High-resolution Ultra-short TE Imaging of ex vivo Human Carotid Plaques Correlates with CT

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INTRODUCTION: Carotid plaques are currently evaluated with multicontrast MR (1), in which T1W, T2W and PDW images are acquired, permitting the categorization of plaque components with the expectation that tissue characterization can lead to better risk assessment of plaque rupture (2). However, calcifications, which are known to affect plaque stability (3), are simply identified as signal voids in all images and may be missed when dealing with endoluminal calcium. Previously, a comparison between ultrashort-TE (UTE) imaging and CT was presented (4), which showed a rough correlation between signal in the UTE images and CTs. In this work, we use a high-resolution UTE imaging sequence (5) to examine *ex vivo* human carotid samples. For comparison and confirmation, high resolution CT images were also acquired.

METHODS: MRI: Five human cadaveric carotid samples were imaged repeatedly. Frozen samples stored at -80ºC were thawed for imaging at room temperature. The samples were then preserved in 10% formaldehyde and the scans were repeated. The samples were imaged on a 3T Achieva system (Philips Medical Systems, Best, The Netherlands) with enhanced gradient hardware (max gradient 60 mT/m) using a 4 cm solenoid coil (Philips Research Europe, Hamburg, Germany). Briefly, the UTE sequence uses a non-selective short RF pulse for excitation. An FID is acquired, starting in the center of k-space, followed by a multi-echo readout. k-space is traversed using a 3D radial trajectory in which profiles cover a sphere with homogeneous angular density, permitting the reconstruction of 3D datasets with isotropic spatial resolution. Imaging was performed using either a previously described single-echo sequence repeated multiple times with different in-phase TEs (5) or with a multi-echo variant which applied an EPI-style readout. Typical scan parameters for single-echo acquisitions were: FOV 45mm^3, α=10°, TR/TE$_0$= 25/0.05 ms repeated for 2.3 and 6.9ms, 2 averages at a bandwidth of 265Hz/pixel, total scan 1h15min, 90% filled radial sampling matrix (relative to Nyquist sampling rates). Images were reconstructed using a 224^3 matrix, yielding an isotropic resolution of 200µm. For 5-echo multi-echo acquisitions, imaging parameters were: FOV 52mm^3, α=10°, TR/TE$_0$/ΔTE=23/0.08/2.3ms, 31min total scan, 200% filled radial sampling matrix. Images were reconstructed using a 128^3 matrix and an isotropic resolution of 400µm. CT: Multi-slice CT datasets were acquired with a Brilliance 16P CT system (Philips Medical Systems, Cleveland, OH) using a high resolution temporal bone protocol designed for fine delineation of small structures. Acquisitions were performed at 120 kV, 225mA, 16x0.75mm collimation, 0.6 relative pitch and 0.5 s gantry rotation speed. Images were reconstructed with 0.70 mm slice thickness, spaced 0.35 mm apart and using a 768x768 matrix with a FOV of 10.5cm, yielding a reconstructed spatial resolution of 0.137x0.137x0.700 mm³.

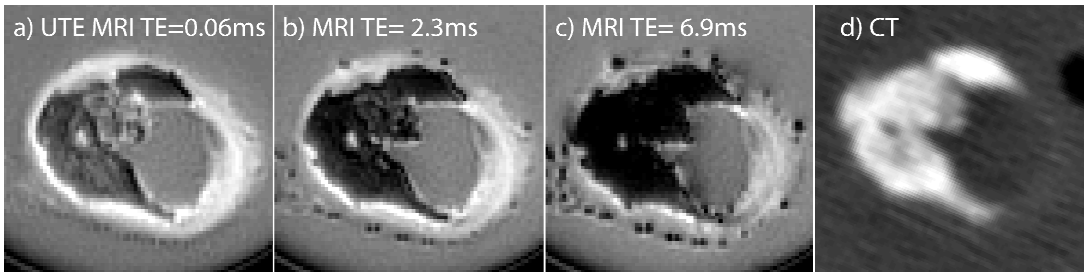

Figure 1: (a) Ex vivo images of human carotid sample acquired with the high-resolution Ultra-short TE (UTE) imaging sequence, and the corresponding in-phase echoes (b,c). The signal from the calcified plaque is clearly identifiable and confirmed by the CT (d). Note the low proton density and lack of signal from the calcification in the longer TE images. The MR images have an isotropic spatial resolution of 200µm. The CT image has a resolution of 137x137x700µm.

RESULTS: As seen in Fig 1, the signal from the calcified regions disappears in images with longer TEs. Since plaques are heterogeneous structures, soft tissue structures with longer T2 and T2* values are also observed in the image. Note that the UTE images more contrast the CT images, particularly when concerning the surrounding soft tissue components of the vascular wall (Fig 2).

DISCUSSION AND CONCLUSIONS: This work demonstrates high-resolution MR capturing signal from calcium deposits within plaques. The comparison with CT images, the gold standard for calcium imaging, had remarkable spatial correlation. The use of UTE reveals that normal imaging, with longer TEs (e.g. 2.3ms or 6.9ms) is not sufficient to detect the signal from calcium deposits within plaques. Furthermore, UTE, a 3D technique, seems to be essential to image calcified regions as it increases the SNR and improves visualization of tissues with low proton density. Sufficient spatial resolution was necessary to avoid partial volume and blurring effects that obscure or corrupt the signal from calcium. This type of UTE scan could be used to obtain more information about plaque structure, thereby permitting better rupture risk assessment, when combined with the current multicontrast approach to plaque characterization. Though highly correlated, the UTE images displays better soft tissue contrast in the plaque than do CT images. In conclusion, UTE is promising for MRI-based plaque characterization. Further work is required to assess the feasibility of these acquisitions *in vivo*, given the resolution necessary to avoid partial volume effects typically seen in the current measurements of calcium load and ultimately for the determination of a calcium score equivalent.

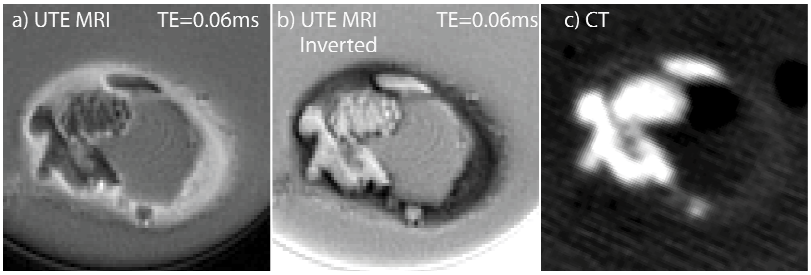

Figure 2: The high-resolution UTE image (a) can be displayed with an inverted colormap (b), yielding an image with remarkable similarity to CT (c) but with better soft-tissue contrast. Note air bubble in CT image.

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