Automated classification of vessel disease based on high-resolution intravascular multi-parametric mapping MRI

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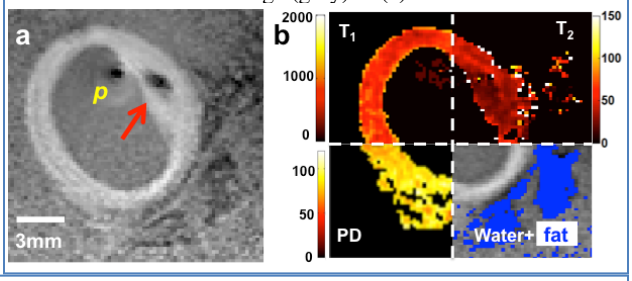
Audience. Cardiologists, interventionalists dieticians interested in the quantitative characterization of vessel disease.

Purpose. Distinguishing early and advanced vascular disease is crucial in assessing disease status, its progression and the effect of interventions, dietary and environmental factors (1). With high-field (3T) intravascular MRI (IVMRI) (2) probes, high-resolution (~200µm) multi-parametric vessel mapping is now feasible (3). Given such spatial resolution, MRI could potentially characterize the disease stage with measures of T_1, T_2, proton density (PD), and lipid. Here, multi-parametric images from an extended population of vessel specimens were acquired and used to train an automatic classifier, to test whether combined T_1, T_2, PD and lipid images could be used to stage vessel disease. Automatic disease classification was then performed, and its accuracy compared with histological observations.

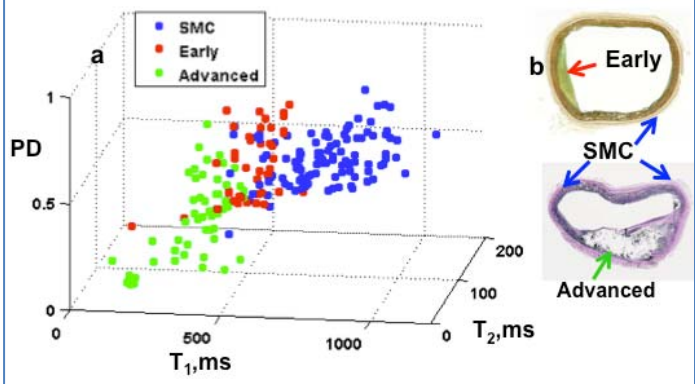
Fig 1. (a) 200 µm "Four-FA" S_2 SPGR image of a human iliac artery acquired with an IV MRI loopless antenna, *p* (red arrow=early lesion). (b) Combined color-coded 200 µm T_1(ms), T_2(ms), PD(units=% vs H_2O) maps and Dixon fat image (blue) over-laid on the water image (gray) in (a).



Methods. IVMRI experiments were conducted on a 3T *Philips* system with a loopless antenna (1) inserted into the lumen of autopsied human iliac and coronary artery specimens (fresh or formalin fixed) from cadavers with varying stages of cardiovascular disease. T_1, T_2 and PD were measured using "Mix-TSE" (4)(2D or 3D; voxel: 0.2x0.2x2mm^3, TSE factor=2, TE_1=29ms, TE_2=100ms, TR_1=1s, TR_2=2.26s) or "Four flip-angle" (FA) methods. The Four-FA method (5) acquires four (S_{1-4}) steady-state spoiled gradient echoes (SPGR; TR=636 or 651ms; flip-angles =30°,80°,140°,30°; 0° BIR4 prepulse =10ms; voxel: 0.2x0.2x1.6mm^3 or 0.27x0.27x5mm^3). "Dixon" (TR= 0.2s; TE=4.6, 5.76, 6.91ms; FA=50°; voxel size: 0.2x0.2x3 mm^3) or chemical-selective saturation methods were used for lipid imaging.

The multi-parametric maps were used to train an automatic disease stage classifier based on a support-vector-machine (SVM) (6) model (3 classes, tolerance=0.05, linear kernel). The accuracy of the classifier prediction was tested by "leave one out" cross validation (7), using histological sections (Movat and VVG staining) as ground truth. The trained classifier can be applied to automatically classify disease in vessel specimens.

Fig. 2. (a) 3D plot of T_1, T_2 and PD values from 3 stages of vessel disease: SMC (blue), and early (red) and advanced (green) lesions from eight vessel segments based on histology exemplified in (b). The SVM classifier was trained using the data in (a).

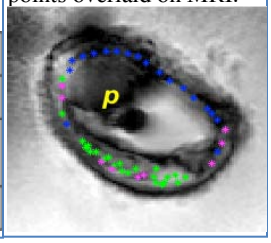


Results. Examples of T_1, T_2, PD maps and a water/fat image in one specimen are shown in Fig.1. Randomly sampled data points on vessel walls from 8 vessel segments are characterized into 3 groups based on histology (Fig.2a), corresponding to smooth muscle cells (SMC; blue, "S"), early lesion (red, "E") and advanced lesion (green, "A"). The T_1 and T_2 of non-calcified formalin fixed tissue were reduced ~20% and were omitted from the analysis. The cross validation testing results (Table 1) indicate that the SVM correctly classified 89-93% of SMC and advanced lesions. Test results exemplifying automatic tissue classification in a vessel are shown on a T_1 weighted MRI in Fig.3.

Table 1. "Leave one out" cross validation results of automatic lesion stage SVM classifier compared to true histology class.

	S	E	A
Histology classification	105	43	54
Correctly classified (automated)	93	25	50
misclassified	**12**	**18**	**4**

Fig 3. Classification points overlaid on MRI.



Discussion. In human specimens, IVMRI-based high-resolution T_1, T_2, PD and fat imaging could be used to automatically distinguish early and advanced vessel disease from healthy and smooth muscle. Multi-parametric MRI affords a quantitative means of staging vessel disease, which, if extended *in vivo* could offer a means of automatically documenting the stage of vessel disease and its response to intervention, diet modification etc.

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., Proc. ISMRM (2014), 2534. **4.** den Kleef JJE et al. Magn Reson Med 1987;5(6):513-524. **4.** Wang G et al. J Magn Reson 2014; 242: 243-255. **6.** Cortes et al. Machine learning 1995;20(3):273-297 **6.** Amari, S-I., et al. Neural Networks, IEEE Transactions 1997;8(5): 985-996. Grant support: R01 EB007829.