Carotid Intima-Media Thickness and Distensibility Measured by MRI at 3T Versus High-Resolution Ultrasound

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Introduction: Increased intima-media-thickness (IMT) of the common carotid artery (CCA) represents atherosclerotic wall changes and is a strong predictor for future cardiovascular events [1]. The carotid distensibility coefficient (DC) is the most reliable parameter for the assessment of carotid stiffness and can be calculated considering maximum diameter change over the cardiac cycle and central blood pressure [2]. The combination of DC with IMT allows for a comprehensive analysis of the individual atherosclerotic burden and improved prediction of aortic atherosclerosis [3]. Both parameters are easily obtained by ultrasound (US). Due to the limitations of US such as observer-dependency, two-dimensional nature of data, and only rough plaque characterization, however, MRI is increasingly used for the detailed analysis of early and advanced stages of carotid atherosclerosis [4, 5]. In contrast to previous MRI studies [5-8] our protocol provided a combined high-resolution assessment of both carotid wall thickness and distensibility at 3 Tesla.

Methods: 32 healthy volunteers (absence of cardiovascular risk factors, history of cardiovascular events, inflammatory vessel disease) and 20 patients with high-grade internal carotid artery stenosis ≥70% were prospectively included. Systolic and diastolic arterial blood pressure were monitored during MRI and ultrasound.
Ultrasound: The CCA was assessed using a 7-12 MHz linear-array probe (Logiq 7, GE Healthcare, USA) by one trained sonographer (Fig. 1 A and B). Carotid compliance was determined in M-mode (Fig. 2 A) as described in a previous study [3] and expressed by the distensibility coefficient DC = $(2\ \Delta d/Dd)/\Delta P\ 10^{-3}$/kPa where Δd is the change in diameter, Dd the end-diastolic diameter, and ΔP the pulse pressure. Pulse pressure (ΔP) was calculated as systolic - diastolic blood pressure.
MRI: MRI measurements were performed on a routine 3T MRI system (TIM TRIO, Siemens, Erlangen, Germany) using a combined 12-element head and 6-element neck coil. Time-of-flight (volunteers) or contrast-enhanced MR angiography (patients) were used to position an axial 3D volume for 3D T1 CINE-imaging (prospective ECG gating, temporal resolution 73.6 ms, voxel size = 0.9x0.7x0.8 mm^3, TE /TR = 1.872ms / 3.8 ms; α = 15°) and 2D dark blood T2-imaging (20 slices, in-plane pixel size = 0.4x0.4 mm^2, slice thickness = 3 mm, TE / TR = 89ms / 5230 ms; refocusing α = 140°) covering the CCA of both sides. Carotid compliance in MRI was calculated analogously to ultrasound. A commercially available software (AquariusNet, TeraRecon, San Mateo, USA) permitted interactive definition and angulation of 2D analysis planes within the 3D volume (Fig. 2 B, C). MRI imaging was repeated in 10 volunteers providing 20 CCA images and enabled calculation of reproducibility, intra- and inter-observer agreement.

Results: US and MRI data of all subjects are given in Table 1. Wall thickness measured by MRI was significantly higher compared to US (p<0.01). This difference was more pronounced in healthy volunteers compared to patients. For carotid distensibility in seven patients values of MRI were considerably higher compared to those in US. However, excellent agreement of both techniques was observed for DC in the 32 healthy volunteers.
For MRI measurements of wall thickness confidence intervals for reproducibility, intra- and inter-observer agreement were: mean 0.056, 95%CI: ±0.004 cm; mean 0.055, 95%CI: ±0.004 cm; mean 0.055, 95% CI: ±0.006 cm, respectively. For the calculation of distensibility coefficient using MRI confidence intervals for reproducibility, intra- and inter-observer agreement were: mean 39.3, 95%CI: ±15.8; mean 39.0, 95%CI: ±12.6; mean 40.2, 95%CI: ±16.6 10-3/kPa, respectively.

Discussion: Both 2D dark blood T2 weighted and 3D T1 CINE imaging were successfully performed with high image quality using 3 Tesla MRI in this study. The combined measurement of morphological and functional properties of the CCA wall allows a more detailed characterization of the carotid arteries compared to the measurement of wall thickness alone. Such an analysis has the potential to precisely assess the vessel wall for longitudinal studies e.g. testing the influence of lipid lowering therapy. Furthermore, this combined measurement strategy could be applied to predict complex aortic plaques in patients with ischemic stroke as recently shown for carotid ultrasound. In contrast to previous 2D studies on carotid compliance by MRI, 3D T1 CINE sequences allow for the analysis of local compliance at every site of the carotid bifurcation and could be ideally combined with current protocols for the characterization of the morphology of ICA stenosis.

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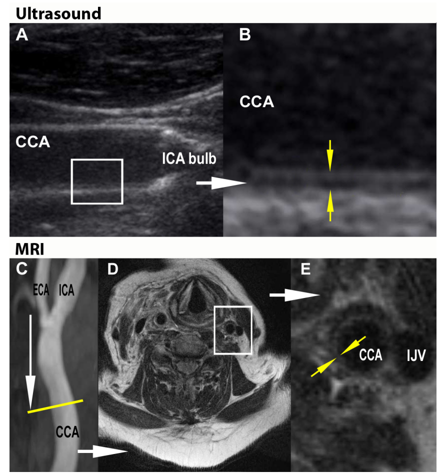

Fig. 1. Measurement of IMT and wall thickness in one patient. Ultrasound: (**A**) Longitudinal overview and measurement of IMT 2 cm proximal to the carotid bifurcation. (**B**) Magnification shows increased IMT (yellow arrows). MRI: A comparable measurement site was identified by TOF-angiography (**C**). Axial slides in T2-weighted imaging were positioned 2 cm distal to the bifurcation (**D**). The thickened dorso-medial wall was measured in magnification (yellow arrows) (**E**). ICA=internal carotid artery, ECA = external carotid artery, IJV = internal jugular vein.

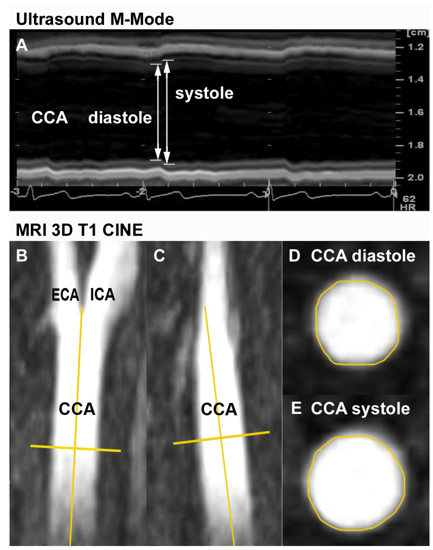

Fig. 3. Measurement of carotid compliance in one volunteer. Ultrasound: (**A**) CCA diameter change in M-mode 2 cm proximal to the bifurcation and determination of maximum systolic and end-diastolic diameter.
MRI: Reconstructed longitudinal view (**B**) and perpendicular view (**C**) of the carotid bifurcation based on reformatted 3D T1 CINE images. Interactive definition of axial planes 2 cm proximal to the bifurcation provided minimum and maximum vessel area during end-diastole (**D**) and early systole (**E**).
Image quality for ultrasound and MRI was graded excellent.

Characteristic	US	MRI	MRI – US [%]	P value
Wall thickness— (cm)				
Volunteers—n = 31	0.04±0.01	0.06±0.01	50.0	<0.001
Patients—n = 16	0.09±0.02	0.12±0.02	33.3	<0.001
All subjects—n = 47	0.06±0.03	0.08±0.03	33.3	<0.001
DC —(10^{-3}/kPa)				
Volunteers—n = 31	41.3±7.4	41.6±9.0	0.7	n.s.
Patients—n = 7	15.2±5.7	26.4±6.5	73.7	0.13
All subjects—n = 38	36.5±12.5	38.8±10.4	6.3	n.s.

Table 1. Comparison of carotid wall thickness and compliance measured by ultrasound (US) and MRI for all subjects assessable by both techniques. Values are mean ± SD. DC = distensibility coefficient, MRI – US [%]: positive values = higher MRI values, n.s. indicates not significant.