Time-Resolved Calf-Foot Bolus Chase MRA with Sub-Millimeter Resolution and Real-Time Table Motion Triggering Using 3D MR Fluoroscopy

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Introduction: Angiographic imaging of the calves and feet is difficult using runoff techniques such as bolus chase MRA and CTA due to the competing demands of adequately long scan time at the calves for high spatial resolution and rapid table advance to avoid venous contamination in the feet. The feet are particularly prone to uncertainties in bolus arrival time and require especially high spatial resolution (<1.0 mm^3). The highest resolution MRA acquisitions of the feet to date have been obtained using dedicated time-resolved foot exams, as have been recently demonstrated with sub-millimeter 3D resolution [1,2]. When imaging diabetics and limb salvage candidates, it would be of great benefit to obtain a calf MRA in addition to a highly-resolved foot MRA to better image the extent of disease and identify patent vessels. Recently, a time-resolved bolus chase technique was demonstrated for imaging the thighs and calves with 1.0 mm isotropic resolution and short frame times (2.5 – 5.0 sec) using CAPR in combination with high 2D SENSE (6x-8x) and 2D homodyne (1.8x) acceleration [3]. The purpose of this work was to adapt this dual-station strategy to generate 3D time-resolved calf-foot arteriograms with <1.0 mm^3 resolution using a single contrast injection. To avoid venous contamination at the foot station, diagnostic quality frames are formed every 2.5 seconds at the calves, reconstructed in real time, and used to perform fluoroscopic triggering of table motion. In vivo studies demonstrate the high quality that can be obtained with the proposed technique with comparable or even superior resolution than has been obtained previously using single-station acquisitions.

Methods: The calves and feet of eight healthy volunteers were imaged under an IRB-approved protocol. The first six studies focused on technical development and involved adjustment of the various parameters. The two most recent volunteers were imaged using the resultant protocol, which is described here. Imaging was performed on a 3.0T GE Signa MRI system. 16 receive coils were used: eight were placed circumferentially around the calves, and the other eight were placed

similarly around the feet. The protocol consisted of the following steps: (i) two-station localizer; (ii) parameter setup; (iii) two-station SENSE calibration scan; (iv) real-time system initialization; (v) subtraction reference scans; and (vi) the time-resolved CE-MRA acquisition. A coronal fast GRE sequence was used. The calf station MRA was imaged with the following parameters: FOV = 35 (S/I) x 31.2 (L/R) x 13.2 (A/P) cm^3; sampling matrix = 400 x 312 x 132 (yielding 0.88 x 1.0 x 1.0 mm^3); N5 CAPR; 8x (4x2) 2D SENSE; 2.5 sec frame time; and 12.1 sec temporal footprint. The foot station used the following: FOV = 30 x 19.8 x 24 cm^3; sampling matrix = 400 x 264 x 256 (yielding 0.75 x 0.75 x 0.93 mm^3); N4 CAPR; 8x (2x4) 2D SENSE; 6.6 sec frame time; and 24.2 sec temporal footprint. Contrast material was administered via power injector immediately following acquisition of subtraction frames: 20 mL Multihance followed by 20 mL saline at 3.0 mL/sec. The 3D CAPR time frames were reconstructed in real-time (450 ms latency) and the coronal MIPs were displayed on the scanner console to guide triggering of table motion to the foot station once the contrast bolus reached the inferior end of the calf FOV.

Results: Figure 1 demonstrates a high quality calf-foot result using the described method. Coronal and sagittal maximum intensity projections (MIPs) of the composite FOV are shown using the last calf time frame and the third foot frame. The arterial lumen is clearly depicted throughout the extended FOV. The visualization of small vessels emphasizes the high spatial resolution of this exam. Negligible venous contamination was seen in the first foot frame (not shown), allowing clear identification of the arteries. The second volunteer study using the protocol yielded similar results.

Conclusion: 3D calf-foot arteriograms can be acquired with high spatial resolution (<1.0 mm^3), high temporal resolution (2.4 and 6.6 sec frame times at the calves and feet, respectively), and excellent overall diagnostic quality. Real-time triggering using rapidly acquired and reconstructed diagnostic time frames provides precise timing of table motion to help avoid venous contamination at the foot station while still providing high quality images of the calves. This work is a significant step toward a dedicated lower extremity highly-resolved MRA exam with extended coverage.

References: [1] Ruhl KM, et al. AJR (2008) 190:W360-W364. [2] Haider CR, et al. ISMRM (2009) #270. [3] Johnson CP, et al. MRM (2010) 64:629-637.

Figure 1: Coronal (A) and sagittal (B) calf-foot MIPs of a volunteer generated using select arterial frames (interpolated to 0.75 mm isotropic). Note the high 3D spatial resolution, crisp depiction of vessels, extended S/I coverage, and lack of interfering venous contamination.