Three-dimensional multi-contrast assessment of the aortic wall at 3 Tesla

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Purpose: Despite complete routine diagnostics, the etiology of stroke remains cryptogenic in ca. 30% of the patients [1]. As a result, optimal secondary prevention is hampered and the detection of previously overlooked sources of cerebral embolism is of high interest. Previous studies have shown, that an additional MRI of the thoracic aorta is able to detect additional complex aortic plaques (i.e. ≥4 mm thick, ulcerated or containing superimposed mobile thrombi) in ca. 30% of patients with otherwise cryptogenic stroke etiology [2]. Here, we present a novel multi-contrast 3D MRI protocol comprising bright-blood T_1-weighted (T1W); dark-blood T_2-weighted (T2W) and proton density-weighted (PDW) images that allows the thorough assessment of the entire thoracic aorta in a clinically feasible time. Accuracy of this protocol was tested in both volunteers and stroke patients with aortic atherosclerosis.

Methods: Study population: Eleven acute ischemic stroke patients (seven males and four females, mean age 73.2±8.6 years) admitted to the stroke unit of our institution and eleven healthy volunteers (eight males and three females, mean age 28.2±6.2 years) were included into this MRI study. Inclusion criteria for patients were an age >50 years and cryptogenic stroke etiology despite completed routine diagnosis. Healthy volunteers had to have no history of retinal or cerebral ischemia. **MR-imaging:** All measurements were performed on a clinical routine 3T MRI (Magnetom Tim Trio, Siemens Healthcare, Erlangen, Germany). The complete 3D multi-contrast protocol was acquired with electrocardiogram (ECG) triggering in combination with short data acquisition (≤ 240ms) in end diastole in order to minimize blurring due to vessel motion. Data acquisition was performed with navigator gating (bright-blood T1W) or navigator triggering (black-blood T2W and PDW) with data acceptance window = ± 2.5 mm in end-expiration. The complete 3D multi-contrast protocol has the same geometric parameters: FOV (read×phase) 264×240 mm^2, matrix=256×178, 56 partitions resulting in a nearly-isotropic spatial resolution of 1.15×1.15×1.17 mm^3.

	Method (RARE- or turbo-factor)	TE/TR [ms]	Flip angle	Acceleration
T1W bright-blood	3D GRE (39)	1.62/6.1	12°/V-FL	GRAPPA (*R*=2)
T2W black-blood	3D SPACE (80)	103/AvRC*	90°/V-FL	Elliptical scanning
PDW black-blood	3D SPACE (84)	23/AvRC*	90°/V-FL	Elliptical scanning

Table 1: Parameters of MR pulse sequence used for plaque detection and characterization. *AvRC = average duration respiratory cycle

The modified American Heart Association (AHA) classification was used for grading atherosclerotic plaques. The multi-contrast 3D datasets were graded by two independent physicians with a minimum experience of three and six years in reading aortic plaque MR images. Subsequently, intra- and inter-observer variability was evaluated. The multi-contrast three-dimensional datasets were graded in three standardized planes perpendicular to the aortic lumen and located in the ascending aorta, aortic arch and proximal descending aorta respectively at the level of the pulmonary trunk. For each plane, image quality was graded using a 5-point scale. Vessel wall definition (i.e. percentage of vessel wall which is detectable with a high level of certainty) was 0 = not assessable (≤50.0%), 1= poor (>50-62.5%), 2= moderate (>62.5-75.0%), 3= good (>75-87.5%), 4= excellent (i.e.>87.5% of the wall circumference was assessable at high image quality).

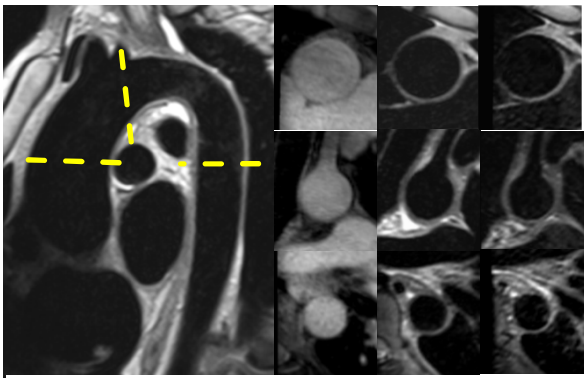

Fig. 1: Multi-contrast MRI in 3 representative planes: T1W (first column), T2W (second column), PDW (third column).

Results: The entire three-dimensional multi-contrast combined bright/black-blood protocol was successfully performed in all 22 subjects. Total examination time of the complete 3D multi-contrast combined bright/black-blood was 25:35±7:05 min (range 16:36 - 44:56 min) which is compatible with clinical investigations. Representative MR images from a 27-year old male volunteer are displayed in Fig. 1. Three representative image planes (3D reformat) in the ascending aorta, aortic arch and descending aorta that were used for data scoring are represented for all three available contrasts. The T1W bright-blood images depict highly homogeneous luminal signal. The blood flow is efficiently suppressed in the T2W and PDW images allowing clear depiction of the aortic wall. Optimal adjustment of diastolic data acquisition windows and navigator gating (T1W images) or navigator triggering (T2W and PDW images) resulted in motion artefact free images. Exemplary results for plaque detection and characterization for one calcified plaque (type VII) and a mobile thrombus (type VI) are represented in Fig. 2.

Inter- and intra-observer variability was quantified using three representative planes in ascending aorta, aortic arch and descending aorta as explained in the Methods section. Representative results for percentage of observed agreements, percentage of data scored in agreement with the highest score and weighted kappa are represented in Table 2.

	Observed agreements	Agreement with highest score	Weighted Kappa
Inter- AAo	54.1 %	40.5 %	0.473
Inter- Aortic Arch	70.3 %	67.6 %	0.434
Inter- DAo	82.4 %	60.1 %	0.463
Intra- AAo	85.1 %	60.8 %	0.771
Intra- Aortic Arch	94.6 %	86.5 %	0.783
Intra- DAo	100 %	97.3 %	1

Table 2: Results of inter- and intra-observer variability.

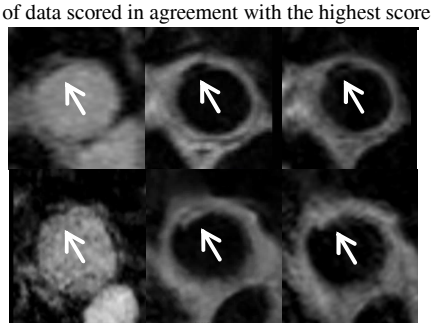

Fig. 2: Plaque detection and characterization with multi-contrast MRI: calcified plaque (type VII) represented in the first row and a mobile thrombus (type VI) in second row.

Discussion/Conclusion: This study demonstrates the feasibility of multi-contrast 3D MRI at 3 T for the assessment of the wall of the entire thoracic aorta in both volunteers and stroke patients. In addition, it was possible to detect and characterize aortic plaques in several patients. In comparison to previous MR studies of the aorta who were primarily based on 3D T1 sequences with additional 2D T2W and PDW sequences at the site of aortic atheroma, the present protocol provides 3D T1W, T2W and PDW sequences in all subjects. This allows a more comprehensive detection of plaques; measurement of both plaque thickness and volume and due to the redundancy of multiple contrasts a higher reliability of image reading. Efficient luminal signal suppression in T2W and PDW 3D images allowed for clear depiction of vessel wall and consequently plaque identification. Due to the combination of bright- and black-blood sequences as used here such errors in discrimination flow artefacts and atheroma is very unlikely and, therefore, an advantage compared to earlier protocols. Accordingly, differentiation between plaque and flow artifacts becomes more reliable and follow-up examination and assessment of plaque progression should be more accurate and reproducible. Image quality regarding the reading of the aortic wall at predefined sites throughout the thoracic aorta was good as determined by two independent readers. However, imaging of ascending aorta remains more challenging due to cardiac and respiratory motion as showed by the number of observed agreements. Typically, the standardized planes in the aortic arch and in the descending aorta were graded with higher scores then the ascending aorta.

References: [1] Harloff A *et al*., Stroke 2006; 37:859-864. [2] Harloff A et al., J Neurol Neurosurg Psychiatry. 2008; 79:540-546.

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