Continuously moving table contrast-enhanced MRA: Technical Development


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Synopsis: Recently a technique has been described in which an image is formed of an extended object while it is moved continuously through the bore of the MR magnet. This initial work described the image formation process, derived the relationship between table velocity and spatial resolution, and provided experimental results in animals. The purpose of this work is to present additional challenges of implementation and describe how these have been addressed for peripheral runoff MR angiography in humans. These challenges include adequate table velocity, adequate SNR, correction for gradient warping, and synchronization of table motion to the transient contrast bolus.

Introduction: MR data acquired during continuous table motion can be used to form images free of artifacts associated with the motion of the patient/table through the scanner bore [1]. Although each measurement is formed from a slightly different table position, all data can be spatially registered. If uniform k-space sampling is desired, the table velocity is given by:

\[ V_{ref} = \frac{FOV_z}{N_z \cdot TR} \]

Where FOVz is the measurement FOV and Nz and Nt specify the phase encode resolution for 3D acquisition. For peripheral MRA, FOVz, which is fixed to the scanner bore, must nominally track the contrast bolus peak from aorta to calf vessels by maintaining sufficient table velocity. To maximize table velocity for some number of phase encodes, TR can be minimized and FOVz maximized.

Methods: As of this writing nineteen healthy volunteers have been scanned using the continuously moving table technique. Volunteers are placed feet first in the scanner and two ml bolus timings are measured, the first at the popliteal trifurcations and the second at the renal artery origins. From the separation distance divided by the difference in arrival times between these two points an average contrast velocity is measured. Prior to initiation of the moving table contrast acquisition, 3D real-time fluoroscopic imaging of the initial FOV is used to detect the arrival of the main contrast bolus. Typical moving table acquisition values for three dimensions were Nz = 128, Nt = 16, and Ns = 768.

Initial studies suffered from inadequate visualization of distal vessels, inadequate SNR, and imprecise triggering. These have been addressed by increasing table velocity and contrast bolus length, use of dynamically switched surface coil arrays and improved triggering for detecting contrast arrival. To increase table velocity, TRs have been reduced and the moving FOVz has been increased as suggested by Eq 1. However, increasing FOVz causes image blurring due to gradient non-linearities [2]. To allow increased FOVz, gradient correction applied to moving table has been implemented [3]. To insure that contrast is present in the calves at the end of the scan the total injection time was increased from 24 to 33 seconds by reducing the injection rate. To increase image SNR an array of surface coils was placed along the S/I direction of the patient. Figure 1 shows this schematically, where eight 25 x 25 cm² coil elements are arranged along the patient from the aortic arch to the feet. The four scanner receivers are switched automatically as the table moves and as FOVz is translated from torso to feet. Initially the top four are enabled. At the end of the scan only the bottom four are enabled. This schematic is superimposed over one of our recent extended FOV moving table acquisitions.

Results: Application of 3D fluoroscopic triggering has allowed greater confidence in contrast bolus arrival. After injection the positional course of the contrast bolus can be monitored through the pulmonary vessels and the heart. When contrast is detected in the aorta, delay from triggering to the start of moving table acquisition is only 300 msec on average.

By decreasing the fraction of the echo acquired from 256 points down to 192 points the scan TR was decreased to 4.8 msec and the TE reduced to 1.6 msec. After the application of moving table gradient non-linearity correction, FOVz could be increased from 25 cm or less to over 35 cm without significant blurring. These changes have collectively allowed an increase of table velocity from 2 cm/sec at the beginning of this study to 3.8 cm/sec with no loss of spatial resolution. This increased table velocity, along with the increased time period in which contrast is present, allows better tracking of the contrast bolus.

Figure 2 shows images of the popliteal trifurcation region of the very first volunteer using the body coil (a) and the most recent using the eight coil array (b). In (a) the slow 2 cm/sec table velocity allowed passage of the contrast bolus through the calves before the moving FOVz reached the area. In (b) a combination of extended bolus time and increased table velocity allowed the vessels to be visualized beyond the trifurcation. Furthermore, a comparison of sum-of-squares eight coil reconstruction to representative body coil image demonstrated an increase in SNR from 29 to 73.

Discussion: Improvements to the basic moving table method have allowed increases in both table velocity and SNR by more than a factor of two. Although higher velocities may still be required, present increases have allowed us to better match table motion to the speed of the contrast bolus. SNR increases allow small peripheral vessels to be visualized beyond that allowed by the body coil alone. In future work, even shorter TRs, additional surface coils and parallel imaging strategies are expected to provide higher special resolution.

References: