Intravoxel Incoherent Motion Modeling Applied to Cardiac Diffusion Weighted MRI: toward Free Breathing Acquisition in Healthy Volunteers

Bénédicte MA Delattre[1], Magalie Viallon[2], Hui Xue[3], Marie-Pierre Jolly[3], Christoph Guetter[3], Hongjiang Wei[1], Yuemin Zhu[1], Thorsten Feiweier[4], Vinay M Pai[5], Han Wen[5], and Pierre Croisille[1,6]

[1]*CREATIS, CNRS (UMR 5220), INSERM (U1044), INSA Lyon, University of Lyon, Lyon, France,* [2]*Department of Radiology, University Hospitals of Geneva, Geneva, Switzerland,* [3]*Siemens Corporate Research, Princeton, New Jersey 08540, United States,* [4]*Siemens Healthcare, Erlangen, Germany,* [5]*Imaging Physics Lab, BBC/NHLBI/NIH, Bethesda, Maryland 20892, United States,* [6]*Jean-Monnet University, Saint-Etienne, France*

Background

Intravoxel Incoherent Motion (IVIM) model [1] is currently a unique method for evaluating perfusion and diffusion parameters from diffusion weighted imaging (DWI) of a tissue without the use of any contrast agent. Despite its relevance, cardiac DWI has so far been limited to low b-values primarily due to signal losses induced by physiological motion. Recently, an efficient cardiac DWI method was proposed where images were acquired at different time points of the cardiac cycle and motion-induced signal-loss was compensated for by Principal Component Analysis (PCA) filtering and temporal MIP (TMIP) techniques (PCATMIP) [2]. While acquiring cardiac DWI during subject's breath-hold (BH) is the most robust manner to obtain accurate IVIM parameters, it is time-consuming and may be difficult to apply in clinical routine. Therefore, performing acquisitions during subject free breathing (FB) appears as an interesting alternative. In this study, our objective was to compare IVIM parameters estimated from BH acquisitions to those from FB acquisitions combined with a motion-correction algorithm.

Method

Measurements were performed on a MAGNETOM Avanto 1.5T (Siemens Healthcare, Erlangen, Germany) using a prototype diffusion EPI sequence. DWI scans were obtained on 12 volunteers for 10 trigger-delay values in mid diastole (sliding the acquisition window of the DWI scan within the RR as suggested in [2]). 13 b-values ranging from 0 to 550 s/mm^2 were used. Acquisitions were performed during both subject BH (acquisition was divided into 3 separate BH of approximately 16s corresponding to 30 BH in total, acquired in a total duration of 30min) and subject FB (total acquisition time ~10min). FB-DWI scans were then co-registered using a novel motion correction algorithm that preserves high accuracy and consistency of the data [3]. Then, PCATMIP algorithm was applied to both BH and coregisted FB images. Signal intensity (SI) was fitted with the IVIM model corrected for T1/T2 relaxation [4]. The pseudo-diffusion coefficient D^* was first estimated on the mean SI for the set of 12 volunteers and perfusion fraction, f, and diffusion coefficient, D, were subsequently evaluated in a pixel-wise manner with a bi-exponential model using the prior estimation of D^*.

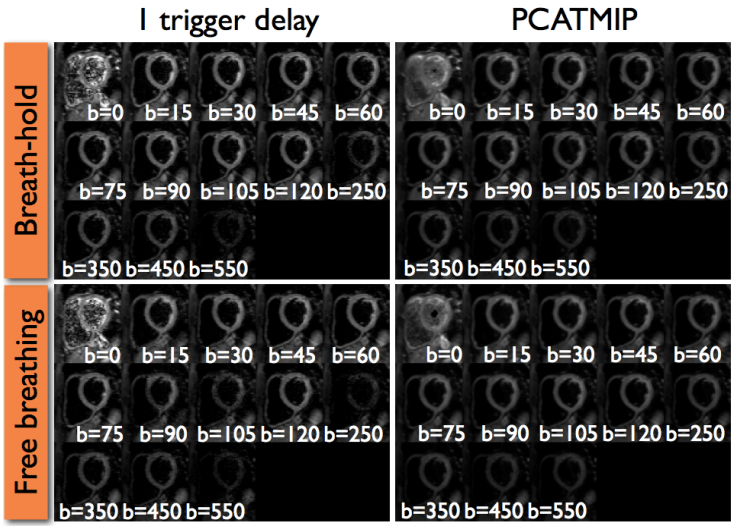

Fig 1: Examples of DWI scans for 1 diastolic trigger delay and after PCATMIP for acquisitions performed during BH and FB. Indicated b-values are in s/mm^2.

Results

During BH, intra-scan motion and RR variability can lead to signal losses (for example, b=250 in Fig 1 left column); these were compensated for by repeated acquisitions (sliding window) and PCATMIP post-processing. On the other hand, FB-DWI scans are affected by additional signal losses due to respiratory motion. However, the use of PCATMIP allows for the recovery of most of the signal leading to reduced standard deviations of f and D estimates in both BH (24% reduction) and FB (32% reduction) acquisitions compared to acquisition at one single trigger delay (see Fig 1 and Fig 2). Fig 3 and table 1 show the f, D and D^* results. The values of D measured during both BH and FB were not significantly different (p=0.069) nor were the values for averaged D^*. However, f was higher when evaluated during subject FB (p=0.001).

Table 1: IVIM parameters obtained after PCATMIP on the segmented myocardium for acquisitions performed during subject BH and FB for the left ventricle. Results are mean ± SD on the 12 volunteers.

	f(-)	D (10^{-3} mm^2/s)	D^*(10^{-3} mm^2/s)
Breath-hold	0.150±0.046	2.43±0.98	76.3
Free breathing	0.228±0.082	2.84±1.11	73.8

Discussion and Conclusion

This study demonstrates the feasibility of cardiac DWI in humans and reports for the first time cardiac IVIM parameters in volunteers while comparing FB and BH techniques. Cardiac DWI images suffer from additional signal loss due to cardiac motion when diffusion preparation is involved, which in turn prevents one from retrieving pure diffusion information by image registration technique alone. PCATMIP minimizes the motion-induced signal loss in BH acquisition but also post image registration in FB acquisition. Similar diffusion coefficient values were obtained while subject was freely breathing, but perfusion fraction was higher than with BH acquisition. The difference obtained for perfusion fraction evaluation between both methods may be explained by additional signal losses due to through-plane motion induced by respiration, and that could not be entirely compensated by repeated acquisitions and PCATMIP. Nevertheless, these results open great perspectives for perfusion measurements without the use of contrast agent and the possibility to acquire these measurements under FB conditions makes this technique viable for potential future clinical use.

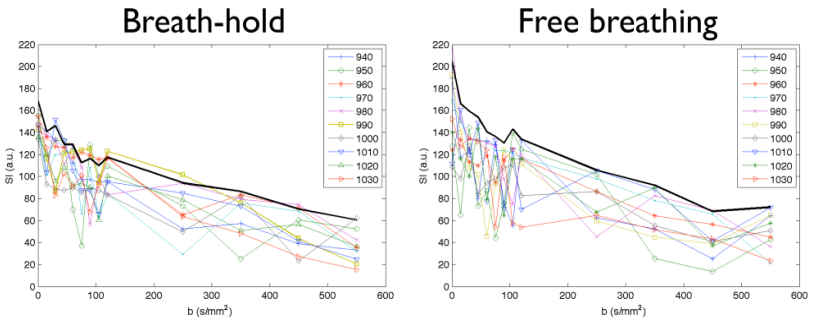

Fig 2: SI of segmented myocardium for images acquired at 10 different time points (legend indicates the trigger-delay in ms) for BH (left) and FB (right). Black bold line (without symbols) corresponds to the SI obtained after PCATMIP (volunteer is the same as Fig 1).

REFERENCES: [1]Le Bihan, Radiology,168(2):497,1988, [2]Rapacchi, Invest Radiol, 15:1,2011, [3]Guetter, IEEE ISBI, pp. 1–4,2011, [4]Lemke, MRM, 64(6) :1580, 2010.

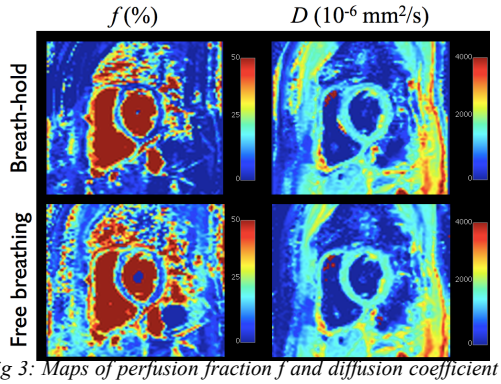

Fig 3: Maps of perfusion fraction f and diffusion coefficient D for acquisitions performed during subject BH and FB (same volunteer as Fig 1). PCATMIP post-processing was used in each case.