Fluoroscopic tracking for real-time guidance for high quality multi-station contrast-enhanced MR angiography of the peripheral vasculature

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Purpose

Contrast-enhanced MR angiography (CE-MRA) is commonly performed of the peripheral vasculature over a long field of view (FOV) which extends from the origins of the renal arteries to the feet. Technical methods used to generate such images include multi-station techniques in which the MRI table is placed at several discrete positions along the FOV [1] as well as continuously moving table methods in which the scanner table is moved continuously in an effort to image the advancing contrast bolus as it advances along the vasculature [2]. These methods are all limited in a fundamental way in that the dwell time of the scanner at a specific axial level must be long enough to capture enough data to provide adequate spatial resolution but it must not be too long so as to allow the contrast bolus to advance to distal locations to the extent of causing venous enhancement and potential interference with radiological interpretation. This can be most problematic at the distal-most (calves-ankles) station where spatial resolution demands are generally highest and where the contrast-enhanced signal is generally lowest because of progressive bolus dilution. To address this, investigators have developed hybrid methods in which the distal-most station is imaged first with a first contrast injection using a time-resolved method, and the two proximal stations (pelvis and thighs) are subsequently imaged using a second injection and either a dual-station or continuously moving table method [3]. Although such methods provide some improved performance, they are still limited in the need for two contrast injections and the potential for residual signal from the first injection interfering with the image quality from the second injection. The overall purpose of this project was to address these issues with the technique of fluoroscopic tracking in which the advancing contrast bolus is visualized in real time with high spatiotemporal resolution, and the operator triggers advance of the table from the current station to the next after contrast has adequately moved distally within the current station. The purpose of this work is to describe the feasibility of fluoroscopic tracking.
Methods and Materials

The technique of fluoroscopic tracking has four distinct technical specifications. First, the method must provide spatial resolution at each station which is adequate for diagnosis. This is generally in the range of 1.0 to 1.3 mm isotropic. Second, the method must have a frame rate which is adequately high to allow visualization of the arriving and advancing contrast bolus with the current FOV. Given the typical contrast dynamics encountered in the peripheral vasculature, a frame time of about 2.5 sec is adequate for this. The third requirement comes about because virtually all MRI acquisition techniques which simultaneously provide spatial resolution as fine as 1.0 - 1.5 mm and frame times as short as 2.5 sec employ some kind of view sharing. View sharing is a method by which images are reconstructed at a frame time shorter than the intrinsic acquisition time of a single image; i.e. individual phase encodings or "views" are shared from one image to the next. With view sharing methods the time required to acquire all data necessary for a single image is called the temporal footprint [4]. With fluoroscopic tracking, because of the need to move the table from one station to the next, it is not possible to prolong the acquisition at an individual station as dictated by a long temporal footprint. Thus, the third requirement is that the temporal footprint of the acquisition be adequately short, less than 10 sec. The fourth technical requirement is that the process be real time. That is, the operator must be able to visualize the advancing contrast bolus while it is happening. Specifically, the image reconstruction time must be short, ideally no longer than several hundred msec.

Fluoroscopic tracking is based on the Cartesian Acquisition with Projection Reconstruction-like sampling (CAPR) pulse sequence. This has been previously demonstrated as providing 1.0 mm isotropic resolution with frame times in the 2.5 - 6.0 sec time range [5]. This performance is allowed because it employs 2D parallel acquisition using the Sensitivity Encoding (SENSE) technique. A schematic diagram of the acquisition scheme is shown in Figure 1, in which the sampling of the ky-kz phase encoding is depicted for two of the three stations (a, b), the temporal ordering of the acquisition of the individual regions is shown at the top of (c, d), and the sorting of the acquired data into the individual images I1, I2, etc. comprising the time series is shown a plane-space sampling is shown in the lower portions of (c, d). In this example the frame time for the thighs station is shorter than that for the calves station. This is because once the table gets to the distal-most calves station there is no longer any need for real time triggering, and high spatial resolution is more quickly generated if the frame time is allowed to be longer. For three-station acquisition the sequence used for the thigh station in Figure 1 was also used for the abdomen.

Fluoroscopic tracking was implemented for three-station imaging of the peripheral vasculature. For each station a linear receiver coil array was used, composed of eight or more individual elements, and wrapped around the patient at that station so as to
circumferentially enclose that subject at that station. Each array was composed of a set of two-element modules, with the number of modules selected on a patient-specific basis depending on body habitus. An eight-element array for the thigh station is shown in Figure 2.

Fluoroscopic tracking was tested in a feasibility study of 21 subjects, composed of 11 volunteers and 10 subjects in whom peripheral angiography was indicated and who had a CT angiogram. For fluoroscopic tracking the subjects were positioned in the MRI scanner bore with the coil arrays as described. The typical contrast administration was composed of 20 mL of Gd agent injected at 3 mL/sec followed by 20 mL of saline flush also administered at 3 mL/sec.
Fig. 1

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Fig. 2

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Results

The fluoroscopic triggering technique was able to routinely allow visualization of contrast bolus arrival and transit across the FOV of the first two of the three stations in the typical exam, allowing routine triggering of table motion from one station to the next. The method would accommodate the broad range of contrast arrival and transit times encountered in the patient group: 12 to 30 sec post-injection arrival time in the abdomen, 25 to 47 arrival time in the thighs, and 30 to 70 sec arrival time in the calves.

Sample results are shown in Figures 3-6. Figure 3 shows the individual Maximum Intensity Projection (MIP) images of the abdomen-pelvis station with the post-injection delay time indicated and depicting bolus transit through the FOV. Triggering to the next station was initiated when the second frame shown (b, 27.6 sec) was observed. Data for generating the next frame (c) was then generated and the table moved to the second (thigh) station. Images from this station are shown in Figure 4. The first image generated (a) already shows bolus transit along the full coronal FOV, and so the operator triggered table motion to the third station. As for the abdomen station, before the table was moved data were collected for a complete frame (b). The first image generated from the distal-most (calves) station is shown in Fig. 5. The 3D nature of the data allows selective sagittal MIPs of the right (a) and left (c) legs as well as the full coronal MIP (b). Finally, Figure 6 shows how results from the three stations generated at peak arterial enhancement can be concatenated to generate an image of the full FOV.
Fig. 3

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Fig. 4

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Fig. 5

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Fig. 6

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Conclusion

Fluoroscopic tracking has been shown to be technically feasible in three-station imaging of the peripheral vasculature. Future work will need to include an evaluation of image quality, particularly as a function of the station position. The method offers advantages over current approaches for peripheral MRA in terms of image quality, spatial resolution, and overall exam simplicity.
References


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