Ultra-high field MRI of aortic plaques in a rabbit model: initial experience and comparison between 1.5T, 3T and 7T

Claudia Calcagno[1], Martin J Willemink[2], Bei Zhang[1], Hadrien Dyvorne[1], Philip M Robson[1], Olivier Lairez[1], Bram F Coolen[3], Gustav J Strijkers[4], Tim Leiner[2], Venkatesh Mani[1], Willem JM Mulder[1,3], and Zahi A Fayad[1]

[1]Department of Radiology, Icahn School of Medicine at Mount Sinai, New York, NY, United States, [2]Department of Radiology, University Medical Center Utrecht, Utrecht, The Netherlands, Netherlands, [3]Department of Radiology, Academic Medical Center, Amsterdam, The Netherlands, Netherlands, [4]Department of Biomedical Engineering and Physics, Academic Medical Center, Amsterdam, The Netherlands, Netherlands

TARGET AUDIENCE: Investigators interested in vascular ultra-high field MRI.

PURPOSE: Atherosclerosis is a chronic disease characterized by the accumulation of lipids, cells and fibrous tissue in the vessel wall of medium and large arteries. Rabbits are a well-established pre-clinical model of aortic atherosclerosis[1-2]. Using conventional 1.5 and 3T whole-body clinical scanners, MRI has been already extensively validated to quantify plaque burden in rabbits[3-5]. Accurate quantification requires imaging with 1) high in-plane spatial resolution, to clearly delineate the vessel wall from the lumen and other neighboring tissues (i.e. lymphnodes); 2) high signal to noise ratio (SNR) in the atherosclerotic vessel wall, and 3) high contrast-to-noise ratio (CNR) between vessel wall, lumen and surrounding tissues. On conventional 1.5T and 3T scanners these parameters can be further optimized at the expense of increased acquisition time. Because of the intrinsically higher signal, vessel wall, imaging at 7T can result in a significantly increased spatial resolution, while maintaining adequate SNR, CNR and imaging time[6-7].In this pilot study, we compared vessel wall SNR and CNR between1.5T, 3T and 7T field strengths using both 2D and 3D MR sequences, while keeping imaging parameters and acquisition time fixed across different scanners.

Table 1: Imaging Parameters	2D						3D	
		LR			HR		LR	HR
	T1	T2	PD	T1	T2	PD	T2 SPACE	
Number of slices		5			1		30	44
Echo time (TE, ms)	6-8	41-42	6-8	7-10	42-44	7-10	77-80	75-78
Repetition time (TR, ms)	1000	5000		1000	5000		1600	
Spatial resolution (mm²)		0.5			0.3		0.6	0.42
Slice thickness (mm)			2				0.6	0.42
Number of averages		1		2	1		1	4
Acquisition time (mm:ss)	2:50	14:10	14:10	1:38	4:10	4:10	2:42	16:29

METHODS: Atherosclerosis was induced in 3 New Zealand White (NZW) rabbits by a combination of high cholesterol diet and double balloon injury of the abdominal aorta[1-2]. Animals were imaged on 3 consecutive days. At 1.5 and 3T, images were acquired using a commercially available15 channel knee coil for signal reception[3-5], while at 7T a custom made, transmit/receive, 12 channel coil was used. At each field strength, axial 2D T1-, T2- and PD-weighted turbo spin echo (TSE) and sagittal 3D T2-weighted SPACE[8] (sampling perfection with application-optimized contrast with different flip-angle evolutions) images were acquired to characterize the atherosclerotic vessel wall. All sequences were acquired both at the lower spatial resolution (LR) used in previously developed 1.5 and 3T protocols[1-5], and at higher spatial resolution (HR), for improved vessel wall/lumen delineation. For 2D sequences, 5 slices were acquired for LR, while 1 slice only was acquired for HR. For 3D sequence 30 slices were acquired for LR, while 44 were imaged for HR. **Imaging parameters and imaging time for the same sequence were kept constant across field strengths (Table 1).To facilitate signal and noise measurements across different field strengths and imaging hardware (such as gradients and the receiving coil), no parallel imaging acceleration was used.** After acquisition, regions of interest (ROIs) were drawn on each acquired axial slice to encompass the atherosclerotic vessel wall, the vessel lumen and, as a measure of noise, an ROI was drawn in the air surrounding the rabbit. Slice-by-slice SNR was calculated by dividing the average signal of the vessel wall by the standard deviation of the noise ROI. Slice-by-slice CNR between the vessel wall and lumen was calculated as $SNR_{Vessel\_Wall} - SNR_{Lumen}$. For each sequence, the median SNR and CNR across field strengths were compared.

Figure 1: 2D T2W

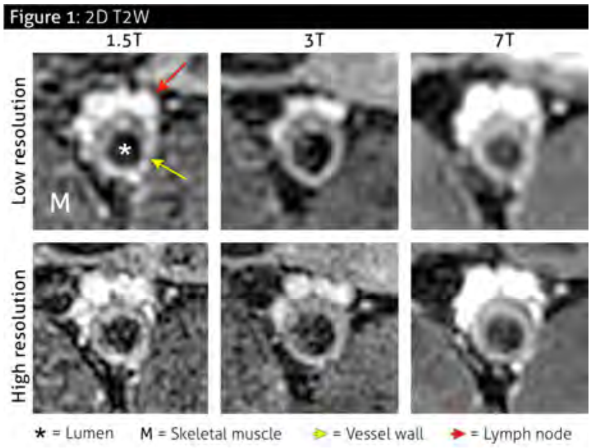
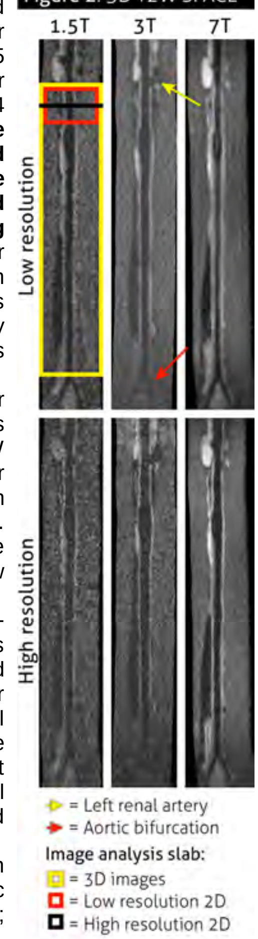
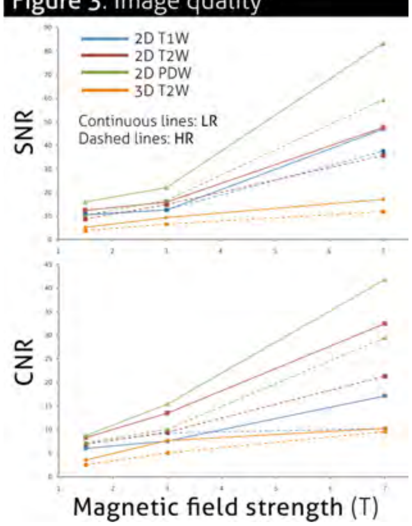


Figure 2: 3D T2W SPACE



RESULTS: Figure 1 depicts representative low and high resolution images of the arterial vessel wall at all field strengths for 2D T2W TSE (matching imaging slice). **Figure 2** shows representative MPRs (multi planar reconstructions) of both low and high spatial resolution 3D T2W SPACE at all field strengths. In both figures, 7T images show markedly higher image quality and SNR, and better delineation between the vessel wall, lumen and neighboring structures, particularly for the high-resolution acquisition. Quantitative analysis (**Figure 3**) revealed that vessel wall SNR and CNR were substantially higher at 7T with respect to both 1.5T and 3T, for both high and low resolution images.

Figure 3: Image quality



DISCUSSION and CONCLUSION: This study demonstrates feasibility of high-resolution, high SNR imaging of the aortic vessel wall in atherosclerotic rabbits on a clinical 7T MR scanner. Given the substantial gain in vessel wall SNR and CNR on the 7T scanner, we foresee that this approach will allow for higher spatial-resolution, high quality imaging of the arterial vessel wall. This will facilitate the more accurate quantification of plaque burden. Alternatively, the gain in image quality may allow reducing acquisition times at 7T without compromising vessel wall SNR and CNR. Longitudinal studies with histological validation are currently being performed to validate if the aforementioned translates in improved monitoring of atherosclerosis progression.

REFERENCES:1. Calcagno C et al, ATVB 2008; 2.Chen J et al. Magn Reson Med 2013; 3.Lobatto ME et al Mol Pharm 2010; 4-5 Vucic E et al, Jacc Cardiovascular Imaging 2011 and 2012; 6. Kroner E et al, Invest Radiol 2012; 7.Rotte A et al Invest Radiol 2014; 8.Fan Z J Magn Reson Imaging 2010.