Accelerated 4D Flow Imaging with Compressed Sensing and Radial Undersampling Pattern on Cartesian Grid

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INTRODUCTION

4D MR flow imaging is powerful tool for comprehensive hemodynamic assessment but is hampered by long scan times [1]. Compressed sensing (CS) has been suggested as a means to accelerate scan time by exploiting image sparsity in spatial domain, temporal domain, and coil sensitivity maps [2,3]. This study explores the compressed sensing technique with radial trajectory like undersampling patterns in the ky-kz plane (on Cartesian coordinates). Our preliminary results of aortic phase-contract imaging showed that the sampling pattern is robust to undersampling artifacts. Compressed sensing image reconstruction with an undersampling factor of 3 has been shown to provide good image quality and accurate flow measurements.

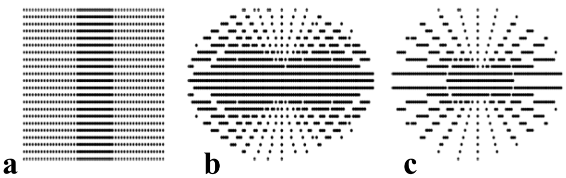

Fig. 1 Undersampling patterns on ky-kz plane, with Undersampling factors R=1.6, 2 and 3 respectively. The matrix size is 96x22. Sampled data is on Cartesian coordinates. The second and third patterns are following radial trajectories.

MATERIALS AND METHODS

A prospectively gated Cartesian 3D CINE phase-contrast sequence with interleaved three-directional velocity encoding was used to acquire phase reference and velocity-encoded data sets on a 1.5T Siemens Avanto scanner with a 4-channel coil. Scanning parameters were: venc = 200 cm/s, FOV = 320x240x55 mm^3, image matrix = 128x96x22, TR/TE = 4.4/2.9 ms, FA=8^o, 19 reconstructed time frames of 35 ms temporal resolution, and ~25 mins scan time with respiratory NAV gating window of 7 mm.

The fully sampled data was reconstructed as the reference image. Different undersampling patterns designed for GRAPPA (Fig. 1a) and CS (Fig. 1b-c) reconstructions were applied on the full data set. In Fig. 1a, along the phase encoding direction (horizontal), data of every other line was taken away at the high frequencies, resulting an undersampling factor of R=1.6. Fig 1 b-c have data on radial lines whose coordinates were rounded onto Cartesian grid, with R=2 and R=3 respectively. Image reconstruction with Zero filling (ZF) was also applied on the undersampled data. ROI in the aorta was selected through all the time frames and the mean velocity within the ROI was measured.

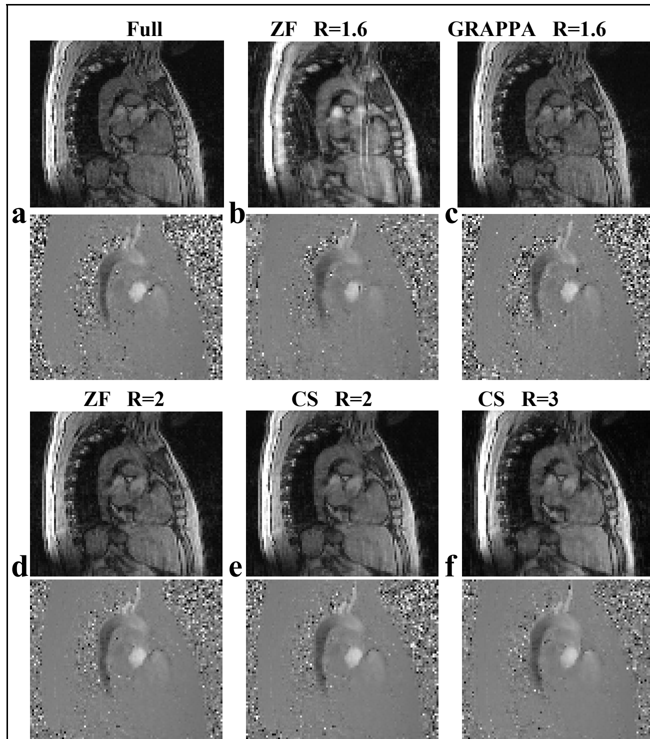

Fig. 2 Magnitude and feet-head velocity images obtained with different undersampling patterns (from Fig. 1) and reconstruction methods.

RESULTS AND DISCUSSION

In Fig. 2 the results obtained with different undersampling patterns and reconstruction methods are compared to the reference magnitude and flow images (Fig. 2a). It demonstrates that the radial like patterns (Fig. 2d-f) have high tolerance to undersampling artifacts. Even for R=2 with zero filling (Fig. 2d), the results are comparable to the reference. Fig. 3 shows the quantitative comparisons of the magnitude image and the aorta flow measurements through the cardiac cycle to those of the reference. Fig. 3a shows that the radial like undersampling pattern with higher acceleration factor (Fig. 1 b-c, R=2, 3) has even lower relative errors than the pattern with phase encodes undersampled (Fig. 1a, R=1.6). The aorta flow measurements with undersampled data are comparable to those of the reference ($p>0.05$), except those with ZF R=1.6, shown in Fig. 3b. The relative errors of the flow measurements are 0.27 (ZF R=1.6), 0.04 (GRAPPA R=1.6), 0.03 (ZF R=2), 0.03 (CS R=2), and 0.07 (CS R=3) respectively.

Combination of parallel imaging and compressed sensing will be investigated, and more subjects will be studied in the future.

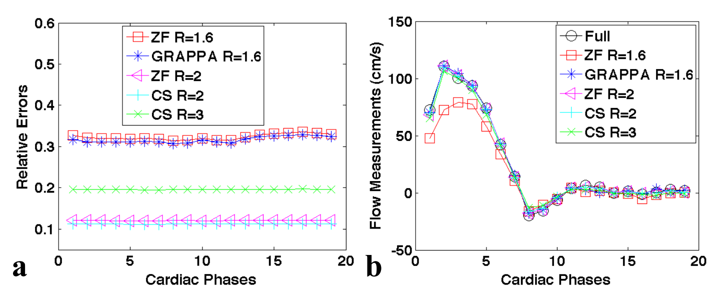

Fig. 3 Relative errors of the magnitude images compared to the reference (a), and the aorta feet-head velocity measurements (b).

CONCLUSIONS

In this study, different undersampling patterns were used to accelerate phase-contrast imaging. Our preliminary results have shown that radial like pattern on Cartesian grid is less sensitive to undersampling artifacts if compared to GRAPPA undersampling. Image reconstruction with compressed sensing provides good image quality and accurate flow measurements at an acceleration factor of 3, which will reduce the 4D flow scan time to be less than 10 minutes.

REFERENCES

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