

Carotid Artery Disease: Effects of Doubling and Tripling Spatial Resolution in 3D Contrast-Enhanced Elliptical Centric Magnetic Resonance Angiography

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Introduction: For the last decade, higher resolution in 3D contrast-enhanced MR Angiography (CEMRA) of the carotid arteries has continually been sought in an effort to approach the in-plane resolution of a diagnostic x-ray angiogram. For carotid artery 3D-CEMRA, a properly timed elliptical centric acquisition provides a method to maximize arterial contrast while minimizing venous signal (1). This method, introduced in 1997, eliminates the concern over jugular vein overlap, which was thought to be a severe limitation on acquisition time. In 1999, the prolongation of the carotid artery bolus curve due to rapid recirculation was rigorously demonstrated, eliminating a further concern over increased scanning times (2). Presently in 2005, with much shorter TR times now possible, the limitation on carotid artery 3D-CEMRA shifts from venous contamination and arterial signal prolongation, to patient motion and signal-to-noise issues. In regard to patient motion, both carotid pulsation due to the systolic pressure wave and patient movement and swallowing must be considered. It is likely that a shorter acquisition time will further limit these movement artifacts. However, the elliptical centric approach is somewhat shielded from severe motion artifact owing to the use of the minimum possible time to acquire the central views. The signal-to-noise reduction is easier to predict. Assuming an ideal, flat bolus curve, the SNR is proportional to the voxel size and the square root of the acquisition time, keeping readout bandwidth, flip angle and TR constant.

The purpose of our study is to determine the preferred image resolution for assessing carotid artery disease using 3D-CEMRA with a 30 mL Magnevist™ dose on a standard 1.5T system using standard RF coils, and demanding full bilateral coverage from aortic arch origins to above the circle-of-Willis. To achieve this purpose, 110 consecutive patients presenting with suspected carotid artery disease were studied. Beginning with “high resolution” 1.0 mm³ voxel volumes, the volumes were decreased progressively to 0.35 mm³ with acquisition times progressively increasing from 21 to 60 seconds.

Methods: 3D contrast-enhanced MR Angiography was performed at 1.5 T on 110 consecutive patients presenting with carotid artery disease in the differential diagnosis. Thirty mL of Magnevist™ was injected at a rate of 3 mL/sec followed by a 20 mL saline flush. The 3D coronal volume extended from the aortic arch origins to past the circle-of-Willis. The acquisition time was increased in steps of 10 seconds from 21 (our clinical standard) to 60 seconds. At least twenty patients were studied within each of the five timepoints. Patient groups were balanced for age, weight, mean time to contrast arrival and mean enhancement factor. Additional scan time was used solely to obtain higher resolution and not to extend the already large volume coverage. The 3D gradient-echo sequence used TE/TR of 1.2 msec/3.2-3.6 ms. Elliptical centric view order without recession was used with fluoroscopic triggering. The typical matrix size was 512 (x) x 137-308 (y) x 72-80 (z). Typical fields of view were 300 mm in the superior-inferior (x) direction, 225 mm in the right-left (y) direction, and 58-88 mm in the anteroposterior (z) slab-select direction with a typical partition thickness of 0.9-1.1 mm. True voxel sizes were 0.95, 0.70, 0.53, 0.42, and 0.35 mm³ for the 21, 30, 40, 50, and 60 second acquisition scans, respectively. A series of quantitative and blinded qualitative measurements were performed on the images. The quantitative measures included: arterial and venous signal intensity, and contrast-to-noise ratio. Qualitative measurements were performed by a neuroradiologist to evaluate overall image quality, degree of artifact and image sharpness. A 3 point scale 0,1,2 was used with 2 excellent, 1 good and 0 poor. A training data set was used to determine the level for each category. Analysis was split between patients with and without stenosis.

Results: The quantitative results on 220 arteries for arterial signal intensity, arterial signal-to-noise ratio, and arterial-to-venous contrast-to-noise ratios are summarized in Table 1, where mean values and standard deviations are listed. As expected SNR decreases with increasing scan time in the manner predicted. SNR and CNR remain acceptable even at the longer scanning times. Table 2 shows one portion of the radiological review illustrating the sharpness at the bifurcation. These results indicate that the 40 second scan is preferable over the standard 21 second scan when stenosis is present. Note that without stenosis, the additional resolution has no benefit, since for these patent vessels, the 1 mm³ high resolution is already sufficient. Figures 1 and 2 give example images.

Table 1: Quantitative Measurements at the Common Carotid

Acquisition Time (s)	Voxel Size (mm ³)	Arterial SNR mean (std. dev)	Artery-to-vein CNR
21	0.95	54.0 (10.9)	41.6 (11.0)
32	0.70	46.4 (13.5)	29.5 (10.0)
40	0.53	37.0 (9.1)	24.7 (7.9)
50	0.42	32.7 (5.8)	23.1 (6.5)
60	0.35	27.3 (6.2)	19.3 (5.8)

Table 2: Radiological Review, Sharpness at Bifurcation

Acquisition Time (s)	All Patients mean(std dev)	With Stenosis mean (std dev)	No Stenosis mean(std dev)
21	1.34 (0.63)	0.67 (0.52)	1.47 (0.60)
32	1.45 (0.59)	1.21 (0.43)*	1.61 (0.64)
40	1.62 (0.49)	1.43 (0.53)*	1.72 (0.45)
50	1.63 (0.53)	1.20 (0.63)	1.76 (0.43)
60	1.20 (0.55)	1.00 (0.55)	1.35 (0.48)

* p < 0.02 when compared to standard 21 second scan

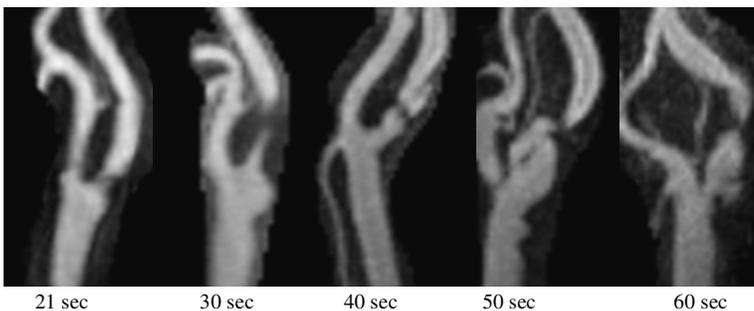
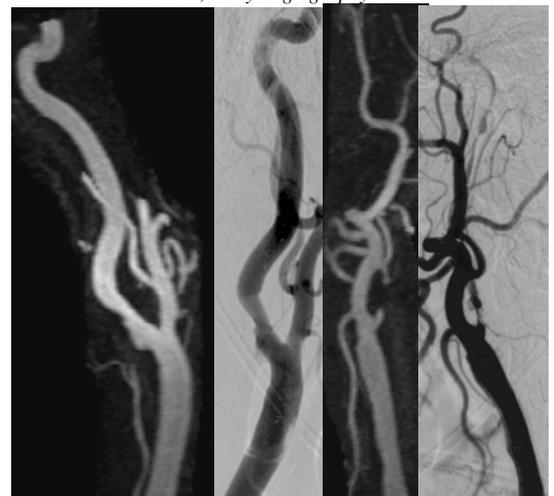


Figure 1 (Left) Contrast-enhanced MRA angiograms of severe internal carotid stenosis in five patients, each acquired at increasing image resolution by increasing the scan time as listed.

Figure 2 (Below) A comparison of a 40-second MRA acquisition with diagnostic x-ray angiography in a patient exhibiting bilateral carotid artery stenosis. MRA with white vessels, x-ray angiography with black vessels



Conclusions: Our findings in this 220 artery study are that in the presence of carotid artery stenosis, increasing the acquisition time from a high resolution 21 second scan with 1 mm³ voxel volumes to a 40 second scan with 0.5 mm³ voxel volumes will result in improved depiction of carotid stenosis (p < 0.02). Further scan time increases led to a degrading of image quality, arising from both SNR losses and increased blurriness likely due to swallowing and increased exposure to systolic pulsation. The increase in image resolution from the 21 second scan was of no benefit for the depiction of normal patent arteries. Finally, 0.5 mm³ true voxel volumes (no zero-filling) over a 300 mm field-of-view can produce improved depiction of carotid artery disease using a standard 1.5 T system with a 30 mL contrast dose. This resolution is twice that presently used in standard clinical protocols.

References 1. Wilman, Radiology **205** 137-46 (1997). 2. Fain, MRM **42** 1106-16 (1999).