Clinical Evaluation and Optimization of Highly Accelerated 2D and 4D Phase Contrast Flow Imaging Applications using Sparse Sampling and Iterative Reconstruction

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Introduction MR phase-contrast flow imaging (PCI) is clinically available and has the potential of providing significant benefits over Doppler ultrasound with its user-dependency and limited coverage; PCI seems most suitable for acceleration due to its multi-dimensionality and data redundancy. Methods have been proposed to accelerate PCI using sparse sampling and iterative reconstruction [1,2,3]. In this work we demonstrate the benefit of an optimized temporal and spatial regularization in 2D k-t-sparse cine phase contrast (Sparse Flow, SF) [4, 5] and validate the method in volunteers and patients. We apply the improved method of iterative reconstruction also to 4D Flow imaging in the aorta, enabling navigator-gated acquisitions in typically 6 minutes.

Methods The SF prototype sequence was implemented as proposed in [3]. Single-slice datasets with through-plane flow encoding were acquired in 5 heartbeats on a clinical 3T scanner (Magnetom Skyra, Siemens Healthcare, Erlangen, Germany) in volunteers (n=12) and patients (n=7) in the aorta (TE/TR 2.5/3.8 ms, temp. res. 36 ms, 240x196 matrix, in-plane res. 1.4x1.7 mm^2, slice thickness 6 mm, R_{eff}=7.5). For comparison, an equivalent conventional flow protocol with longer scan time (GRAPPA R=2, 19 heartbeats, TR 38 ms) was acquired. In another setup, 4D Flow datasets (n=5) of the thoracic aorta were acquired (TE/TR 2.7/4.0 ms, temp. res. 40 ms, 192x128x20-24 matrix, in-plane resolution 2.0x2.4x2.5 mm^3). The protocols were acquired with both TPAT R=2 reconstructed with product software and R=4 reconstructed using iterative reconstruction. Analysis was performed using commercial flow analysis software (ARGUS Flow, Siemens Healthcare, Erlangen, Germany and CVI42, Circle, Calgary, AB, Canada). Net forward flow volume and peak velocity were calculated. 4D Flow datasets were processed using prototype analysis software (Siemens 4D Flow V2.4) and flow results for forward volume and velocity were determined using the automated slice positioning and segmentation.

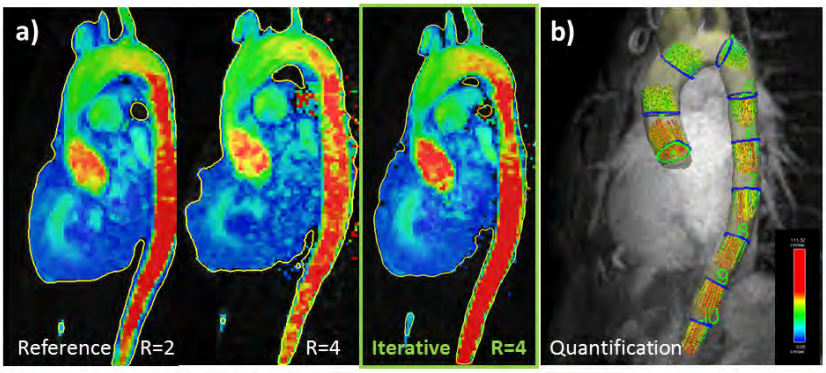

Fig.1: a) Visualizations of 4D Flow results for R=4 with iterative reconstruction and R=4 with standard reconstruction in a healthy volunteer; b) quantification planes with vector flow display.

Results Sparse Flow iterative data reconstruction could be performed in-line at 1 s/frame. In all patients the accelerated method gave diagnostic results. For the 2D measurements, the average absolute difference between reference and SF was 3.10 ml for net forward volume and 8.58 ml for peak velocity, systematic difference was -0.65% for net forward volume and 1.19% for peak velocity. Fig. 2 shows the flow results in a patient for standard vs. accelerated sparse flow measurement. Navigator gated 4D Flow datasets could be acquired in 13.3±0.9 min for R=2 and in 6.5±0.5 min. In fig. 2a), visualizations of the 4D Flow results for R=2 and R=4 with iterative reconstruction are shown for a representative volunteer scan. The quantitative flow results were compared in 10 different planes in the aorta as shown in fig. 1b). The average relative difference between the standard and iterative reconstructions was -3.75% for peak velocity and -3.32% for net forward volume, average absolute difference was 7.91% and 5.23% for peak velocity and net forward volume.

Discussion and Conclusions Sparse Flow extends the possibilities of flow acquisitions in a clinical setting. With optimized regularization, short-breathhold single-slice and fast 4D flow acquisitions are feasible without any apparent drawbacks in image quality or quantitative results. The inline reconstruction on a standard clinical scanner within seconds (2D PC) or minutes (4D Flow) allows the use of iterative reconstruction techniques in clinical practice. In the initial implementation, SF showed an increased background signal compared to the reference, as a consequence of the irregular sampling and regularization [6]. The optimization of regularization parameters in this work helped to overcome this limitation. 4D Flow was implemented with conventional TPAT sampling in this work but can be further accelerated using irregular sampling in the future. Due to the high level of integration, SF can easily replace the established protocols and will facilitate the clinical routine use of 2D and 4D flow imaging in difficult patients.

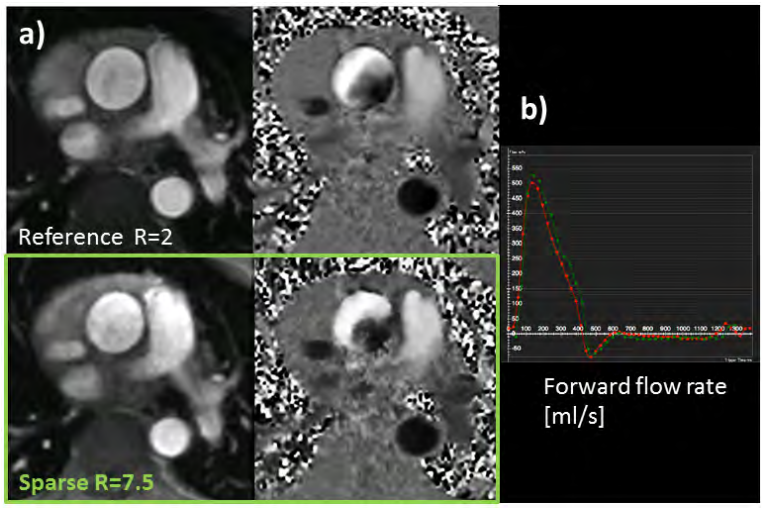

Fig.2: Patient results; a) left: reference with GRAPPA R=2, 18 heartbeats (RR); right: sparse acquisition with R_{eff}=7.5, 5 RR. Aortic swirling is visible in both reconstructions; b) Patient with mild aortic stenosis; red: reference; green: sparse.

References

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