High Resolution Imaging of Brain Vessels at 7 Tesla

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INTRODUCTION

Atherosclerosis is a condition in which the vessel walls thicken as the result of the deposit of lipids and fibrous elements. MRI appears as a method of choice to measure non-invasively total plaque volume and reliably identify the morphologic features of the vulnerable plaque. MR imaging of intracranial atherosclerosis, however, remains a challenge, given the small size of the vessels and their localization deep in the brain. Furthermore, blood and CSF signal suppression is required to eliminate signals originating from the lumen and from spaces surrounding the vessels. Brain vessel wall MRI has been demonstrated [1,2], but the spatial resolution utilized so far makes it difficult to assess contrast or structure *inside* the wall thickness. Optimizing acquisition parameters in the context of low signal to noise is difficult. In this report we describe the initial implementation of a multi modality approach, which will investigate both ex-vivo and in-vivo achievable cerebral vessel MR, limits in terms of contrast and spatial resolution. A high field of 7 Tesla was chosen to benefit from expected gains in Signal to Noise Ratio (SNR) and tissue contrast. The initial target for ex-vivo study was the circle of Willis excised from human cadaver brains displaying atherosclerosis plaques in different locations. Direct comparison with virtual histology intravascular ultrasound (VH IVUS) was used to validate the plaque morphology on MR images. Initial vessel MR images on healthy volunteers at 7 Tesla are shown.

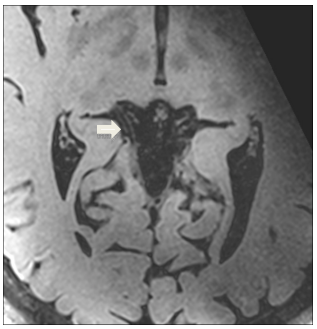

Figure 1. In vivo MR image of the distal PCA vessel wall (arrow).

METHODS

Sample preparation *(*Human brain cadaver) Cadaver cerebral circulation was perfused with saline and 10% formalin through a carotid artery. The whole brain was removed after excising carotid arteries at the supraclinoid segment and intracranial segments of vertebral arteries. The circle of Willis (CW) was removed from brain after excising perforators, M2 segments, A2, segments and P2 segments. ***Ex-vivo MR Imaging*** Prior to imaging, CW samples placed between two plastic plates with a spacer between the plates immersed in a rectangular box (125x98x3mm^3) filled Fomblin [3] (perfluoro-polyether, Solvay Solexis). Fomblin does not possess water proton, thus only signal from the sample was measured in the latter case. A volume coverage head coil [4] (16 transceiver channels) was used for excitation and reception. To improve signal to noise ratio, signal was also received on a home built preamplifier-decoupled (Microwave tech) 2-loop receive coil (5cm each) made out of 12 gage silver plated copper wire on which the sample box was directly positioned. In preliminary experiments with multi-echo T_2 and multi-TI IR sequences, average T_2 and T_1 values of the vessel walls at 7T were estimated to be ~35ms and ~1400ms respectively. In order to preserve similarity between ex-vivo and typical in-vivo acquisition, the SPACE sequence was used in both cases [5]. Ex-vivo 3D images were obtained with two sets of parameters: (1) TR/TE = 3000/60 ms, FOV = 95mm*119 mm*10.4 mm, Echo Train Length (ETL)= 14, GRAPPA =2. Scan duration: 7 h 33 min, acquisition resolution =(0.13mm)^3. (2) TR/TE = 1500/52 ms, FOV = 95mm* 191mm* 8.28 mm, Echo Train Length (ETL)= 14, GRAPPA =2. Scan duration: 12 min, acquisition resolution =(0.23mm)^3. ***Ultrasound*** (***VH IVUS)*** Vessel was connected to a fluid pump. IVUS catheter (Eagle Eye Gold, 20 MHZ Digital, 64 Bement, s5 Imaging System, Volcano Corp.) was inserted in the distal end of the vessel. Then virtual histology was performed while the catheter slowly pulled back using a pullback device. An electrocardiogram simulator was used to trigger the virtual histological data acquisition. ***In Vivo MR Imaging*** Healthy volunteers who provided informed consent were imaged at 7 Tesla with the same 16 transceiver array used to image the samples. High resolution obtained with the SPACE sequence with: FOV=320 mm *320 mm, TR/TE/TI= 3000/22/1100 ms, acquisition time: 13 min and acquisition resolution: (0.64 mm)^3. The slab of 12mm was positioned with the help of TOF images.

RESULTS

Our initial results suggest that high resolution (0.13mm x 0.13mm x 0.13mm) images allow for clear distinction of vessel boundaries. *The presence of a necrotic core and calcification is expected to give low signal in MRI.* A visual comparison between MR images and virtual histology may correspond to the depiction of different plaque components visible in MR images. In vivo images were acquired with the same sequence and the same system successfully showed cancellation of blood and CSF signal to depict vessel wall boundaries.

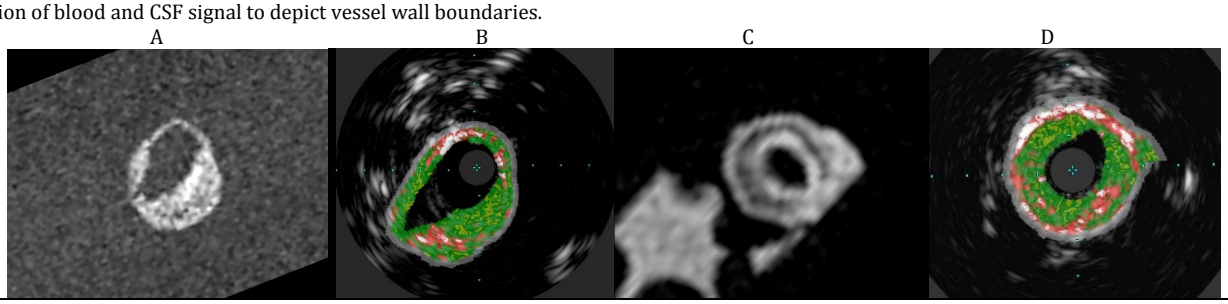

Figure 2. Comparison between MR images at two different acquired spatial resolution and VH IVUS of excised Circle of Willis. The color code in virtual histology is: white = dense calcification, red=necrotic core, green = fibrous area, light green= fibro-fatty component **A.** MR image acquired with a 0.13mm isotropic resolution with the setup (1). **B.** Corresponding VI IVUS image. **C.** MR image acquired with a (0.23mm)^3 resolution with the setup.(2). A 3D interpolation was performed to bring the reconstruction resolution to 0.12mm isotropic. **D.** Corresponding VH IVUS image of the vessel on the right in C.

DISCUSSION

Our goal is to ultimately provide rationales to optimize contrast and spatial resolution tradeoff in clinical protocols aiming at imaging intracerebral arteries within limits of scanning time acceptable for neurological patients. Several specificities of the current study generate a favorable context to explore the limits of vessel wall imaging in humans: 1) samples are imaged with the same sequences and on the same system used for in-vivo studies, facilitating sequence and parameter transfer, 2) histopathology will be directly compared with MR images. First results on healthy volunteers show the feasibility of sequence parameter transfer from ex-vivo to in-vivo.

REFERENCES: [1] Ryu CW et al., Proc. ISMRM (2010). [2] Zwanenburg et al. ISMRM 2010 p1811. [3] Benveniste H et al. ,NeuroImage *11*, 601–611 (2000) [4] Adriany G et al., MRM. *59*, 590–597 (2008) [5] Mugler JP et al., ISMRM 12, 695 (2004).

Acknowledgment: P41 RR008079, S10 RR026783 KECK Foundation, R21 EB009133