High-resolution multi-parametric characterization of atherosclerotic lesions with 3T intravascular MRI

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Audience. Cardiologists, radiologist and interventionalists interested in vessel disease.

Purpose. The identification of plaque components is crucial for distinguishing early and advanced vascular disease, and its progression and/or management with intervention (1). With adequate spatial resolution, MRI could potentially characterize and image vessel T1, T2, proton density (PD), and plaque lipid burden. Today, resolution of 80-300 μm is possible with high-field intravascular MRI (IVMRI) (2). Here, we combine high-resolution IVMRI with a novel B1 self-correcting ‘Tri-Flip-Angle’ (Tri-FA) method, to provide water T1, T2, PD, and fat images, to yield a truly multi-parametric view of human vessel specimens at 3T.

Methods. IVMRI experiments were conducted on a clinical 3T Philips system with a receive-only loopless antenna (2) inserted into the lumens of autopsied human iliac and carotid artery specimens immersed in a tank of body-equivalent (3.5 g L⁻¹) saline.

The Tri-FA method acquires three steady-state signals (S1-3) using a spoiled gradient echo sequence (SPGR; repetition time TR=636 or 651ms; flip-angles θ1-3=30°, 80°, 140°; 3D voxel size =0.2x0.2x1.6mm³ or 0.27x0.27x5mm³). A 4th signal, S4, is acquired with a long (τ=10ms) 0° BIR4 prepulse (with FA=θ1) to encode the T2 information (3). The Dixon (4) or chemical-selective saturation (5) methods can be used to image the lipid pool (Dixon: TR=0.2s; TE=4.6, 5.76, 6.91ms; FA=50°; voxel size: 0.2x0.2x3 mm³).

It can be shown that S1-3=M0(1-E1)sin(q.θ1-3)/(1-E1.cos(q.θ1-3)), where E1=exp(-TR/T1) and q reflects the B1 field inhomogeneity. S4=M0(1-E1).sin(q.θ1)Ep2./(1-E1.cos(q.θ1).Ep2) with Ep2=exp(-0.72.τ/T2). T1, T2, M0, and q are solved from S1-4. PD maps and water/fat images are corrected for the ~1/r dependence of the receiver’s sensitivity. The method was validated against standard partial saturation and multi spin-echo T2, T1 and PD images in phantoms and specimens.

Fresh and formalin-fixed human artery segments (predominantly iliac and carotid) were imaged. Histological sections are obtained for comparison.

Results. Examples of Tri-FA T1, T2, PD maps and a Dixon water/fat image in one specimen are shown in Fig.1(a-d). Vessel components are characterized into 3 major groups based on the measured T1, T2, PD values (Fig.1e) with mean and standard deviations (SD) listed in (Table 1), corresponding to smooth muscle (blue), non-calciﬁed lesion (green) and ﬁbrosus cap (purple).

Discussion. Multi-parametric high-resolution T1, T2, PD and fat images of human vessels are provided for the first time, using minimum-acquisition IVMRI, self-corrected for field inhomogeneity. The maps, taken together, offer the potential for differential characterization of key plaque components, and optimization of MRI sequence contrast to detect them. Chemical-selective imaging can provide unambiguous detection of lesion lipid content not possible by existing vascular imaging methods. Extending IVMRI technology in vivo (2) could offer new opportunities for detecting vessel disease, its progression, and response to intervention.


Fig 1. (a-c) 200 μm resolution, color-coded Tri-FA T1, T2, PD maps and (d) Dixon fat image (blue) overlaid on the water image of a slice of a human iliac artery specimen obtained from an intravascular loopless antenna p. (e) 3D plot of T1, T2 and PD values of sampled points in three types of vessel components (blue, green, purple) from four vessel segments. Mean and SD T1, T2 and PD values of the three groups are shown in the Table 1. Some of the sampled points are marked on Fig1(a). Note that this vessel segment does not include the purple component.

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