Adaptive Navigator Gated Time-Resolved 3D MR Velocity Mapping at 3T: Assessment of Normal and Pathological Vascular Anatomy and Blood Flow

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Introduction: Time-resolved 3D MR-velocity mapping offers the opportunity to assess blood flow with true 3D and temporal coverage. However, previous implementations and data analysis strategies suffered from incomplete respiration control [1, 2], limited SNR [3] and lack of advanced 3D visualization of vasculature and hemodynamics [4].
Here, we present an image acquisition and data processing strategy for which the optimal use of combined anatomical and functional information is coupled with advanced respiration control and imaging at 3T for improved SNR and scan efficiency. Pure respiratory gating with typical acceptance windows of 4-6mm would result in unacceptably long scan times or insufficient spatial resolution. To increase navigator efficiency, a wider data acceptance window (12-14mm) was used and potential respiration artifacts were minimized by real time adaptive k-space reordering [5-7]. For the evaluation of 3D blood flow, phase contrast MR angiography (PC-MRA) data and spatially co-registered three-directional blood flow velocities were derived from the same data set. Results from volunteer and patient examinations demonstrate the potential for visualization of normal and pathological time-resolved 3D blood flow with high detail.

Methods: All examinations were performed on a 3T system (TRIO, Siemens, Germany) using an 8-element phased array body coil. Data were acquired in a sagital oblique 3D volume that included the entire thoracic aorta (spatial resolution = (2.4-3.8 x 1.6-2.1 x 3.0-4.5) mm^3) using a rf-spoiled gradient echo sequence with interleaved 3-directional velocity encoding ($\alpha = 15°$, venc=150cm/s, TE =3.7ms, TR = 6.1ms, temporal resolution = 48.8ms). Measurements were performed during free breathing and prospectively gated to the ECG cycle. Data within a pre-selected navigator acceptance window were used to generate real time estimates of the respiratory position which was then translated into phase encoding amplitudes such that the final data set appeared to be collected during a single fraction of the respiration cycle (figure 1). In addition, the navigator acceptance window was dynamically adapted to the maximum respiratory position to provide stable scan efficiency even for noticeable changes in respiration patterns.
A 3D PC-MRA data set was derived from the magnitude and velocity data by calculating the weighted sum of absolute velocity images of individual time-frames with background suppression by magnitude weighting. 3D visualization (EnSight, CEI, NC, USA) included velocity vector fields mapped onto user-selected planes, 3D stream-lines, and time-resolved 3D particle traces (path of virtual particles over the cardiac cycle) [8].

Results: Adaptive navigator gating with scan efficiencies ranging between 60-80% was successfully performed for all examinations and kept overall scan times at acceptable levels (15-19min) while allowing for improved temporal resolution compared to previous studies [1,3]. No major respiration artifacts such as ghosting or severe image blurring were seen in the acquired volunteer and patient data sets.
Figure 2 shows exemplary 3D visualization results for a volunteer, including the semi-transparent 3D PC-MRA representation of the thoracic aortic geometry which aids the visual assessment of spatially co-registered 3D blood flow. Normal blood flow during systole including initial filling of the supra-aortic braches as well as accelerated blood flow in the descending aorta can clearly be appreciated. No disturbances in flow patters such as vortex formation or altered flow profiles were seen in normal subjects.
In contrast, changes in local blood flow patterns could be identified in a patient with a mild stenosis in the left proximal subclavian artery but otherwise normal aortic geometry (figure 3). The corresponding vascular segment could be identified using 3D PC-MRA iso-surface rendering and demonstrated marked flow acceleration through the luminal narrowing (solid arrows) while other vascular regions showed no disturbances in 3D blood flow if compared to the volunteer data.

Discussion: Results from volunteer and patient experiments in the thoracic aorta illustrate the feasibility of time-resolved 3D MR velocity mapping at 3T for the simultaneous assessment of 3D vascular anatomy and time resolved 3D blood flow characteristics. Adaptive navigator gating could successfully be used to compensate for motion artifacts and permits the use of wider gating window and thus increased scan efficiency. However, due to the basic principle of adaptive gating (i.e. phase encoding as a function of the respiration phase) some residual blurring and thus degradation of spatial resolution is unavoidable and further studies with inter- and intra-subject evaluation are necessary to investigate the optimal trade-off between gating window and scan efficiency. 3D MR velocity mapping has great potential to benefit from higher field strength since it is largely insensitive to susceptibility effects and rf-power deposition and the gain in SNR is directly translated in reduced noise in the velocity encoded images.

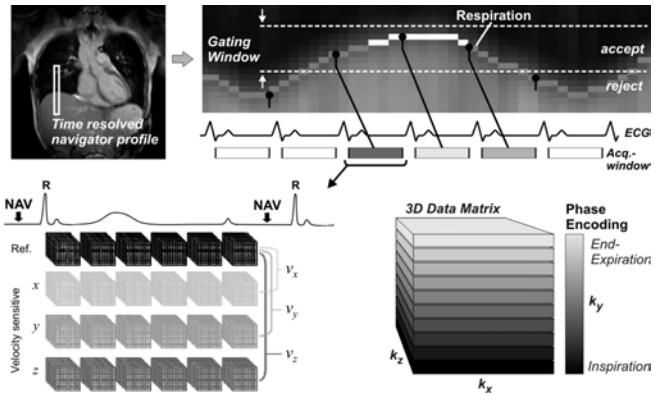

Fig. 1: Schematic illustration of respiration control (adaptive navigator gating) and synchronization with the cardiac cycle (interleaved three-directional velocity encoding and prospective ECG gating). The late diastolic navigator signal (NAV) of the lung-liver interface is used for prospective respiration estimation. Data within the acceptance range are sorted into k-space according to their respiratory position as schematically indicated for differently gray shaded sections of 3D k-space (lower right).

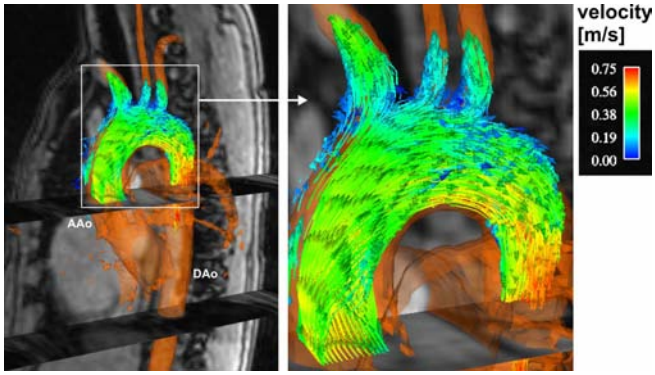

Fig. 2: 3D particle trace visualization of systolic (t_{ECG} = 195ms) blood flow in the ascending aorta (AAo), aortic arch and distal descending thoracic aorta (DAo). Initial filling of the supra-aortic vessels can clearly be appreciated. Semi-transparent 3D iso-surface rendering of PC-MRA data assists in blood flow visualization by defining vessel boundaries in 3D.

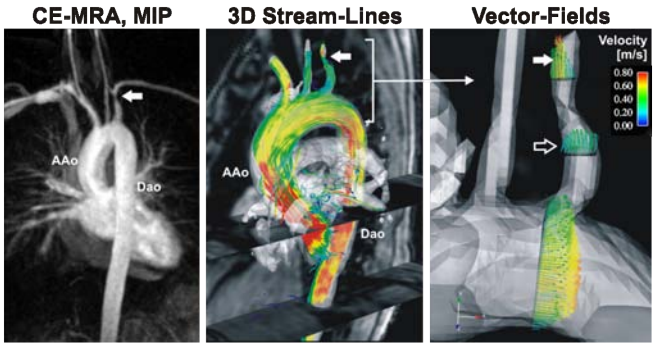

Fig. 2: Vascular geometry and hemodynamics for a patient with a mild stenosis in the left proximal subclavian artery as shown by contrast enhanced MRA (left, arrow). 3D PC-MRA data (gray shaded semi-transparent iso-surface) in conjunction with 3D stream-lines (mid) permit the 3D depiction of systolic blood flow within the entire thoracic aorta, already indicating flow alteration due to luminal narrowing (arrow). Systolic velocity vector fields placed in the aortic arch and left subclavian artery illustrate the potential for detailed analysis of local flow profiles at any location within the 3D data set. Marked flow acceleration distal to the stenosis (solid arrow) is clearly visible if compared to flow profiles before the stenosis (open arrow).

References:

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