Intra-Cardiac 4D flow MRI using spiral k-space trajectories
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1. Introduction
Time-resolved three-dimensional phase contrast MRI (4D flow) is a powerful tool for hemodynamic assessment in the cardiovascular system. However, the application of the method has been hindered by long scan times. By using spiral k-space trajectories, improved efficiency provides a means of reducing scan times without decreasing SNR. Spiral readouts have previously been used for 4D flow measurements in the aorta using prospective ECG gating [1]. Using retrospective gating, the entire cardiac cycle is covered, which allows analysis of late diastole and tracking of blood over a complete cardiac cycle. These are crucial for cardiac 4D flow studies, and allow for pathline based data quality assessment.

The aim of this work is to develop a retrospectively gated 4D flow sequence using a stack of spiral readouts for the measurement of intra-cardiac velocities.

2. Methods
A retrospectively gated 4D flow sequence using a stack of spirals was implemented on a Philips Achieva 1.5T. Six healthy volunteers (age 28±3 years) were imaged. The following parameters were used for the spiral measurements: field of view 280x280x101-112 mm³; voxel-size 2.8 mm isotropic; VENC 1.2 m/s; temporal resolution 48 ms; spiral duration 5.5 ms; 10 spiral interleaves. A Cartesian scan with the same spatial resolution using a SENSE reduction factor of 2 was carried out for comparison.

The data quality was evaluated by comparison with 2D through–plane velocity measurements in the proximal ascending aorta and quantitative pathline analysis. Pathlines were released backward and forward from the left ventricle (LV) to compute inflow and outflow volumes for the LV [2]; a small difference between the inflow and outflow values indicates good data quality. Furthermore, to facilitate aortic flow comparison, the 4D flow data was reformatted to the same slice location as the 2D data.

3. Results
Using spiral k-space trajectories, a 57% reduction in scan time could be achieved compared to the Cartesian scan, as shown in Table 1. Comparison with the 2D through-plane measurement does not show any decrease in data quality. The outflow values from the pathline analysis were slightly lower for some of the spiral acquisitions. Visual inspection of the pathlines did not reveal any major differences in data quality (see Figure 1).

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<tr>
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<td>93±20</td>
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Figure 1: Pathlines visualizing the blood flow going from the left atrium, through the ventricle, out in the aorta from 4D flow measurements from one of the healthy volunteers using a) spiral readouts and b) Cartesian readouts.

4. Conclusion
A retrospectively gated spiral 4D flow sequence was successfully implemented. The spiral readouts resulted in more than a two-fold reduction in scan time compared to a conventional Cartesian scan, which was already accelerated using parallel imaging, without any notable loss in data quality. Additional improvements in scan time and resolution can be obtained by using parallel imaging.