underlies regional cardiac function. This has motivated the development of cardiac diffusion tensor imaging (cDTI) to analyze myocardial microstructure during different phases of contraction [1]. Single-shot spin-echo planar imaging (SS-EPI) approaches present the advantage of being faster and offering higher SNR than its stimulated-echo counterpart [2]. However, *in vivo* SS-EPI acquisitions are challenging due to the involvement of bulk motion compensation techniques [3] and can only be acquired at specific trigger delays (TD) in the cardiac cycle [4]. These TDs have been shown to be patient specific and requires individualized settings [5].

In this work, we have designed a fast TD scout sequence that allows the user to quickly estimate a patient specific TD for SS-EPI cDTI. The TD scout information was then used to determine available cardiac phases for cDTI. The mean diffusivity (MD) and fraction of anisotropy (FA) is studied in healthy volunteers at three different contraction phases.

Methods

Nine healthy volunteers (N=9) were imaged on a 3T scanner (Prisma, Siemens). Both TD scout and cDTI were acquired using the same image parameters in a single mid short-axis slice using a second order motion compensated diffusion encoding waveform [3] with the following parameters: TE=61ms, 1.6x1.6x8mm interpolated to 0.8x0.8x8mm. Thirty cardiac phases with three diffusion encoding directions at a b-value of 350s/mm² were first obtained using the TD scout sequence during free-breathing (TR=~2000ms, 90 images/~3 minutes total). For the cDTI acquisition, a total of three cardiac phases, early systole (Syst1), late systole (Syst2) and diastole (Diast) were then manually placed using the TDs observed during the scout (Figure 1). Two b-values (0 and 350s/mm²), twelve diffusion encoding directions and five averages were obtained using an end-respiratory navigator trigger (TR=~4000ms 250 images/~5 minutes of free-breathing per cardiac phase, 15 min total). The distributions of MD and FA across volunteers were reported and compared at different cardiac phases.

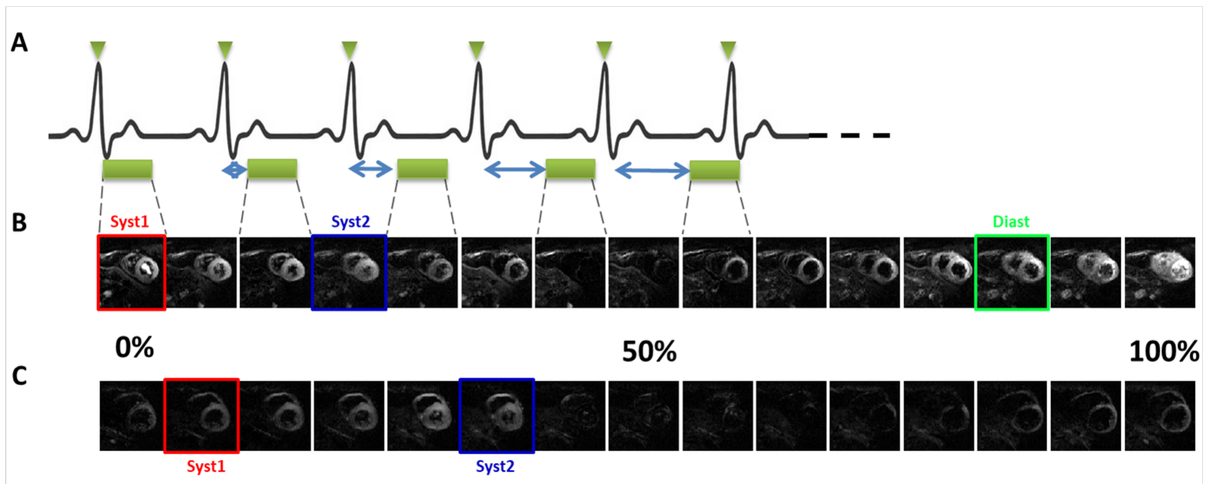

Figure 1: A) TD scout principle: one image is acquired per heart-beat. Once three directions have been obtained, the TD is incremented until a total of thirty phases have been acquired. An example of fifteen TDs DWI images corresponding to 0 to 100% of the RR duration on volunteers with (B) and without (C) stable diastolic phase. The TDs during the cDTI experiments were acquired in early systole (red box), late systole (blue box) and diastole (green box).

Results

An example of the TD scout acquisition is shown in Figure 1. The mean DWI signal as a function of TD across volunteers is shown in Figure 2. Higher signal was obtained in the systole phase with a maximum occurring at peak contraction. The period after peak contraction shows strong signal dropout due to cardiac motion. A stable cardiac phase was measured on some volunteers during diastasis. The period corresponding to the R wave was not screened by the TD scout.

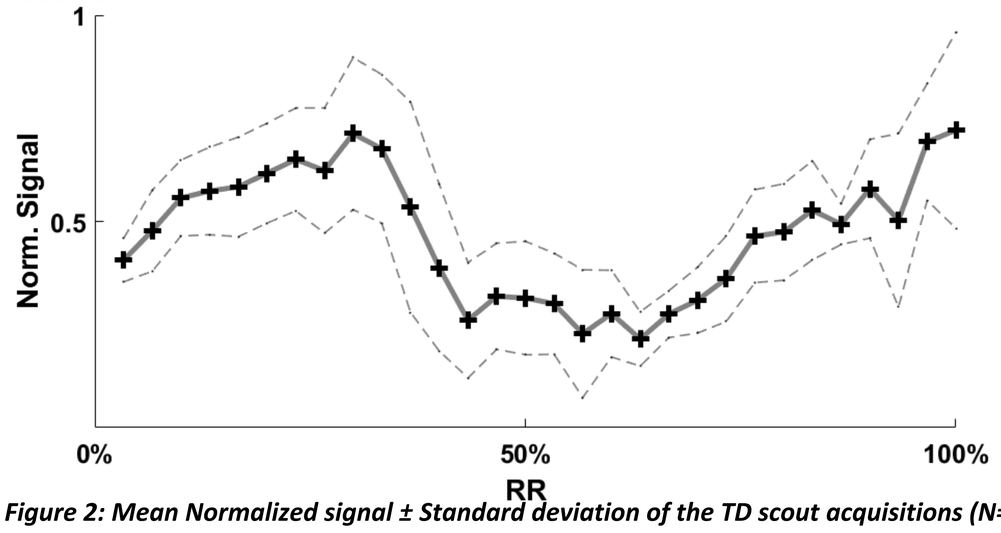

Figure 2: Mean Normalized signal ± Standard deviation of the TD scout acquisitions (N=9)

Results (Cont.)

cDTI data was successfully acquired during Syst2 in all nine volunteers (Success=100%). The early systolic and diastolic acquisitions were only possible in seven volunteers (Success=78%) and six volunteers (Success=67%) as shown in the TD scout examples given Figures 1 and 2.

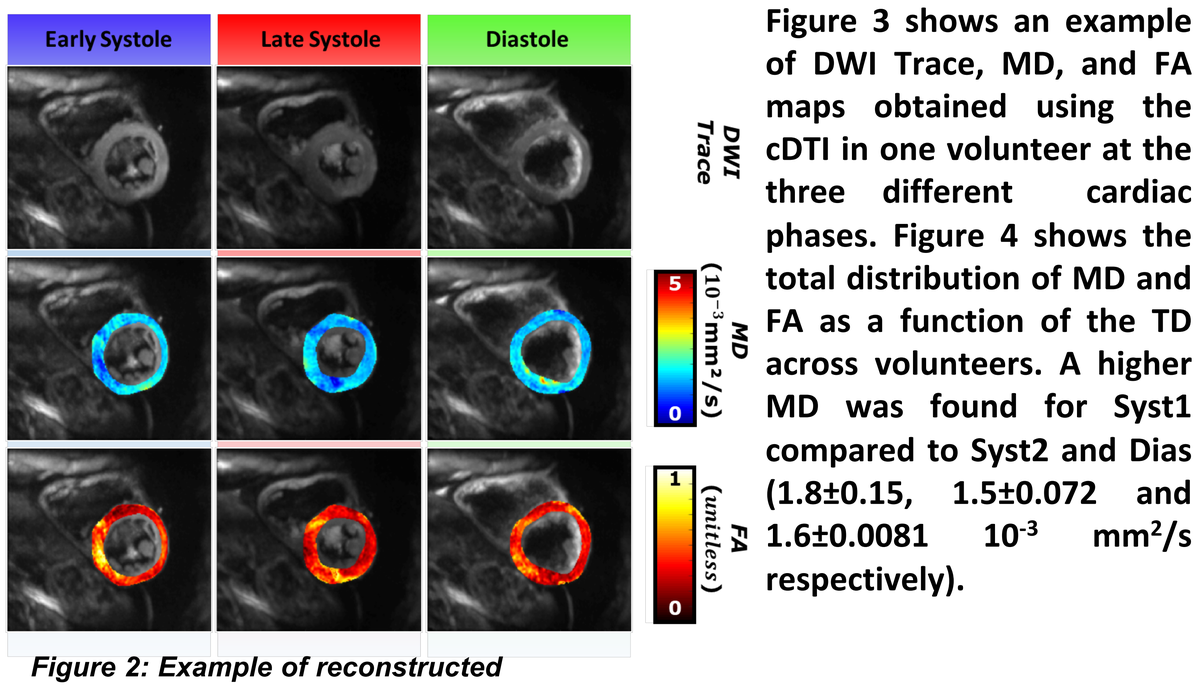

Figure 2: Example of reconstructed DWI Trace, MD and FA maps on one volunteer at the three cardiac phases.

Similarly, FA was slightly higher at early Systole than late Systole and Diastole (0.39±0.045, 0.35±0.021 and 0.37±0.025 respectively). Using T-test, statistical differences were found between cardiac phases Sys1/Syst2 for MD (MD p=0.0051, FA p=0.0987). FA was different between Syst2/Diast (MD p=0.3106, FA p=0.006) and Syst1/Diast (MD p=0.0685, FA p= 0.0418).

Figure 3 shows an example of DWI Trace, MD, and FA maps obtained using the cDTI in one volunteer at the three different cardiac phases. Figure 4 shows the total distribution of MD and FA as a function of the TD across volunteers. A higher MD was found for Syst1 compared to Syst2 and Dias (1.8±0.15, 1.5±0.072 and 1.6±0.0081 10^{-3} mm²/s respectively).

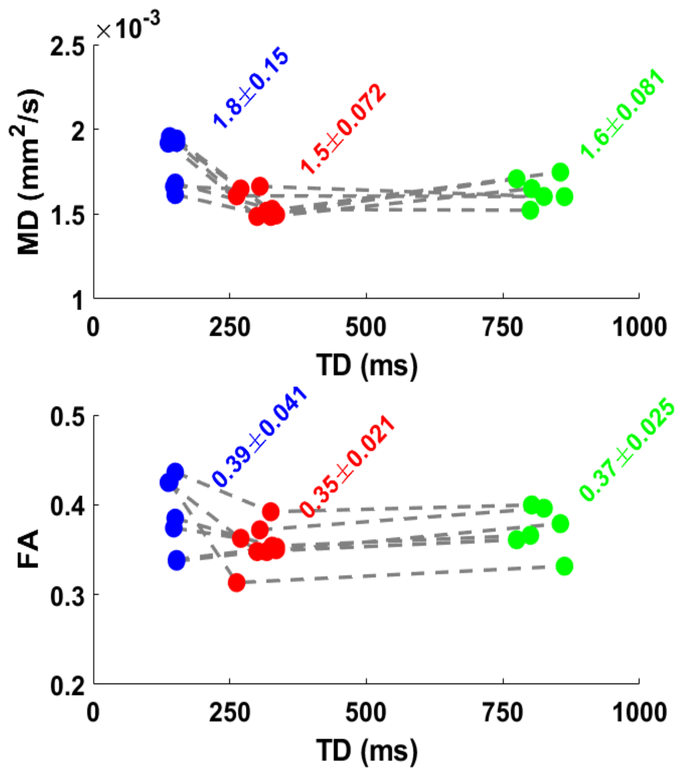

Figure 3: Distribution of mean MD and mean FA across volunteers for the corresponding TD at each cardiac phase.

Conclusions

The dynamic range and applicability of the SS-EPI DWI approach was assessed using a TD scout sequence. This scout was then used to define the TDs for three cDTI multi-phase acquisitions. Herein, systolic images were successfully obtained in all volunteers at a late systolic cardiac phase close to peak contraction offering a thick cardiac volume. A strong patient dependence remains in early systole and diastole phases, which couldn't have been scan on all volunteers [6]. Significant differences were found for both MD and FA, which shows a cardiac phase dependence.

The TD scout facilitates high quality cDTI acquisitions by prospectively helping to define the available cardiac phases. This approach enables the user of cardiac diffusion imaging *in-vivo* with clinically acceptable scan times.

References

(1) Nielles-Vallespin et al. JACC 2017
(2) Von Deuster et al. MRM 2015
(3) Aliotta et al. MRM 2016
(4) Stoeck et al. PlOs One 2014
(5) Rapacchi et al. Invest Rad 2011
(6) Moulin et al. MRM 2016

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