In vivo cardiac NMR Diffusion Weighted Imaging(DWI) for the human heart: tackling motion issue with temporal Maximum Intensity Projection(tMIP)-DWI and first results in humans

S. Rapacchi[1], P. Croisille[2], M. Viallon[3], D. Grenier[1], P. Kellman[4], and H. Wen[4]

[1]Creatis-LRMN, Université Lyon 1, INSA Lyon, Lyon, France, [2]Hopital Cardiologique et Pneumologique L. Pradel, Lyon, France, [3]Hopital Cantonal Universitaire de Genève, Genève, Switzerland, [4]National Heart, Lung and Blood Institute, NIH, Bethesda, MD, United States

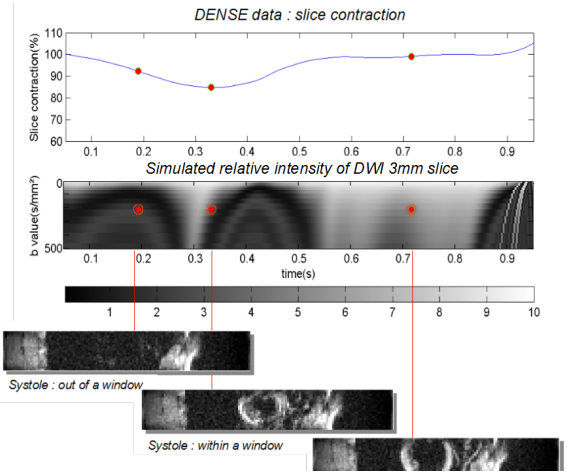
Purpose:

The purpose of this study is to develop a diffusion weighted imaging (DWI) approach that can cope with physiological motion and demonstrate its feasibility in routine clinical practice.

Introduction:

Diffusion weighted imaging in the heart is greatly affected by contractile motion and remains challenging to date. Stimulated-echo approaches have relatively low signal level and require complete beat-to-beat positional repeatability which may not be met in patients(1, 2). With spin-echo techniques, Gamper et al. recently proposed a robust motion-compensated sequence(3). However, through-slice diffusion was still difficult to measure. From their work, we developed an alternative approach for DWI, where a number of single-shot images of the same diffusion weighting are acquired at a series of different time points in diastole, and these are projected along the temporal axis by maximum-intensity-projection (tMIP) to form a true DWI. Through quantifying the motion-induced signal loss in DWI of a single slice based on experimental myocardial strain, we show the validity of tMIP and preliminary results in free-breathing scans of volunteers.

Figure 1: Images matches expected signal-loss and confirm the location of temporal windows within which DWI is valid in the heart.



Theory:

We simulated signal-loss of a simple spin-echo diffusion-weighted sequence with EPI readout. From displacement-encoded images (DENSE(4)) of volunteers, the through-slice strain over the cardiac cycle serves as the input for the simulation at different diffusion weighting (b) and cardiac phase. The signal-loss was found to scale with the slice thickness (3), and the calculated relative intensity of a DWI 3mm slice is represented in gray scale in the 2D space of *b* and cardiac phase (Fig.1). This study reveals narrow time windows at end-systole and during diastole wherein it is possible to acquire DWIs of the heart with a preferable thin slice. Since motion reduces the image intensity outside the windows, we propose a Maximum Intensity Projection (MIP) over an enlarged time window covered by serial acquisitions. DWIs over the cardiac cycle confirm the positions of the windows (Fig.1). Temporal MIP is performed for each pixel of the image individually to account for asynchronous cardiac motion.

Method:

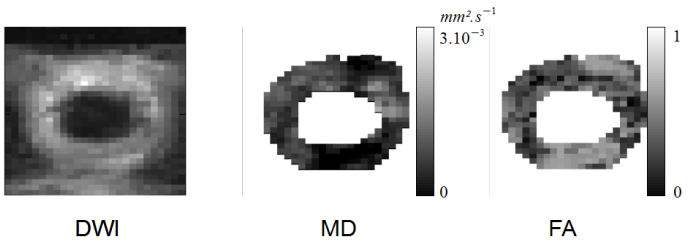
For patient comfort, scans were performed under free-breathing in 1.5T clinical scanners (Avanto, Siemens). Images were acquired in early diastole. A complete data set included 3 diffusion directions of b = 50 and 200s/mm² each, and lasted 4 min. Other parameters were FOV of 281.6 x 70.4 mm² with inner volume excitation, in-plane resolution of 2.2x2.2 mm², slice thickness of 3.2mm and 5 time points per heartbeat. We performed semi-automatic segmentation based on level-set contour propagation(5) from which we registered the images with a non rigid b-spline algorithm(6) to remove respiratory motion.

Preliminary Results and Discussion:

Fig.2 shows, from left to right, a tMIP diffusion-weighted image of a healthy volunteer and the resulting maps of mean diffusivity (MD) and fractional anisotropy (FA). While the mean MD is in agreement with literature values in healthy volunteers (7), the mean FA is higher.

Mean trace ADC	0.0010 mm^2s^{-1}
Mean FA	72 %

Figure 2: results from a healthy volunteer: DWI, Mean Diffusion and Fractional Anisotropy maps



The tMIP-DWI technique is a potential solution to the problem of interference from physiological motion, particularly in the heart. The single-shot sequence is robust and adaptable to efficient parallel imaging techniques. A necessary condition for its use is that the enlarged time window covers the narrow permissible windows of DWI. For cyclic motion including heart beat and breathing, the appropriate times are the semi-static plateaus of peak-systole, diastole, end-inspiration and end-expiration. Temporal coverage and resolution can be optimized according to the length of these periods. This technique is well tolerated and compatible with uncooperative or patients of poor conditions.

References:

1. Tseng WYI, Dou JG, Reese TG, *JMRI* 2006; 23(1):1-8. **2.** Callot V, Bennett E, Decking UKM, Balaban RS, Wen H, *MRM* 2003; 50:531-540. **3.** Gamper U, Boesiger P, Kozerke S. *MRM* 2007; 57(2):331-337. **4.** Aletras AH, Ding SJ, Balaban RS, Wen H. *JMR* 1999;137(1):247-252. **5.** Chan T, Vese L. *IEEE TIP* 2001;10(2):266-277. **6.** Rueckert D, Sonoda L, Hayes C, et al. *IEEE TMI* 1999;18(8):712-721. **7.** Wu M, Tseng WI, Su MM, et al. *Circulation* 2006;105.545863.