Off Resonance Contrast Angiography Using Frequency-Shifting Catheter Coatings

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Introduction: Off Resonance Contrast Angiography (ORCA) is a novel MR imaging method that shows early promise for catheter tracking during endovascular intervention. It relies on a combination of off-resonance frequency-selective excitation and on-resonance frequency-selective presaturation to excite selected concentrations of paramagnetic contrast agent while completely suppressing background tissue signals. We have recently demonstrated the feasibility of passive catheter tracking during MR-guided endovascular procedures by filling the catheter lumen with a dilute gadolinium chelate; the dilute gadolinium shifts the intra-catheter resonance frequency and thereby enables catheter imaging with ORCA. A drawback of this approach is the sensitivity of the gadolinium-induced frequency shifts to catheter orientation. In order to overcome this limitation, we tested the feasibility of using catheter coatings that shift the resonance frequency. Such coatings can be applied in arbitrary shapes that minimize or eliminate the orientation dependence of the frequency shift.

Methods: Imaging was performed on a 16-channel 3 Tesla GE HDx system. Extension tubing was filled with water and bathed in a 1/200 dilution (2.5mM) of gadolinium-DTPA. The ORCA pulse sequence consisted of a magnetization preparation with a 4480 microsecond frequency-selective on-resonance SLR pulse, followed by a 2400 microsecond frequency-selective SLR RF excitation shifted 650 Hz from the center frequency and a standard 3D gradient-echo pulse sequence for data acquisition. A quick-drying epoxy resin was mixed with ultra-small particle iron oxide contrast agent (Ferumoxytol, Advanced Magnetics, Cambridge, MA). The mixture was painted onto one tubing and epoxy without iron oxide onto another **(Figure 1A);** the coatings were allowed to dry for at least 30 minutes before imaging was done.

Results: Neither coating produced signal enhancement with standard MR angiography (MRA) technique; only the Gd-containing water bath was seen in the MRA projection image **(Figure 1B)..** On the other hand, the iron oxide-epoxy coating produced a high degree of focal signal enhancement of the tubing surface and therefore excellent conspicuity when imaged with ORCA, whereas the signal intensities of the water bath as well as the tubing whose mid-section was coated with epoxy without iron oxide were at background noise levels **(Figure 1C)**.

Discussion: MR guidance during endovascular intervention is an area of intense interest and research activity. "Active" tracking methods using small RF coils permit real-time tracking of the catheter tip. However, they require the use of modified catheters, demonstrate only a small length of the catheter, and entail the risk of heating. "Passive" tracking methods are not always capable of displaying the entire catheter length and sometimes produce poor catheter conspicuity on full-thickness projections. Coating techniques used to assist passive tracking have been predicated upon T1-dependent signal enhancement from a gadolinium-based coating[1] or susceptibility-dependent signal loss from implanted dysprosium rings[2]. The mechanism of our technique is entirely different, being based on frequency shifts produced by the coating. We have demonstrated that a thin coating of an iron oxide-epoxy mixture is capable of producing frequency shifts of hundreds of Hz, sufficient for ORCA imaging. The coated region is clearly visualized even on a full-thickness ORCA projection image due to the complete background suppression afforded by the ORCA technique. Our results indicate that the use of frequency-shifting coatings represents a promising new approach for passive catheter tracking.

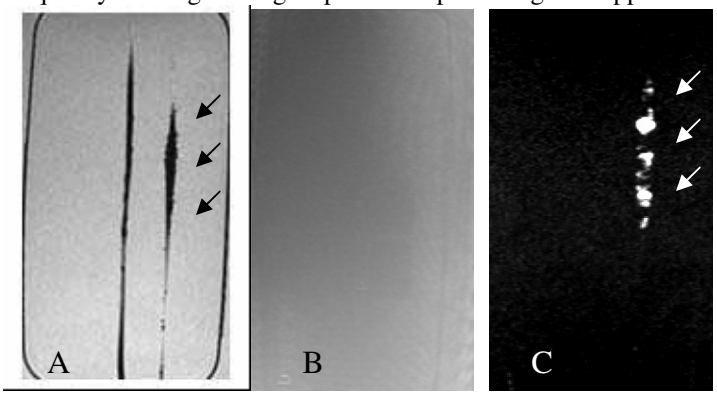

Figure 1. Left tubing has epoxy coating (without iron oxide) in mid-section; right tubing has iron oxide-epoxy coating (black arrows) in mid-section. A) Single MRA slice shows no enhancement from either coating. (Note that neither tubing lies entirely within the single slice.) B) T1-weighted MRA projection image shows signal from water bath but no signal from either tubing. C) ORCA projection image completely suppresses Gd-water bath and shows excellent conspicuity of the iron oxide-epoxy coated section of tubing (white arrows).

[1] Unal O et al. J. Magn. Reson. Imaging 2006;23:763–769.
[2] Brucker A et al. J Vasc Interv Radiol 2001; 12:753–756