An Iterative Approach to Respiratory Self-Navigation enables 100% Scan Efficiency in 3D Free-Breathing Whole-Heart Phase Sensitive Inversion Recovery MRI

Giulia Ginami[1], Simone Coppo[1], Gabriele Bonanno[1], Tobias Rutz[2], Juerg Schwitter[2], Matthias Stuber[1], and Davide Piccini[1,3]
[1]Center for Biomedical Imaging (CIBM), Department of Radiology, University Hospital (CHUV) and University of Lausanne (UNIL), Lausanne, Switzerland, [2]Division of Cardiology and Cardiac MR Center, University Hospital of Lausanne (CHUV), Lausanne, Switzerland, [3]Advanced Clinical Imaging Technology, Siemens Healthcare IM BM PI, Lausanne, Switzerland

TARGET AUDIENCE: Scientists and clinicians interested in myocardial fibrosis detection and motion compensation.

INTRODUCTION: Respiratory Self-navigation (SN) for whole-heart coronary MRA [1] has shown to improve the ease of use and scan efficiency when compared to more conventional diaphragmatic navigator-gated (NAV) approaches [2]. In some implementations of 1D SN, the position of the heart along the superior-inferior (SI) direction is extracted from dedicated SI readouts and used for respiratory motion correction [1,3]. While SN has successfully been used to visualize the anatomy of the heart chambers, the coronary arteries, and the great vessels, its use for correcting respiratory motion in 3D phase-sensitive inversion-recovery (3D-PSIR) late gadolinium enhanced (LGE) imaging has not been exploited. Whole-heart 3D-PSIR imaging aims at precise volumetric evaluation of scar tissue after contrast injections; in this context, respiratory motion correction is obtained by using NAV approaches [4]. Prolonged acquisition time implied by the use of 3D NAV approaches makes the use of the 2D-PSIR counterparts still preferred in clinical practice. Both 2D and 3D-PSIR acquisitions are conventionally segmented over two consecutive heartbeats, where a first T1 weighted image is acquired after a non selective inversion recovery pulse (IR) in the first heartbeat, and a reference image is then acquired with a small radio frequency (RF) excitation angle during the second heart-beat (Fig.1a,b). The two datasets are then combined as described in [5]. In this scenario, integrating 1D SN with a 3D-PSIR acquisition is not entirely straightforward: contrast variations occur between the first and second heartbeat (Fig.1c,d), and SN based on the choice of a specific reference SI readout is not directly applicable. An iterative approach to SN (IT-SN), which aims at minimizing the SI displacement over the entire scan and does not rely on any specific respiratory reference position, has shown some improvements in image quality in patients with irregular breathing patterns [6]. Since the IT-SN method no longer relies on the segmentation of the blood-pool for respiratory motion correction, we hypothesize that such an iterative algorithm is directly applicable to images with different types of contrast such as those obtained with 3D PSIR. To test this hypothesis, the IT-SN technique was applied to 3D-PSIR datasets acquired in a group of patients with positive LGE findings.

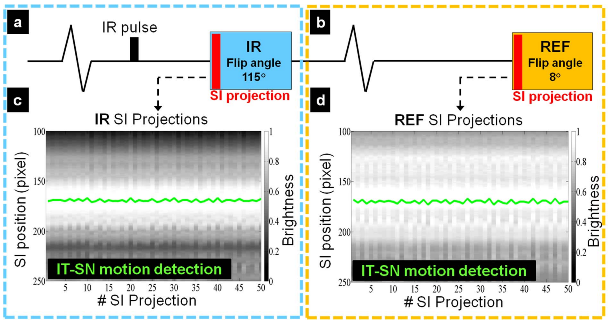

Fig.1: 3D-SN PSIR acquisition scheme. Two separate 3D volumes (IR and REF) are acquired (a,b). After inversion recovery and with different RF excitation angles, the two sets of SI projections used to estimate the respiratory motion are characterized by a different contrast (c,d). In both datasets, respiratory motion was estimated using the IT-SN algorithm (green line).

METHODS: An existing prototype 3D radial imaging sequence adapted to 1D SN motion correction along the SI direction [3] was modified to perform whole-heart 3D-PSIR acquisitions (Fig. 1). SN 3D-PSIR datasets were acquired on a 1.5T clinical MRI scanner (MAGNETOM Aera, Siemens AG, Erlangen, Germany) in N=8 patients with positive findings by regular 2D PSIR LGE imaging at the end of a clinical MRI session. The conventional gradient echo-based 2D-PSIR acquisition was performed with the following parameters: TR/TE 6.3/3.2ms, TI 250-320 ms, FOV (~200x380)mm^2, voxel size (~2.0x1.5)mm^2. Subsequently, a free-breathing SN 3D-PSIR data set was acquired segmented and ECG-triggered to the most quiescent diastolic cardiac resting phase. The relevant parameters were: TR/TE 2.9/1.45ms, FOV (220mm)^3, spatial resolution (1.4mm)^3 , RF excitation angle 115° (IR) and 8° (reference image), bandwidth 898Hz/pixel. The inversion time (TI) of the SN 3D-PSIR acquisitions was matched to that of the last regular 2D-PSIR scan. A total number of 8100 radial readouts was acquired over (300x2) heartbeats. The two acquired images (IR and reference) were separately re-gridded, motion corrected with the IT-SN algorithm (Fig.1), and combined to obtain the phase-sensitive reconstruction. All datasets were also reconstructed without motion correction, for comparison. A 3D image rigid registration tool was used to identify residual relative displacement along the SI direction between the IT-SN corrected IR dataset and the IT-SN corrected reference. Visual grading of the three datasets (2D-PSIR, uncorrected 3D-PSIR, and IT-SN corrected 3D-PSIR) was performed by two experienced clinicians. All images were graded using a scale from 1 to 4, were 4 indicates a sharp and diagnostic dataset, 1 indicates a non-diagnostic dataset, and 3 and 2 indicate moderate and severe blurring, respectively. Additional quantitative analyses were performed on the 3D-PSIR datasets (uncorrected and IT-SN corrected) to evaluate the performance of IT-SN. In particular, endocardial border sharpness (EBS) was quantified as described in [7] and, in presence of noticeable scars, the percentage scar sharpness (%SS), scar length and scar thickness was evaluated by using the tool described in [8]. Statistical analyses were performed with a two-tailed paired Student's t-test with $p<0.05$ considered statistically significant.

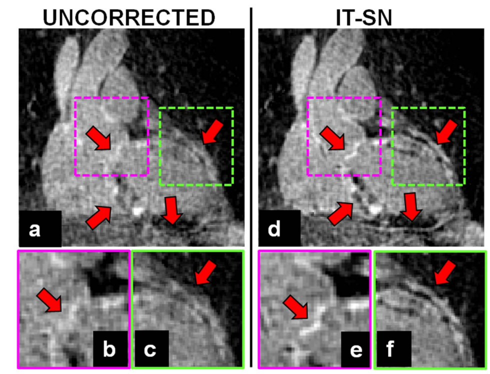

Fig. 2: Comparison between an uncorrected dataset (left) and its IT-SN corrected counterpart (right) obtained in a patient with anterior myocardial infarction. Image quality is highly improved in the corrected dataset (red arrows). Sharp visualization of myocardial scar tissue (green zoomed section in c,f) and calcified structures in the region of the aortic valve (purple zoomed section in b,e) is achieved with IT-SN correction.

RESULTS: Data acquisition, motion detection (Fig.1), and reconstruction were successful in all cases. Residual relative displacements along the SI direction between IT-SN corrected IR and IT-SN corrected reference were inferior to 1 pixel in all cases (0.58±0.44 pixels). Consistently, IT-SN motion corrected 3D-PSIR datasets visually provided an improved image quality in comparison to the non corrected counterparts (Fig.2, Fig.3). This trend was confirmed by the expert grading scores which was on average 2.7±1.0 for the uncorrected 3D images, and 3.3±0.8 for the IT-SN corrected 3D datasets ($p<0.05$). While 3/8 cases were graded with the maximum score as were all of the 2D-PSIR counterparts ($p<0.05$), of the remaining 5 cases, only one 3D dataset was considered non-diagnostic due to the increased time delay between injection and the 3D acquisition caused by a lengthy 2D PSIR examination. This patient was therefore excluded from the quantitative analysis. The average computed EBS increased from 0.17±0.93 pixel for the non corrected datasets to 0.23±0.1 pixel for the IT-SN corrected datasets ($p<0.05$). In addition, on a total number of 12 scar segments analyzed in 5 patients (average scar thickness 4.71±0.52mm, scar length 3.82±0.86cm) the %SS increased from 10.65±7.39 for the uncorrected datasets to 13.96±5.36 for the IT-SN corrected datasets ($p<0.005$).

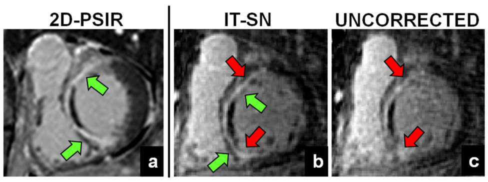

Fig. 3: Comparison between the gold standard 2D-PSIR acquisition (a) and 3D-PSIR with (b) and without (c) IT-SN obtained in a patient with myocardial infarction. A sub-endocardial crescent of LGE is well visible in a and b (green arrows). In c, the same structure appears blurred and the scar is no longer well delineated (red arrows).

DISCUSSION and CONCLUSIONS: The IT-SN algorithm was successfully implemented and applied for respiratory motion correction to a 3D radial whole-heart SN PSIR acquisition sequence, thus enabling 100% scan efficiency. Although the IR dataset and the reference datasets were separately corrected, 3D registration showed only minor residual relative shift in the SI direction. This suggests that IT-SN intrinsically performs motion correction to the level of the most frequent respiratory SI position of the patient's respiratory pattern in both cases [6], independent of the contrast of the SI readouts. Image quality of the IT-SN corrected datasets significantly improved when compared to non corrected datasets. Such improvement was consistent for both subjective and quantitative end-points including visual grading, EBS, and %SS. Further tests will be conducted on a pre-selected patient cohort in a more controlled environment, where the time after injection will no longer be dependent on the timing of 2D PSIR.

REFERENCES: [1] Stehning, et al, MRM 2005; 54:476-480; [2] Stuber, et al, Radiology 1999; 212:579-587; [3] Piccini, et al, MRM 2012; 68:571-579; [4] Zuehlsdorff, et al, ISMRM 2007; 683. [5] Kellman, et al, MRM 2002 ; 47 :372-383. [6] Ginami, et al, ISMRM 2014; 4387. [7] Kording, et al, MRM; DOI:10.1002/mrm.25502. [8] Etienne, at al, MRM 2002; 48:656-666.