Gadolinium-Enhanced Off Resonance Contrast Angiography

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Introduction: We describe a novel physical basis and methodology for gadolinium-enhanced magnetic resonance angiography (MRA), which we call "Off Resonance Contrast Angiography (ORCA)". Unlike standard contrast-enhanced MRA, ORCA contrast depends not on T1 but rather on gadolinium-induced shifts in intravascular resonance frequency due to the bulk magnetic susceptibility effects of gadolinium.

Subjects and Methods: Imaging was performed at 3 tesla using a 16 channel Excite HDx whole body scanner (GE Healthcare, Waukesha, WI). The method was evaluated in phantoms with a range of dilutions of gadolinium-DTPA and ultra-small iron oxide contrast agent. The clinical study was approved by the hospital institutional review board. A total of 11 subjects (ages 19 to 38, three male) were imaged. Several three-dimensional (3D) imaging techniques were tested, including frequency-selective excitation and/or frequency-selective presaturation. For frequency-selective excitation, spatially non-selective Shinnar-Le Roux (SLR) pulses ranging from 2400 to 4000 microsecond duration and excitation flip angles of 5 to 60 degrees were tested. For frequency-selective presaturation, SLR pulses ranging from 4480 to 8320 microsecond duration were tested For phantom imaging, the center frequency of the RF pulse was varied in 50 Hz increments, with a 3D data set acquired for each frequency shift.

Results: Using ORCA, selective imaging of particular gadolinium concentrations with complete background suppression was obtained without image subtraction (Figure 1). This feature may make ORCA particularly attractive as a means for passive catheter tracking during MR-guided endovascular procedures. In human subjects, gadolinium-induced intravascular frequency shifts were measured and found to be in the expected range. ORCA was used to create angiograms of forearm veins comparable in quality to standard contrast-enhanced MRA (Figure 2). In addition, ORCA images of the extracranial carotid bifurcation were successfully acquired during intravenous contrast administration.

Discussion: ORCA represents an entirely new approach for MR angiography using a standard paramagnetic contrast agent. Tissue contrast depends not on T1 relaxation times, but rather on contrast agent-induced shifts in resonance frequency and spectral characteristics of the RF pulses. Despite superficial similarities in the appearance of the vessels to conventional MRA, there are fundamental differences. For instance, complete background suppression is feasible using ORCA without image subtraction. Moreover, contrast enhancement is essentially limited to the vessels with little or no soft tissue enhancement. While the eventual clinical utility is not yet known, potential applications extend beyond MRA, e.g. quantitatiion of tissue perfusion and catheter tracking. However, significant technical restrictions also exist, including dependence on vessel orientation with respect to B_0 and sensitivity to static field inhomogeneities. Further study is needed to determine the practicality of the method and eventual clinical utility.

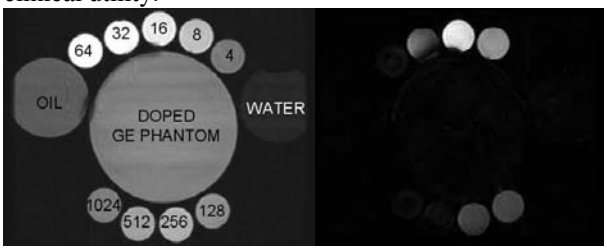

Figure 1. Left: phantom with dilutions ranging from 1/64 to 1/4 of Gd-DTPA (top) and from 1/1024 to 1/128 of ferumoxytol (bottom). Right: Same with spectrally-selective excitation (bandwidth 877Hz) shifted 850Hz from center frequency showing selective imaging of higher concentrations of paramagnetic contrast agent.

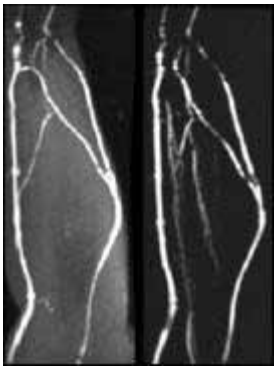

Figure 2. Forearm vein imaging during infusions of 30 ml of 1/12 dilution of gadolinium-DTPA in hand vein. L*eft:* MIP obtained with standard MRA. Right*:* MIP obtained with ORCA. Note improved depiction of the deep veins with ORCA due to complete background suppression.