4D flow-sensitive MRI of the thoracic aorta using 12- and 32-channel coils

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Introduction: 4D flow-sensitive MRI is characterized by its high-dimensionality (depiction in three dimensions and over time of anatomy and three-directional blood flow velocities) that allows comprehensive blood flow and vessel wall analysis within complete arterial segments (1-3). However, the high-dimensionality of 4D-flow-sensitive MRI is limiting the clinical application of the technique by making image acquisition time-consuming. In this context, recent developments in MRI acceleration techniques such as parallel imaging (4), non-cartesian (5,6), compressed or sparse sensing are promising. Nevertheless, high acceleration factors are known to substantially degrade image quality. Additionally, the use of many surface coil results in high SNR near to the coil but lower SNR with increased distance from the coil (7,8). The benefits of multi-channel coil arrays and parallel imaging can thus be limited when imaging structures centered in the body such as the thoracic aorta. It was the aim of this study to evaluate the performance of 4D flow-sensitive MRI in the thoracic aorta with 12- and 32-channel coils using parallel imaging (GRAPPA).

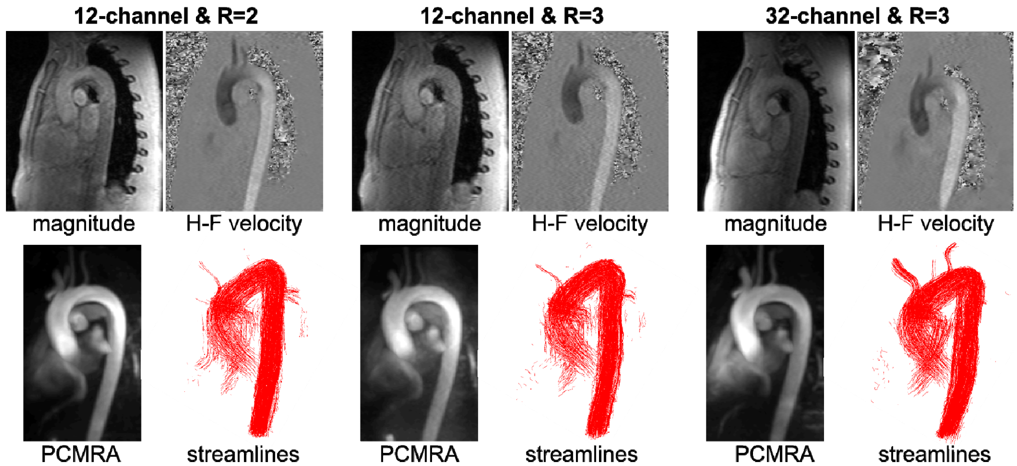

Fig.1: 4D flow-sensitive MRI in a 26 years old volunteer: magnitude and head-foot velocity (sagittal plane), phase-contrast MR angiography (maximum intensity projection) and streamlines.

Methods: 4D flow measurements were performed in the thoracic aorta in 11 healthy subjects using a 3T MR system and a standard 12-channel body coil as well as a research 32-channel body coil (Invivo Corp., Gainesville, FL, USA). The sequence made use of parallel imaging based on the GRAPPA technique in one direction. For every subject, three 4D flow acquisitions were performed with different coils and acceleration factors (R): (i) 12-channel coil, R=2, (ii) 12-channel coil, R=3, (iii) 32-channel coil, R=3. The imaging parameters were: voxel size: 2.68-2.98 × 1.30-1.46 × 2.70-3.00 mm^3, temporal resolution: 43.2 ms, venc: 200 cm/s, Number of calibration lines: 24, mean acquisition time: 14.2 min (R=2) and 11.4 min (R=3). Data were fully-automatically processed including corrections for Maxwell terms and eddy currents (2^{nd} order correction) (9). The signal-to-noise ratio (SNR) in the vessels was estimated based on the last two end-diastolic timeframes, which were assumed to represent repeated measurements (7). In addition, the residual divergence of the measured velocity field was used as an estimator of the presence of noise in the data because of the non-compressible behavior of blood which should induce zero-divergence (10). 3D Streamlines were calculated at peak-systole and the length of the traces was calculated based on the median value between all traces. Image quality was independently evaluated by two radiologists on a scale from 1-poor to 4-excellent based on phase-contrast MR angiograms (PCMRA) and streamlines visualizations.

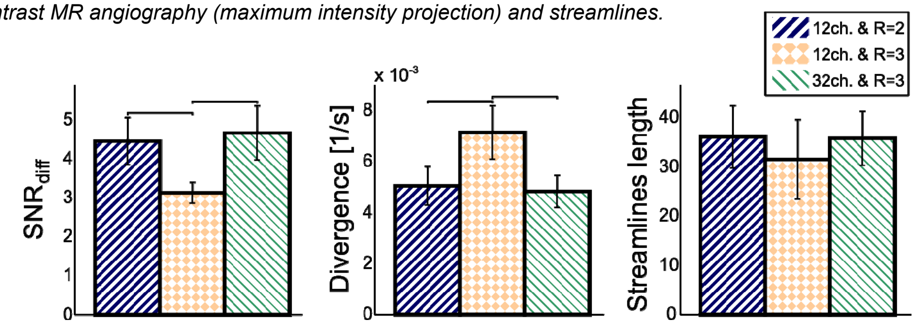

Fig.2: Quantitative analysis: SNR, divergence and streamline length. The error bars are given for +/- the standard deviation between volunteers. The horizontal brackets indicate a significant difference (p<0.05) between two modalities.

Results: When using the same 12-channel coil, changing from R=2 to R=3 induced significant loss of quality: lower SNR and higher residual divergence (Fig.2), reduced lumen contrast and increased noisy streamlines (Fig.3). Based on an acceleration factor R=3, changing from 12 to 32 channels, allowed significant gain in image quality: higher SNR and lower residual divergence (Fig.2) as well as better depiction of supra-aortic branches and higher quality of streamlines (Fig.3).

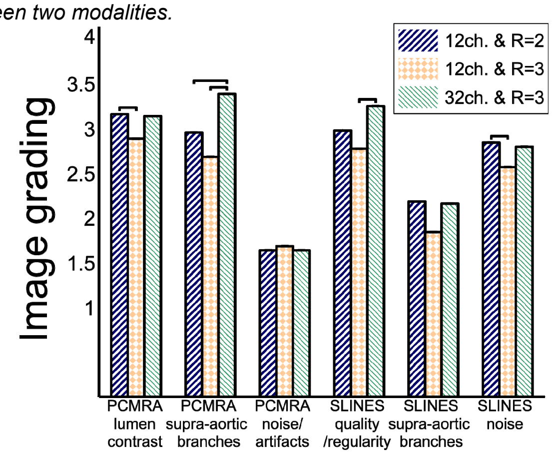

Fig.3: Image grading from two radiologists for PCMRA and peak-systolic streamlines images. The horizontal brackets indicate a significant difference (p<0.05) between two modalities.

Discussion: Using the 32-channel coil and an acceleration factor R=3 allowed to save 19.5±5% in total scan time compared to R=2 (14.2±2.4 min) while producing similar quality data compared to the 12-channel coil with R=2. Using 32-channel coil arrays is thus beneficial for 4D flow-sensitive imaging of the thoracic aorta. While these figures are only based on one-dimensional GRAPPA, developments in fast imaging techniques (e.g. parallel imaging, compressed or sparse sensing) can be expected to further support the use of such coils.

References: 1.Bogren Hg, et al. J Thorac Cardiovasc Surg 1995;110, 2.Napel S, et al. J Magn Reson Imaging 1992;2, 3.Buonocore Mh. Magn Reson Med 1994;31, 4.Griswold Ma, et al. Magn Reson Med 2002;47, 5.Johnson Km, et al. Magn Reson Med 2008;60, 6.Tsao J, et al. Magn Reson Med 2003;50, 7.Reeder Sb, et al. Magn Reson Med 2005;54, 8.Schmitt M, et al. Magn Reson Med 2008;59, 9.Bernstein Ma, et al. Magn Reson Med 1998;39, 10.Quarteroni A, et al. Comput Visual Sci 2000;2