Flow Velocity Measurement in the Carotid Bifurcation Using 4D Flow-Sensitive MRI and Doppler Ultrasound

A. Harloff[1], T. Zech[1], F. Wegent[1], S. Bauer[1], M. Schumacher[1], and M. Markl[1]
[1]University Hospital Freiburg, Freiburg, Baden-Württemberg, Germany

Introduction: Conventional digital subtraction angiography (DSA) is the reference method for the calculation of the degree of internal carotid artery (ICA) stenosis. However, the frequent poststenotic vessel dilatation and the fact that measurements are merely based on morphological criteria hamper measurement accuracy. Although time-resolved contrast-enhanced MR angiography provides both dynamic and morphological information its accuracy is still limited in high-grade ICA stenosis. As the current reference standard, Doppler ultrasound (US) provides an assessment of stenosis severity based on quantitative blood flow velocities considering multiple direct and indirect stenosis criteria (i.e. pre-, intra- and poststenotic velocity data, side-to-side comparison) and reaches the diagnostic accuracy of DSA for the assessment of ICA stenosis.

Flow-sensitive 4D MRI offers the opportunity of retrospective quantification of flow parameters at any location in the entire carotid bifurcation and may help to improve the diagnostic performance of MRI. In a recent study a small number of volunteers and patients were examined by both 3D MRA and US.[1] However, this study focused only on the common carotid artery of healthy volunteers and the spatial resolution of 4D flow-sensitive MRI for the measurement of blood flow velocities was limited. It was the purpose of this study to apply an improved MRI protocol to the carotid bifurcation in a larger cohort of 51 volunteers and patients. To systematically evaluate the performance of flow-sensitive 4D MRI, reproducibility and inter-observer variability were tested in a subgroup of 10 volunteers. Moreover, MRI results were compared to Doppler ultrasound.

Methods: 32 healthy volunteers (age 25.3±3.4 years) without a history of cardiovascular disease were included. Furthermore, 19 patients with a local degree of ICA stenosis ≥70% in Doppler ultrasound were measured before and after surgical removal of the carotid plaque. Doppler ultrasound was performed using a 7-12 MHz linear array scanner (Logiq 7, GE).

Flow-sensitive 4D-MRI at 3 Tesla (Siemens Trio, flip angle = 15°, TE/TR = 3.1/5.7 ms, venc = 150 cm/s, resolution = 1.1 x 0.9 x 1.4 mm³, slab thickness = 50.4 mm, 36 slices per slab) was used to assess time-resolved 3D blood flow. Data processing included corrections for concomitant gradients, eddy current and velocity aliasing. For quantification, seven analysis planes were manually positioned in the common (CCA), external (ECA), and internal (ICA) carotid artery as shown in figure 1. For each analysis plane, manual vessel segmentation was performed and velocity-time curves of mean and maximum velocities were calculated.

MRI examination (time between scans: 5-6 months) and data analysis was repeated in 10 healthy volunteers in order to calculate reproducibility and inter-observer reliability. Data obtained by MRI and US in the CCA and distal ICA were compared using the approach by Bland and Altman.

Results: Absolute blood flow velocities could be successfully obtained for all analysis planes distributed along the carotid bifurcation in a systematic fashion as displayed in Figure 1 (summary of the findings of all normal 64 carotid bifurcations). Typical shapes of the flow velocity curves over time and particularly the dampening of the flow curves during the passage though the bulbic ICA region can clearly be appreciated. Also, the typically higher pulsatility of the CCA and the external carotid artery (ECA) compared to the ICA was found. The high consistency of the data is reflected by the small error bars representing inter-individual variations, which is confirmed by good reproducibility and low inter-observer variability in MRI as summarized in figure 2. Comparison of blood flow velocities between MRI and ultrasound are given in Figure 3.

Discussion: Measurement of carotid blood flow velocities was successfully performed along the entire carotid bifurcation in healthy volunteers and patients using flow-sensitive 4D MRI. We obtained typical velocity-time curves and pulsatility for the specific vessel segments within the carotid artery bifurcation. The underestimation of maximum systolic blood flow velocities by MRI is most probably due to the currently inferior spatial and temporal resolution compared to US. Future data regarding flow velocities and pulsatility ratios within the CCA, ICA and ECA will be analyzed shortly. The overall good agreement of systolic and particularly diastolic blood flow velocities point to the potential to combine both morphologic and functional information on occlusive carotid artery diseases in order to perform a non-invasive and optimized assessment of ICA stenosis. Further potential clinical applications include the quantification of cerebral perfusion by measuring blood volume over time in both internal carotid and vertebral arteries.

Acknowledgements: Grant support: DFG, Grant # MA 2383/4-1 and Bundesministerium für Bildung und Forschung (BMBF), Grant # 01EV0706.

References: 1. Harloff A et al. Magn Reson Med. 2009;61:65-74.

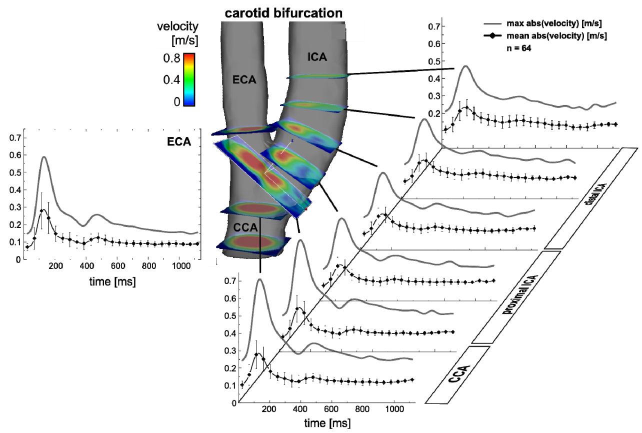

Figure 1: Average velocity-time curves for all evaluated analysis planes in the common (CCA), internal (ICA) and external (ECA) carotid artery. The lines, data points and error bars represent mean velocities and standard deviations over 64 carotid arteries of the 32 healthy volunteers.

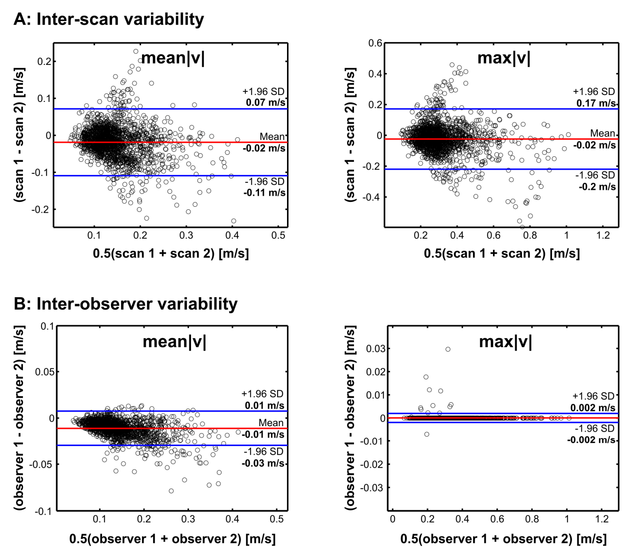

Figure 3: Reproducibility (A) and inter-observer variability (B) in 10 volunteers (20 carotid bifurcations) for velocity data in seven analysis planes as shown in figure 1.

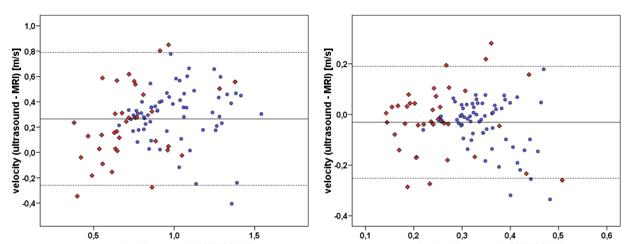

Figure 4: Bland-Altman plot comparing systolic (left) and diastolic (right) flow velocity measurements in the common carotid artery in 64 carotid bifurcation of the healthy volunteers (blue points) and in 25 carotid bifurcations of patients with ICA stenosis (red squares) before and after recanalization therapy. Mean underestimation of MRI for systolic flow velocities was approximately 33% while MRI values were only ca. 10% higher compared to ultrasound in terms of diastolic blood flow velocities.