Real-time intravascular MRI endoscopy at 3T

S. Sathyanarayana[1], M. Schär[2,3], M. Solaiyappan[2], and P. A. Bottomley[1,2]

[1]Electrical and Computer Engineering, Johns Hopkins University, Baltimore, Maryland, United States, [2]Radiology, Johns Hopkins University, Baltimore, Maryland, United States, [3]Philips Healthcare, Cleveland, Ohio, United States

Introduction. Until now, interventional MRI employing internal detectors relied entirely on the scanner's fixed external gradient system so that the signals were intrinsically locked to the laboratory frame-of-reference (FoR). A method for high-resolution MRI using active internal probes whose spatial properties are modified to provide localization from the viewpoint of the probe itself, was recently introduced [1]. Because these properties are intrinsic to the probe, they move with it, transforming the MRI FoR from the laboratory to the device, analogous to an endoscope. We now report the implementation of real-time 200µm resolution "MRI-endoscopy" at 3T in diseased human vessel specimens *in vitro*, and in an atherosclerotic rabbit model *in-vivo* with visualization of endoscopic 3D views of the advancing probe. Suspect lesions identified from real-time images are then imaged at 80-100µm resolution *in situ*.

Methods. MRI endoscopy probes with inherently localized sensitivity in an axial "slice" are constructed using a loop catheter transmit/receive coil design with 4 or 5 turns of insulated copper wire, and tuned to 128MHz with a chip capacitor. The coil is interfaced to a Philips 3T scanner using either a 2.8mm diameter UT-85C semi-rigid copper coaxial cable for *in-vitro* studies, or a 0.8 mm diameter biocompatible super-elastic nitinol coaxial cable for intravascular MRI *in-vivo*. The probes are excited with adiabatic BIR-4 pulses [2] (duration, 2-8ms; frequency sweep $\pm$ 15-40 kHz) applied at just 0.25W input RF power, greatly reducing eddy-current coupling and Specific Absorption Rate (SAR), as compared to whole-body MRI excitation [1]. The combined result of the transmit/receive sensitivity is a selected "slice" intrinsically localized about the coil center orthogonal to the cable, with a substantially uniform flip-angle therein. The "slice" is 1.5-4 mm thick out to 3% of the probe's sensitivity. Conventional gradient encoding is used to localize in the other two dimensions, and the intense MRI signals simply relocated to the image center to provide the view from the probehead. Slice orientation is occasionally updated to ameliorate partial volume effects when the probe is skewed relative to B_O.

MRI endoscopy is implemented in real-time with gradient recalled echo (GRE) MRI at up to 4 frames-per-second (fps) and 200µm in-plane resolution. High-resolution (80-100µm) scans (>1min) are then performed where atherosclerotic lesions are suspected. Post-mortem sections are harvested and stained for comparison with MRI. The real-time images, acquired as the probe is advanced, are cross-correlated to ensure alignment and assembled into a progressive 3D set.

In vivo studies are performed on anesthetized hyper-lipidemic Watanabe rabbits that develop atherosclerotic lesions when fed a high-cholesterol diet for up to 90days. The aorta is accessed via a cutdown. After MRI, animals are sacrificed and vessels sectioned to compare with images. Diseased human vessels for *in vitro* studies are obtained from this institution's Autopsy Service.

Results. Endoscopic MRI of a diseased human iliac specimen acquired at 0.7 fps in (Fig. 1a-d) shows a suspect atherosclerotic lesion (Fig 1c), revealed in 100µm images at this location (Fig 1e). The endoscope's sensitivity affords a "forward-looking" capability, as seen at the iliac bifurcation (Fig 1d), and confirmed by surface coil MRI (Fig 1f). Real time *in vivo* endoscopy at 2fps in a Watanabe rabbit (Fig 2a-d) reveals a suspect plaque (Fig 2c), shown in the 80µm endoscopic image (Fig 2e), and Verhoeff-Van Gieson (VVG)-stained post-mortem section (Fig 2f). A 3D rendering of the image series from the rabbit vessel highlights the plaque (Fig. 3).

Conclusion. RF transmission and reception by modified internal probes inherently localizes the MRI signal to the probe-head, creating an MRI endoscope. Real-time implementation at 3T in diseased human specimens *in vitro,* and in a rabbit atherosclerosis model *in-vivo* demonstrates resolution sufficient to detect suspect lesions, that can then be imaged at high-resolution. Thus, 3T MRI endoscopy offers the potential for fast high-resolution intravascular imaging of vascular pathology and morphology.

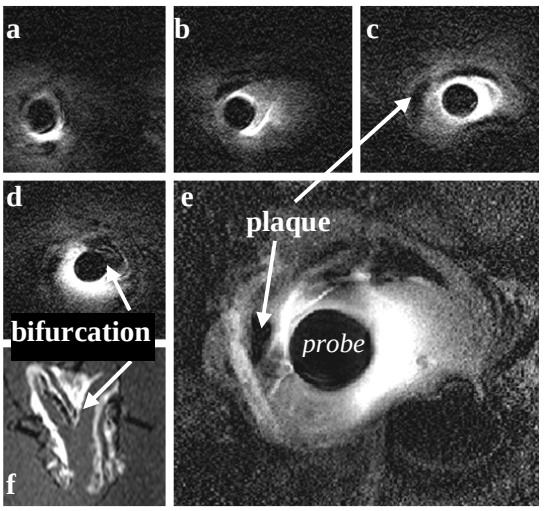

Fig 1. (a-d) 0.7fps MRI of human iliac in saline (TR/TE =13/3ms; 200µm). (e)Plaque from (c) at 100µm resolution. (f) Surface coil image near (d) showing bifurcation.

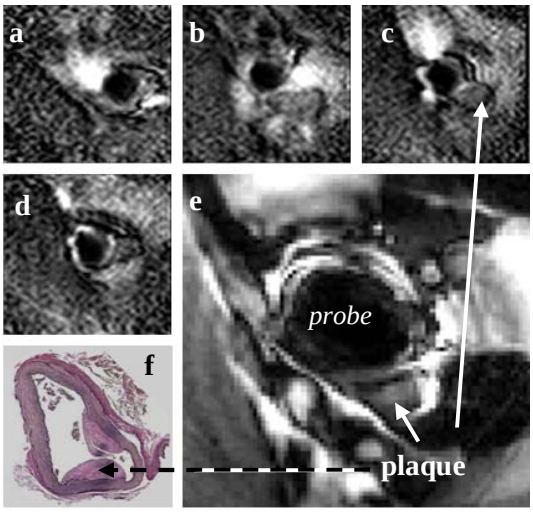

Fig 2. (a-d) 2fps *in vivo* images of rabbit aorta (TR/TE =11/3ms, 200µm resolution). (e)High resolution image (80µm) of plaque (gated,TR/TE=860/21ms). (f)VVG stained histological section.

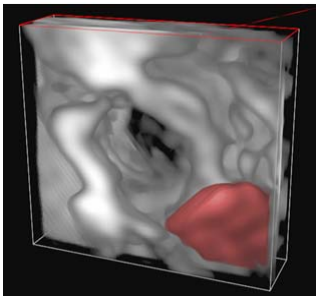

Fig 3. 3D rendering of real-time *in vivo* images. Plaque identified and shaded.

References: [1] Sathyanarayana S, et. al. Proc ISMRM 16, 2008; pp 279. **[2]** Garwood M, Ke Y. JMR 1991; 94:511-525.

Supported by NIH grant R01 HL090728.