Accelerated high-resolution 3D magnetic resonance angiography using SENSE: fast and accurate assessment of carotid artery stenosis in ApoE ko mice

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INTRODUCTION Mouse models of atherosclerosis are widely used for studying atherogenesis. This has led to an enhanced interest in non-invasive imaging of mice, e.g. using high resolution MRA for detecting atherosclerotic plaques. However, high resolution MRA is hampered by long acquisition times putting high demands on the physiological stability of the animal. Parallel imaging technique strategies such as SENSE [1] in combination with high resolution 3D-MRA represent a possible solution to overcome this problem, however at the expense of reduced SNR. Since small animal MRA is inherently hampered by low sensitivity, we have evaluated to what extent acceleration of data acquisition might affect detection and accuracy of the morphometric assessments of vascular lesions. The aim of this work was to implement a SENSE based high resolution 3D ToF MR angiography protocol for analyzing vascular lesions in murine supra-aortic vessels. Angiograms obtained from fully sampled data sets were quantitatively compared to those obtained from accelerated acquisitions. The analysis comprised morphometric assessments of stenotic lesions and investigation of the degree of stenosis (DoS), as well as correlation of the various MRA readouts with histological data.

METHODS All *in vivo* experiments were carried out on a Bruker Pharmascan 47/16 (Bruker BioSpin MRI, Ettlingen, Germany) small animal MR system operating at 200 MHz using a volume resonator operating in quadrature for excitation and a four element (2x2) phased array surface coil for signal reception. The experiments were performed using five male apolipoprotein E knock-out (*ApoE*$^{-/-}$) mice in strict adherence with the Swiss law for animal protection. Data acquisition was performed using a flow-compensated 3D gradient echo sequence with acquisition parameters: FOV=17x19x20mm^3, spatial resolution=80x80x80µm^3, pulse angle=80°, TE/TR=3.7/70ms. Data sets were collected without acceleration and with acceleration along both phase encoding directions resulting in net acceleration factors (R) of 2.0, 2.6 and 3.3. Coil sensitivity maps were estimated from separate 3D low resolution scans. Reconstruction was performed on a separate workstation using in-house software written in IDL (RSI, Boulder, USA). DoS were calculated as the ratio of cross-sectional area at stenosis and proximal site, respectively. In order to investigate the effect of accelerated data collection on the DoS, the mean deviation of DoS (ΔDoS) from reference (DoS for R=1.0) was calculated according to:

$$\Delta DoS = \frac{1}{N}\sum_{i=1}^{N}\frac{\left|DoS_{R,i} - DoS_{Ref,i}\right|}{DoS_{Ref,i}} \cdot 100$$

where $DoS_{R,i}$ is defined as the degree of stenosis for acceleration factor R (R=2.0, 2.6, 3.3) and $DoS_{Ref,i}$ as the degree of stenosis for acceleration factor 1.0 for each animal i.

Furthermore, the vascular cross-sectional area was determined at different levels with respect to the stenosis to assess the effect of accelerated data collection on the visualization of vessel stenoses. In addition, MRA readouts were compared with results obtained from histopathological examinations.

RESULTS Vessel representation was only weakly compromised for the data recorded using accelerated acquisition when compared to the reference MIP: stenoses could be reliably depicted even for acceleration factors of 3.3 (Fig.1). Quantitative morphometric analysis was carried out for stenotic lesions: analysis of vascular cross-sectional areas (lumen area) at various levels relative to the stenosis yielded consistent values with regard to the non-accelerated acquisition for all investigated acceleration factors (Fig.2a). Calculation of ΔDoS over all animals revealed mean deviations of DoS from reference (DoS values for R=1.0) of less than 5% (Fig.2b).

Similar profiles of cross-sectional areas across the stenotic lesion were found for MRA and histology: even the stepwise changes in vascular diameter on the side distal to the lesion were detected by both modalities (Fig.3a). A correlation analysis (slope of linear regression and R^2-values) of absolute values of lumen areas revealed values being on average smaller by a factor of 2 for the histological evaluation when compared to the cross-sectional areas obtained from MRA (Fig.3b). Despite discrepancies in absolute measures of vessel cross-sectional areas, there was good correlation between MRA and histology regarding the DoS (Fig.3c).

DISCUSSION High resolution 3D-MRA (voxel: 80x80x80µm^3) of the aortic arch, subclavian and carotid arteries in mice was successfully accelerated using SENSE. The reduced SNR of the accelerated data sets had only minor effects on image quality and the subsequent morphometric analyses for vessels of an average diameter > 250µm. Even for R=3.3 (corresponding to a reduction in acquisition time from 69 to 21 min.), all lesions could be reliably detected. Morphometric analysis revealed that accelerated data acquisition did not reduce the accuracy of assessing lumen areas and stenotic degrees of atherosclerotic lesions for acceleration factors up to 3.3. Smaller lumen areas in histological analyses are most probably due to tissue shrinkage during the histological preparation [2].

REFERENCES [1] Pruessmann, KP, et al., MRM; 42:952-962, 1999, **[2]** Cook, NS, et al., Cardiovasc Res; 28(2):215-220, 1994

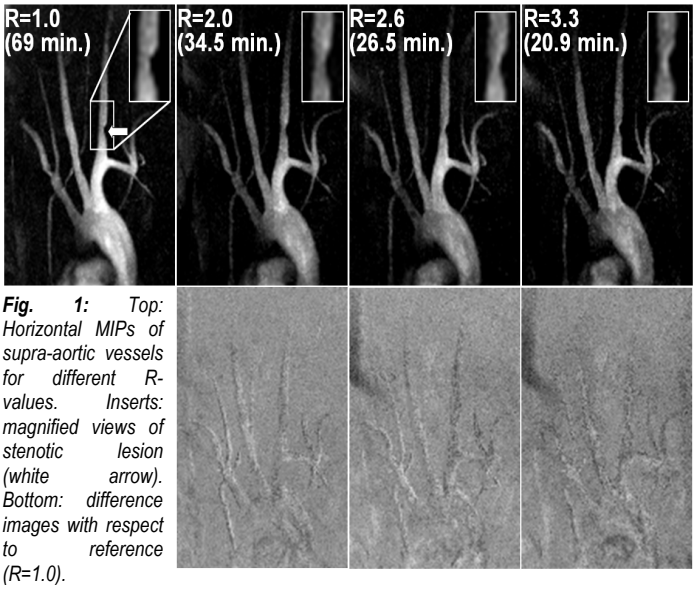

Fig. 1: Top: Horizontal MIPs of supra-aortic vessels for different R-values. Inserts: magnified views of stenotic lesion (white arrow). Bottom: difference images with respect to reference (R=1.0).

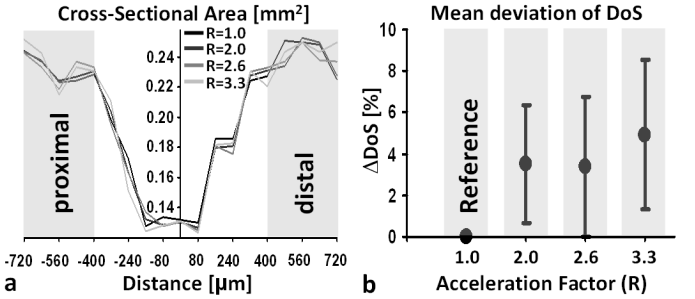

Fig. 2: (a) Morphometric analysis of cross-sectional areas at various levels relative to the stenosis for R=1.0,2.0,2.6,3.3. (b) ΔDoS for all investigated acceleration factors R.

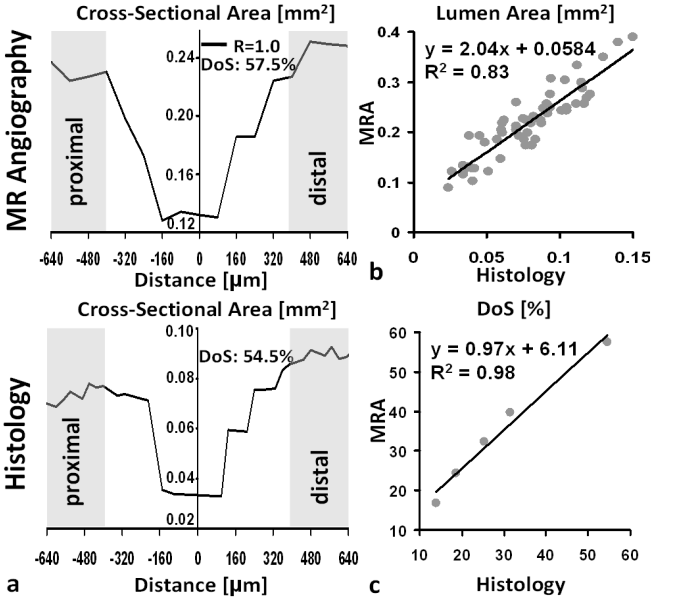

Fig. 3: (a) Morphometric analysis of cross-sectional areas at various levels relative to the stenosis for MR angiography (top) and histology (bottom) for one representative animal. Correlation of MRA with histology for vessel lumen area (b) and DoS (c).