Using flow models to study the effects of bolus timing on CE-MRA images

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Target Audience: Researchers interested in contrast-enhanced MR angiography

Purpose: Image quality in patients undergoing Contrast Enhanced Magnetic Resonance Angiography(CE-MRA) is highly sensitive to correct synchronization of the image acquisition with the injected bolus(1). For first-pass contrast agents there is only one opportunity to acquire the full MRA. Given the concerns about multiple injections and the contamination of subsequent runs by the first injection, there are few options for studying the effect of bolus timing in patient studies. In this work, we utilize a patient specific flow model and a computer controlled flow loop to provide an exact reproduction of geometric conditions and physiologic waveforms that are present for specific patients. Using this model we studied the effects of timing on CE-MRA images.

Methods: A replica of an actual fusiform basilar artery was connected to a flow mixer and a computer controlled flow pump. The model and associated tubing were filled with un-doped water. Then, a power injector(Spectrum Solaris EP, Medrad) was used to pump 20cc diluted [1:30] contrast agent at 2.7 cc/s followed by a 100 cc flush of undoped water also at 2.7 cc/s to reproduce physiological flow rates in the basilar artery. A 2D bolus timing sequence was performed to determine a base delay time. The start time of a 3D CE-MRA (TR=3.66, TE=1.4, FOV=182 mm x 224mm x 84 mm, .7mm isotropic, flip angle=20 deg, elliptic centric ordering, time to center=6s) was varied in 2 second intervals with respect to the start of injection, and the resulting CE-MRA images were compared. The contrast agent was completely flushed out of the model between each scan. All imaging was done on a 3T scanner (Skyra, Siemens Healthcare, Erlangen, Germany).

Results: An analysis of the 2D bolus timing run indicated that contrast reached the imaging plane at approximately 7 seconds, and reached its peak at 15 seconds(Fig 1). Varying the imaging start time relative to bolus injection showed a substantial effect on image quality (Fig 2), with earlier injections showing incomplete filling of contrast in the phantom. Start times occurring in the flattened section of the intensity curve resulted in more homogenous signal intensity in the model.

Discussion: In this study, start times on the lower end of the signal intensity curve produced poor images due to incomplete filling of contrast agent during acquisition of the center of k-space. The model also showed that image quality varied from proximal to distal vessels for a given scan delay because of contrast transport. Similarly, flow recirculation effects in the aneurysmal pouch resulted in variable visualization with different scan delays. The use of a flow phantom to study contrast timing allows for repeated studies with a high temporal resolution that would not be possible in vivo. Due to this high temporal resolution, effects such as the inflow of contrast via a jet(Fig 2D) can be seen.

Conclusion: The use of a flow phantom provides an excellent test bed to perform repeated experiments allowing one to study the effects of temporal variations. In addition, this method can be used to study other effects such as bolus profile or concentration that would not be possible in vivo.

References

1) Zhang H, Maki J.H, Prince M.R. 3D contrast-enhanced MR angiography. JMRI. 2007 25:13-25
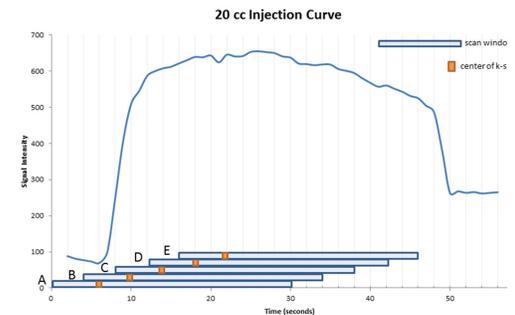
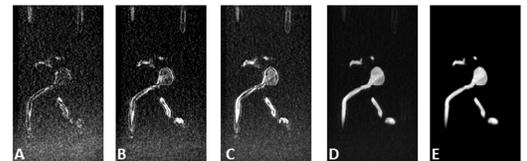Figure 1: Signal Intensity Curve from 20cc injection and scan windows for various CE-MRA studies.

Figure 2: Comparison of sample slice from 3D CE-MRA datasets started at different positions relative to injection. Letters correspond to scan windows on intensity curve in Figure 1.