Arterial Phase Carotid and Vertebral Artery Imaging in Contrast-Enhanced 3D MRA by Combining Fluoroscopic Triggering with an Elliptical Centric View Order

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Introduction
Obtaining adequate spatial resolution in three-dimensional contrast-enhanced carotid artery MR imaging can be difficult owing to the limited arterial phase time window prior to overwhelming jugular vein enhancement. Initial attempts with long acquisition times proved unsuccessful at reliably limiting venous enhancement (1, 2). Techniques that achieve higher time resolution, either through acquisition times under ten seconds (3), or through rapid updating of the central imaging views (4), have been more successful at capturing the arterial phase. However, both approaches must limit the spatial resolution or total volume coverage in order to assure sufficiently rapid time resolution to account for the unknown bolus arrival time. If real-time bolus monitoring is used instead (5,6), it is then possible to optimize the 3D acquisition to take maximal advantage of the fleeting bolus enhancement. However, bolus monitoring of the carotid arteries must overcome the confounding effects of high blood pulsatility that can mask contrast enhancement with time-of-flight enhancement, and small vessel size neither of which is a concern when monitoring the abdominal aorta.

In this work we demonstrate a reliable method for obtaining venous-suppressed carotid artery 3D angiograms using extended acquisition times as long as thirty seconds. The technique combines fluoroscopic bolus monitoring with the elliptical centric view order and is a tailored version of the technique that has been applied previously to renal artery imaging (6).

Methods
An integrated pulse sequence was developed that combines rapid 2D fluoroscopic imaging with instantaneous triggering of a 3D MRA acquisition (6). Owing to the increased blood pulsatility in the carotid arteries, automatic trigger thresholding (5) was purposely avoided in favour of complete operator control. To maximize the available arterial-to-venous contrast, and provide the highest possible spatial resolution for the given scanning time, the elliptical centric phase encoding order was used for the 3D acquisition (7). This 3D order always sampled the most central views first by adapting to the specific sampling of the k-space phase encoding plane as dictated by the desired fields-of-view and resolution.

The fluoro-triggered pulse sequence was tested on twenty patients for imaging the carotid and vertebral arteries bilaterally from aortic arch origins to above the carotid bifurcation. Prior to injection of Gd (0.15 mmol/kg), the fluoroscopic portion of the integrated pulse sequence was used to rapidly determine the best viewing plane to observe the Gd arrival. Typically, it took under two minutes to obtain a double oblique slice that maximized inplane flow by including the aortic arch, the left carotid artery and the descending thoracic aorta. Once this plane was determined, the injection was made, and continual fluoroscopic imaging was performed at 1 image per second until the operator observed the arrival of the Gd contrast bolus. At this point, the 3D sequence was instantly triggered by the operator. The patient breathed quietly throughout the whole procedure.

Results
Fluoroscopic bolus monitoring was successful in 18 of the 20 patients with the two failures being attributed to insufficient suppression of time-of-flight enhancement caused by the limited extent of the RF excitation coil. For the 18 successfully triggered cases, arterial-phase 3D images were obtained with excellent venous suppression as demonstrated by an average internal jugular vein to common carotid signal enhancement ratio of only 0.05 ± 0.04. Figures 1 and 2 illustrate this high degree of venous suppression.

Figure 1 The same 3D MRA source image location from (a) the arterial phase and (b) the later venous phase. Note the jugular veins in (a) are barely visible as desired. The acquisition time was 31 s, the slices were 1.5 mm thick.

Figure 2 Two examples of 3D MRA MIP images from the complete volume. Both acquisitions were longer than 36 s, but there is no evident jugular-signal in either MIP.

Conclusions
Fluoroscopic bolus monitoring provided a means for accurate and reliable monitoring of contrast bolus arrival in the carotid arteries. With fluoroscopic triggering, the elliptical centric view order produced venous suppressed 3D MR angiograms of the carotid arteries using 3D acquisition times greater than 30 seconds.

References