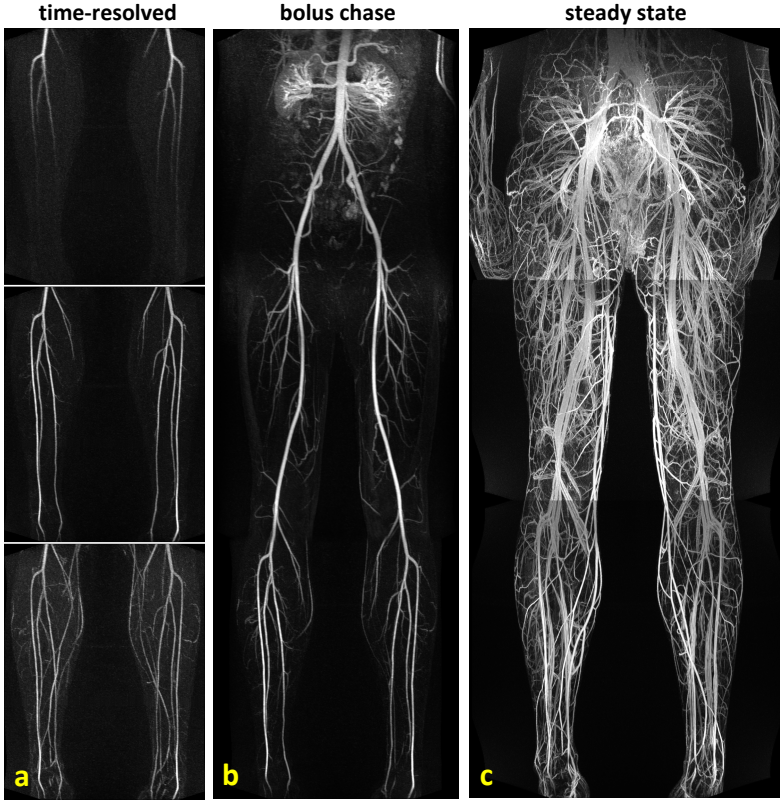
Three-station MR angiography with high-resolution steady-state vascular imaging using ferumoxytol

P. Storey[1], M. T. Bruno[1], R. P. Lim[1], H. Chandarana[1], D. R. Stoffel[1], and V. S. Lee[1]
[1]Radiology Department, New York University School of Medicine, New York, New York, United States

Introduction: Feraheme (ferumoxytol) is an ultrasmall superparamagnetic iron oxide (USPIO) agent that has recently been approved for human use in the United States. Its approved indication is the treatment of iron deficiency anemia in adults with chronic kidney disease. However, its high T1 relaxivity makes it promising for vascular imaging [1,2]. Since it is not eliminated by the kidney, and has been extensively tested in patients with kidney disease, it is of interest as an alternative to gadolinium for patients with renal insufficiency. Furthermore, its intravascular distribution and long plasma half-life (15 hours in humans) offer potential advantages over gadolinium for venous assessment. The primary goal of this study was to determine whether ferumoxytol could be used in a conventional three-station MR angiography (MRA) protocol including both time-resolved imaging of the calves and bolus-chase imaging from the abdomen to the feet. Since any ferumoxytol that is injected will remain in the blood pool for the duration of the examination, the question was whether diagnostic-quality time-resolved images could be obtained without compromising the bolus chase. A secondary goal of the study was to assess the potential of ferumoxytol for high-resolution steady-state vascular imaging.

Methods: All imaging was performed at 1.5T (Avanto, Siemens) using a peripheral phased array coil in combination with body phased array coils and spine coil elements. Six healthy volunteers (2 women/4 men, ages 22 – 57) were included, and all gave informed consent to participate under an IRB-approved protocol. Among the exclusion criteria were pregnancy, a history of anaphylactic reaction and iron overload as determined by prior T2* imaging of the liver [3]. All vascular imaging was conducted using Siemens product sequences and a GRAPPA acceleration factor of 2. Time-resolved and bolus-chase imaging were performed with FA = 20° and 25° respectively, FOV = 450mm (calf) and 500mm (thigh and abdomen), in-plane voxel size between 1.5x1.2mm^2 (calf) and 1.9x1.3mm^2 (abdomen), slice thickness/resolution between 1.3mm/81% (calf) and 1.4mm/70% (abdomen), and TR/TE between 2.34ms/0.79ms (abdomen) and 2.41ms/0.84ms (calf). High-resolution steady-state imaging was performed using FA = 25°, FOV = 450mm, true 1.0x1.0x1.0mm^3 isotropic resolution, and TR/TE ≈3.0ms/1.1ms depending on slab thickness. Timing for the bolus chase was determined using fluoroscopic triggering in the first four subjects and a timing bolus in the remaining two. Ferumoxytol (30mg/mL Fe, AMAG Pharmaceuticals, Cambridge, MA) was purchased through our hospital pharmacy and diluted with saline prior to injection. A dose of 4 mg/kg Fe was used for the MRA, of which 0.050 – 0.083 mg/kg Fe was used for the timing bolus where applicable, 0.625 – 0.750 mg/kg Fe for time-resolved imaging, and the remainder for the bolus chase. A further 1 mg/kg Fe was injected prior to steady-state imaging. All images were assessed qualitatively by a board-certified radiologist.

Results: In all subjects, the time-resolved images were of diagnostic quality, and the high-resolution steady-state images provided clear depiction of vessel margins and excellent signal contrast between vessel lumina and background tissue. The quality of the bolus-chase images was found to depend on the dilution factor chosen for the ferumoxytol. It was determined empirically that for an injection rate of 2cc/sec in a subject with normal cardiac output (~5L/min) a dilution factor of at least 4 was required to obtain optimal arterial conspicuity, a result that is consistent with previous observations [1]. A lower dilution factor (i.e. higher concentration) was found to result in reduced arterial signal and poor discrimination of renal arteries from renal veins. For subjects with lower cardiac output, it is expected that a higher dilution factor or slower injection rate would be necessary.



Fluoroscopic triggering was used instead of a timing bolus in the first four subjects to avoid any enhancement of the vascular signal prior to diagnostic imaging. Due to mixed success with this approach, we resorted to the use of a timing bolus in the last two subjects, and observed no apparent loss of image quality in the MRA data.

Figure 1 shows results in a 22 year old man, in whom a timing bolus was used. Diagnostic-quality MRA images were obtained for both the time-resolved and bolus-chase acquisitions, demonstrating that sufficient contrast can be injected for the timing bolus and time-resolved imaging without compromising the bolus-chase MRA.

Discussion: Although we calculated the dose of ferumoxytol according to weight, it is known that the ratio of blood volume to body weight is not a constant, but depends on body mass index [4]. Since ferumoxytol is a blood pool agent, it may be preferable to calculate dose from a parameter such as body surface area that better predicts blood volume [4].

Conclusions: A conventional three-station MRA protocol is feasible using ferumoxytol and may offer a useful alternative for patients in whom gadolinium is contraindicated due to renal insufficiency. In addition, ferumoxytol offers the possibility of high-resolution steady-state imaging.

Acknowledgements: Grant support: NIH HL092439

References: [1] JMRI 2005;21:46-52, [2] Radiology 2007;242:873-81, [3] AJR 2009;193:1261-7, [4] Circulation 1977;56:605-12.

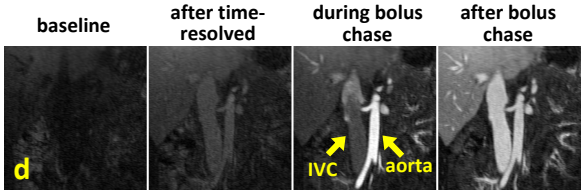


Figure 1: Results in a 72kg man with cardiac output of 5.3L/min. 12cc ferumoxytol (5mg/kg Fe) was diluted in saline by factor of 5 to make a total volume of 60cc. Of the mix, we injected 1cc at 2cc/sec for the timing bolus, 8cc at 3cc/sec for time-resolved imaging (a), 39cc at 2cc/sec for the bolus chase (b), and the remaining 12cc prior to steady-state imaging (c). In all cases MIPs of the subtracted data sets (post – pre injection) are shown. To the left (d) are images of a single slice through the aorta and inferior vena cava (IVC), acquired with the bolus-chase sequence at different timepoints and showing accumulation of contrast after successive injections.