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 T_1, T_2, proton density (PD), and plaque lipid burden. Today, resolution of 80-300μm is possible with high-field intravascular MRI (IVMRI) (2). Here, we combine high-resolution IVMRI with a novel B_1 self-correcting 'Tri-Flip-Angle' (Tri-FA) method, to provide water T_1, T_2, 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 ($S_{1\text{-}3}$) using a spoiled gradient echo sequence (SPGR; repetition time TR=636 or 651ms; flip-angles $\theta_{1\text{-}3}$=30°, 80°, 140°; 3D voxel size =0.2x0.2x1.6mm^3 or 0.27x0.27x5mm^3). A 4th signal, S_4 is acquired with a long (τ=10ms) 0° BIR4 prepulse (with FA=θ_1) to encode the T_2 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 mm^3).

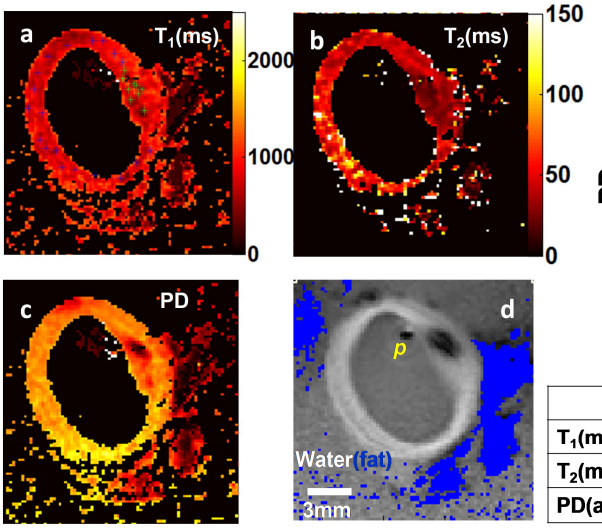
It can be shown that $S_{1\text{-}3}=M_0(1-E_1)\sin(q.\theta_{1\text{-}3})/(1-E_1.\cos(q.\theta_{1\text{-}3}))$, where $E_1=\exp(-TR/T_1)$ and q reflects the B_1 field inhomogeneity. $S_4=M_0(1-E_1).\sin(q.\theta_1)E_{p2}./(1-E_1.\cos(q.\theta_1).E_{p2})$ with $E_{p2}=\exp(-0.72.\tau/T_2)$. T_1, T_2, M_0, and q are solved from $S_{1\text{-}4}$. 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 T_2, T_1 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 T_1, T_2, 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 T_1, T_2, PD values (Fig.1e) with mean and standard deviations (SD) listed in (Table 1), corresponding to smooth muscle (blue), non-calcified lesion (green) and fibrous cap (purple).

Discussion. Multi-parametric high-resolution T_1, T_2, 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.

References. 1. Stary HC et al. Circ 1995; 92: 1355-74. **2.** El-Sharkawy AM et al. Med Phys 2008; 35:1995-2006. **3.** Wang G et al. J Magn Reson 214(2012): 273–280. **4.** Glover GH et al. Magn Reson Med 1991;18(2):371-383. **5**. Bottomley et al Lancet 1984; 323: 1120.



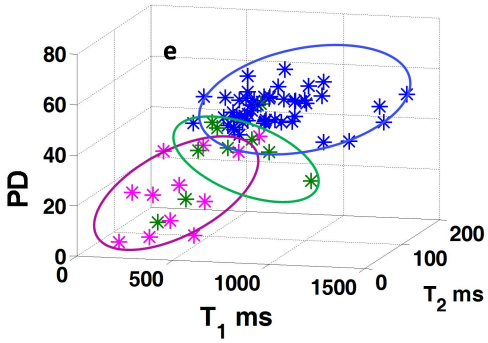


Table 1. Measured parameters mean ±SD

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T_1(ms)	935±315	743±222	492±206
T_2(ms)	60±27	24±5.7	25±8.8
PD(arbitrary unit)	56±7	40±14	25±15

Fig 1. (a-c) 200 μm resolution, color-coded Tri-FA T_1, T_2, 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 T_1, T_2 and PD values of sampled points in three types of vessel components (blue, green, purple) from four vessel segments. Mean and SD T_1, T_2 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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