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MR Angiography of the Extracranial Carotid Arteries Using a Two-Slab Oblique 3-D Acquisition

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PURPOSE: To describe an oblique, two-slab 3-D acquisition technique for MR angiography of the extracranial carotid arteries, an approach chosen to minimize saturation effects when the body coil is used as transmitter, as is often the situation when a dedicated neck coil is used as receiver. **SUBJECTS:** Five healthy subjects and 17 patients in whom carotid artery disease was suspected underwent MR angiography using the above technique. **RESULTS:** Flow contrast was much better than in direct sagittal acquisition. Comparisons between multislab transverse 3-D acquisition and the oblique approach showed that a greater length of the carotid arteries was depicted and scan time was less for oblique acquisitions. **CONCLUSION:** Use of oblique imaging is a simple and effective solution to the problem of coil-related saturation effects.

Index terms: Arteries, carotid; Magnetic resonance, technique; Magnetic resonance angiography (MRA)

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Several techniques have been described for magnetic resonance (MR) angiography of the extracranial carotid arteries, including 2-D time of flight (1), 3-D time of flight (2), and 3-D phase contrast (3). Accurate results have been reported using a two-slab sagittal 3-D sequence and a head coil as both transmitter and receiver (4). However, this approach works less well when the body coil is used as transmitter and a surface coil is used as the receiver. Saturation of the blood pool in the heart and aortic arch may cause loss of flow contrast in this situation. As a solution to this problem, we tested an oblique two-slab 3-D acquisition that avoids saturation effects.

Subjects and Methods

All studies were performed at 1.5 T with a whole-body imaging system (Magnetom SP; Siemens Medical Systems, Iselin, NJ). A Helmholtz coil, which conforms to the shape of the neck, was used for signal detection, and the body coil was the transmitter. Twenty-two subjects (14 men, 8 women; mean age 58.7 years; range, 24–84 years) included five healthy volunteers (4 men, 1 woman; mean age, 49.5 years; range, 38–65 years) without any history of carotid artery disease and 17 patients (10 men, 7 women; mean age, 60.7 years; range, 24–84 years) in whom carotid artery disease was suspected because of bruit or clinical symptoms. In the seven patients undergoing conventional angiography, cut films or intraarterial digital subtraction angiograms (9″ image intensifier with 1024 × 1024 matrix) were obtained in at least two projections.

All subjects were studied with a two-slab 3-D oblique sagittal acquisition and 18 subjects (17 patients, one volunteer) were also studied with multislab transverse 3-D acquisitions. In addition, seven patients underwent selective carotid angiography within 1–13 days of the MR examination. In one healthy subject, the two-slab 3-D oblique acquisition was compared with a direct sagittal two-slab 3-D acquisition using identical sequence parameters.

The obliquity of the 3-D slabs was determined from 2-D gradient-echo coronal localizer images (Fig. 1). Oblique angles ranged from −7 to −20 degrees on the right side (mean −10.9 degrees) and 9 to 18 degrees (mean 13.7 degrees) on the left side. A 50-mm transverse presaturation slab placed over the skull base suppressed venous signal. Imaging variables were 53/6.4/1 (TR/TE/excitations), 20 degree flip angle, 48-mm slab thickness, 32 partitions (1.5-mm section thickness), 256 × 192 matrix, and 21 cm × 15 cm field of view. Scan time for the entire two-slab acquisition was 5 minutes 28 seconds.

For multislab 3-D transverse acquisitions, imaging variables were 29/6.4/1 (TR/TE/excitations), 20 degree flip

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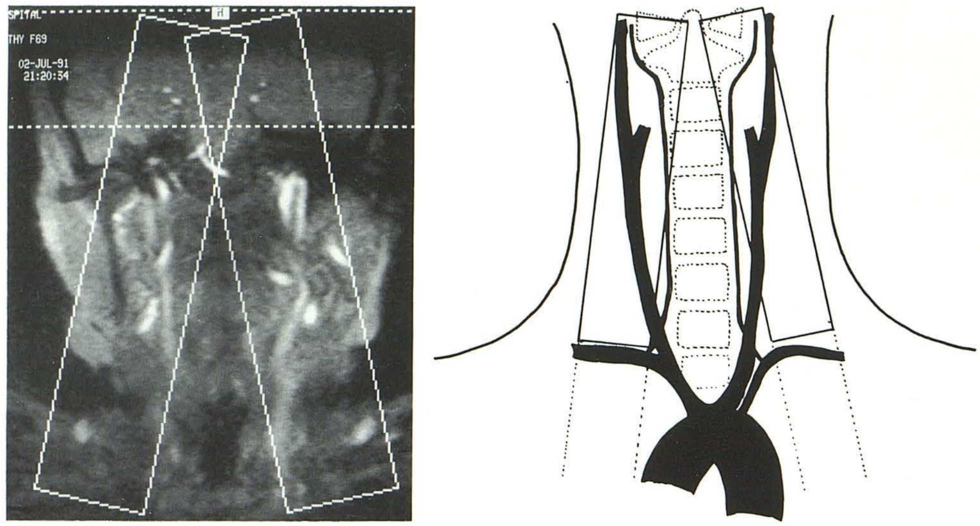


A B

Fig. 1. Prescription of oblique 3-D slabs.

A, The two slabs are set up on a coronal localizer image slightly obliqued from a sagittal orientation. The transverse slab on the top is the position of the RF presaturation.

B, The oblique slabs do not encompass the heart, aorta, or proximal common carotid arteries.

angle, 52-mm thickness for each slab, 64 partitions (0.8 mm section thickness), 256 × 192 matrix, and 20 cm × 14 cm field of view. Scan time for each slab was 5 minutes 59 seconds. The shift between the centers of sequentially acquired transverse slabs was typically 30 mm, allowing for some overlap of the slabs, which is needed due to nonrectangular slab profiles. Typically, two or three 3-D transverse slabs were acquired for a total scan time of 12 or 18 minutes, respectively. The images obtained were postprocessed by using a maximum-intensity projection algorithm to produce projection images. End partitions of inferior quality from the 3-D acquisitions were not included for postprocessing.

Projection images obtained from the two-slab oblique 3-D sequence and multislab transverse 3-D sequences were compared in three respects: 1) anatomic depiction of vessels, 2) flow contrast, and 3) accuracy of demonstration of pathology (based on the results of seven cases of conventional angiography). Flow contrast was calculated as (flow signal − stationary tissue signal)/(flow signal + stationary tissue signal). The flow signal was measured with a region of interest in the vessel lumen at the carotid bifurcation. The signal intensity of stationary tissue was measured adjacent to the carotid bifurcation. The size of regions of interest for both flow and tissue were typically 6 × 6 pixels. Flow contrast was compared for the two types of acquisitions using a paired Student's *t*-test.

The accuracy of MR angiography was evaluated in a nonblinded manner by an experienced neuroradiologist using the following five-point grading system for all studies: 1) normal; 2) mild stenosis of the internal carotid artery (<50% diameter reduction in the sagittal plane); 3) moderate stenosis of the internal carotid artery (50% to 75% diameter reduction in the sagittal plane); 4) severe stenosis of the internal carotid artery (>75% diameter reduction in the sagittal plane); and 5) occlusion of the internal carotid artery. In addition, note was made of any artifacts in the MR images.

Results

Anatomic Depiction of Vessels

Of the 44 carotid arteries (22 subjects) studied with the two-slab oblique sagittal sequences, 41 arteries were demonstrated, three were not visualized (one a technical error due to improper angulation, two due to occlusion of the common carotid artery).

Of 36 carotid arteries (18 cases) studied with multislab transverse 3-D acquisitions, 34 arteries were demonstrated, and two were not seen due to occlusion. There was significant discontinuity of the carotid arteries at the junction of sequential 3-D slabs in six arteries (17%) due to patient motion between slabs (Fig. 2). A linear artifact between slabs could be seen on projection images in all arteries, but did not interfere with interpretation.

The two-slab oblique method usually showed greater lengths of the common and internal carotid arteries (7.2–15.1 cm, mean 12.5 cm) than the multislab transverse studies (two slabs: 6.8–8.2 cm, mean 7.3 cm; three slabs: 9.5–11.1 cm, mean, 10.4 cm; all: 6.8–11.1 cm, mean 7.8 cm). The visualized length of the carotid arteries by the two-slab oblique method was 71% longer than that for the two-slab transverse and 20% longer than for the three-slab transverse acquisitions. However, the proximal portion of the common carotid artery was occasionally truncated on the obliquely acquired images, although this never interfered with image interpretation.

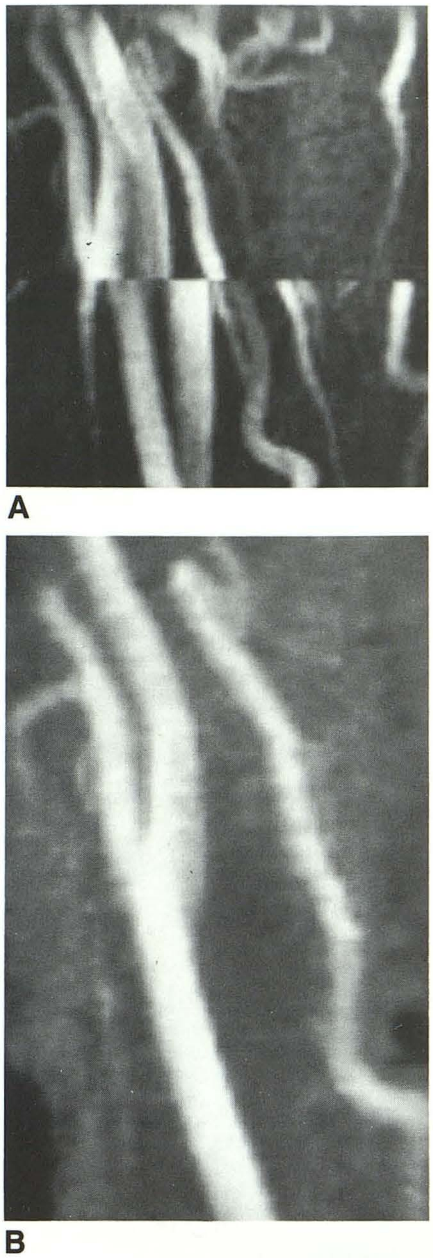


Fig. 2. Discontinuity artifact.

A, On a multislab transverse 3-D MR angiogram, there is a significant discontinuity of the carotid artery at the junction of sequential 3-D slabs.

B, Oblique sagittal MR angiogram shows a normal carotid artery.

Flow Contrast

For all subjects, the mean of flow contrast for the two-slab oblique method was 0.34 (range, 0.24–0.46; SD 0.07) and for the multislab transverse 3-D method 0.45 (range, 0.24–0.58; SD 0.08), with a significant difference between the means (P = .0001). In the one subject studied with a direct sagittal two-slab 3-D acquisition, the average of the flow contrast for the two carotid arteries was 0.21, much lower than that for the two-slab oblique scan (0.41) and for the 3-D transverse scan (0.52) (Fig. 3).

Demonstration of Pathology

Of the 22 cases, nine cases were normal, which included five healthy subjects and four patients. Three patients had disease on one side (one stenosis of the internal carotid artery, one stenosis and one occlusion of the common carotid artery). Ten patients had disease on both sides in which 16 internal carotid arteries (15 stenoses, one occlusion) and four common carotid arteries (two stenoses, two occlusions) were involved. All disease found using the multislab transverse 3-D studies was detected with the two-slab oblique method (Figs. 4 and 5). Comparison of the two-slab oblique and multislab transverse studies in the seven cases with conventional angiography showed that both MR angiography techniques correctly graded the carotid lesions in all arteries (grade 1, three arteries; grade 2, two arteries; grade 3, one artery; grade 4, six arteries; grade 5, two arteries).

Discussion

Our results indicate that the simple procedure of using a slightly obliqued 3-D acquisition is an effective means for reducing saturation effects when the body coil is used as transmitter. Compared with a direct sagittal acquisition, flow contrast is greatly improved. The reason is that, unlike the direct sagittal acquisition, the obliquely oriented 3-D slab does not encompass the heart, aortic arch, or proximal common carotid artery (Fig. 1), so that saturation effects are minimized. Compared with a multislab transverse 3-D acquisition, a greater length of the carotid arteries is depicted and scan time is much less.

Masaryk and coworkers (2, 4) used a linearly polarized head coil for their extracranial carotid studies. In our experience, it may be difficult to encompass the carotid bifurcation in some subjects using this coil, so we generally use a Helmholtz coil as the receiver with the body coil as transmitter. Dedicated vascular coils that function as both transmitters and receivers will soon come into use (5), and may overcome much of the problems with saturation effects; however, this type of coil is not currently available to us.

Given that the "optimal" scan variables for transverse and oblique sagittal acquisitions are

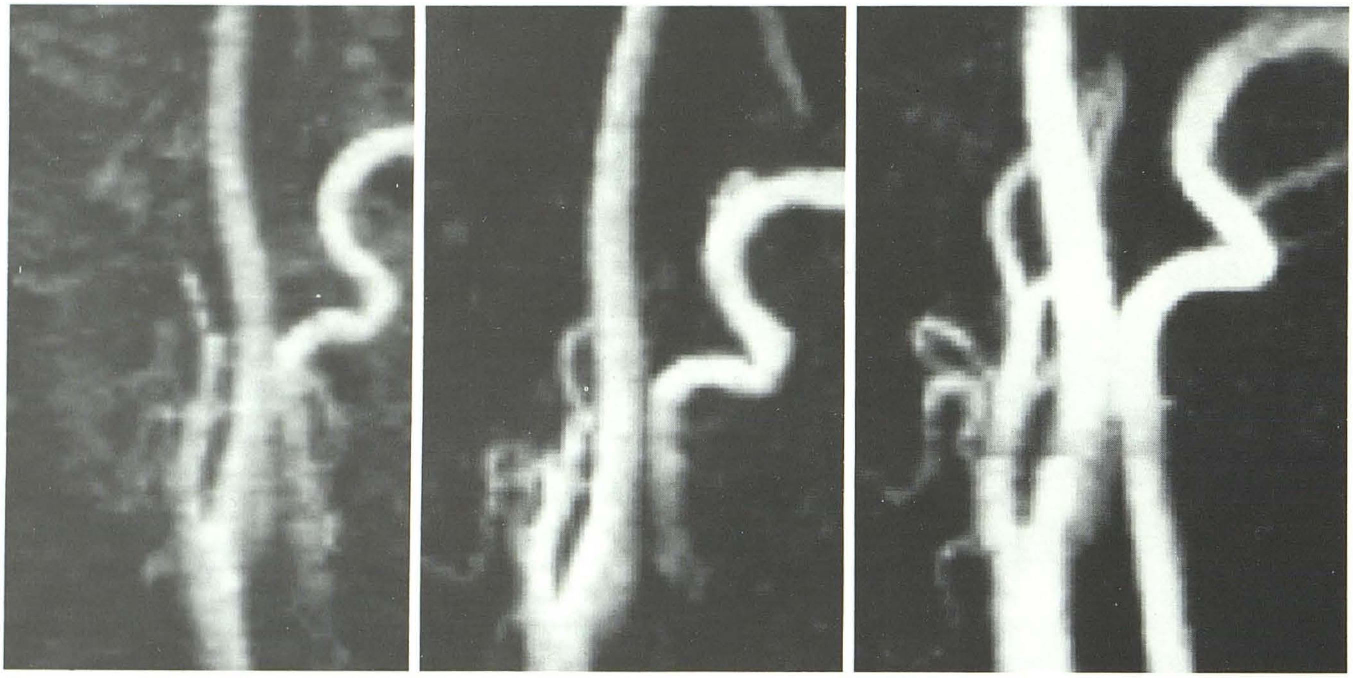


Fig. 3. Comparison of MR angiograms obtained with different techniques in a healthy volunteer.

A, MR angiogram obtained from direct sagittal two-slab 3-D acquisition. The average flow contrast was 0.21.

B, MR angiogram obtained from oblique sagittal two-slab 3-D acquisition. The average flow contrast was 0.41.

C, MR angiogram obtained from multislab transverse 3-D acquisition. The average flow contrast was 0.52. A linear artifact between slabs can be seen.

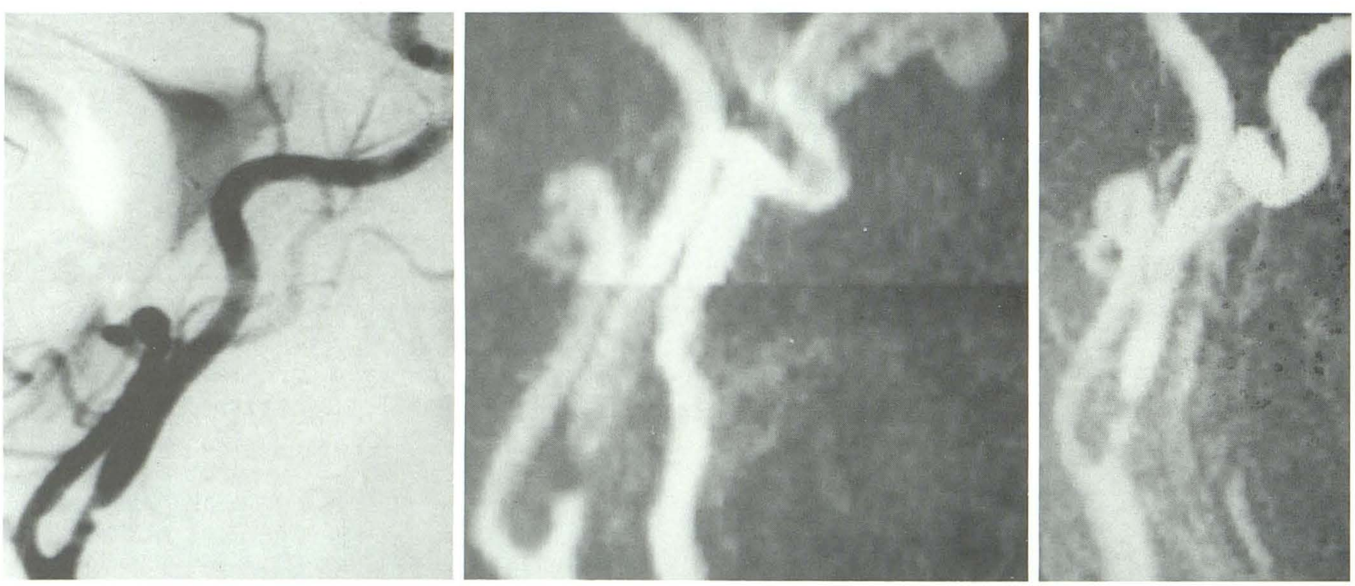
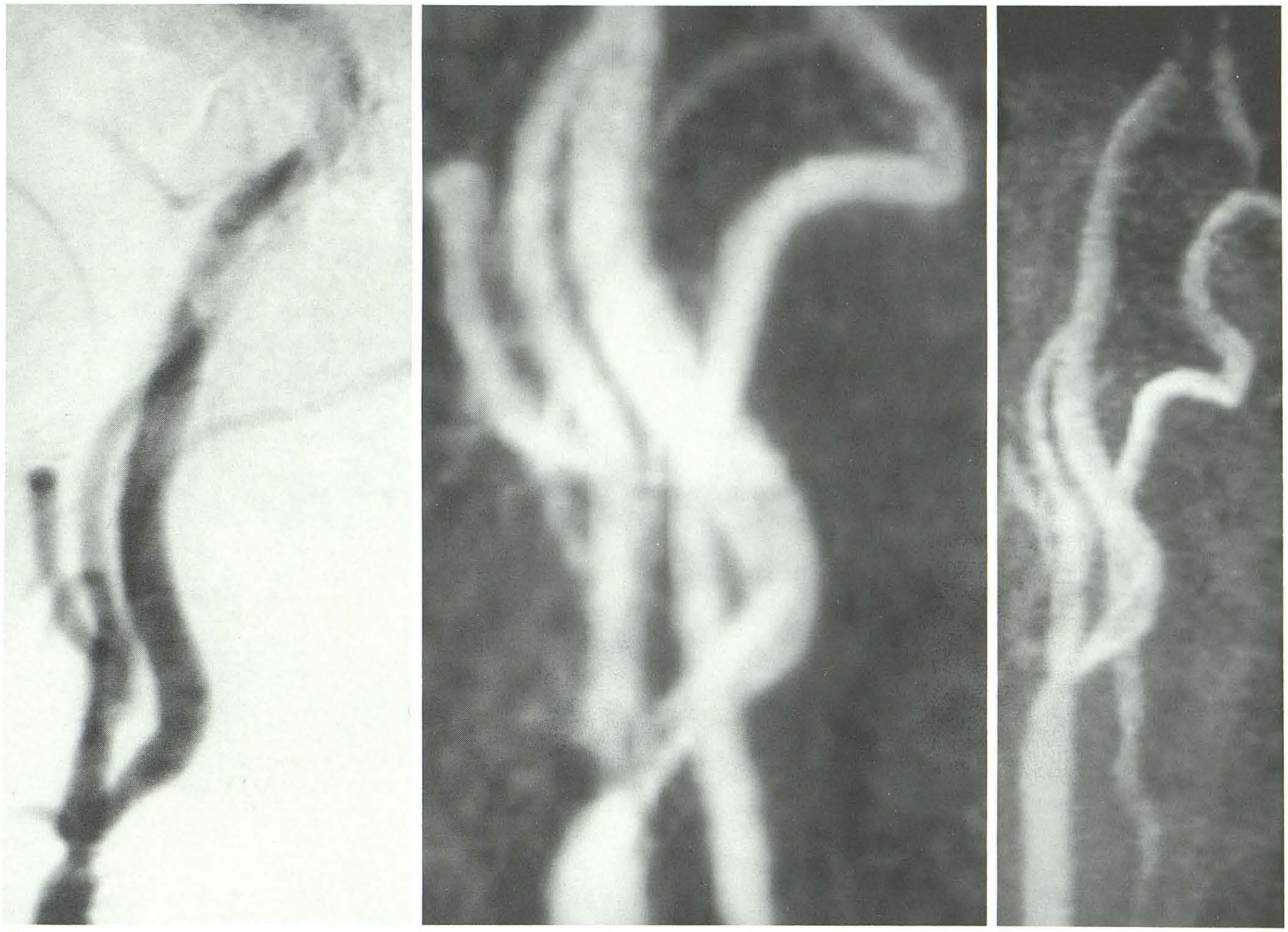


Fig. 4. Stenosis of left internal carotid artery.

A, A conventional selective carotid angiogram shows a severe stenosis at the proximal left internal carotid artery, approximately 1.5 cm from the bifurcation. The more proximal segment of the left internal carotid artery is circumferentially narrowed by plaque.

B, Multislab transverse 3-D acquisition, and *C*, two-slab oblique sagittal MR angiograms show the stenosis, but *C* has better correspondence with the conventional angiogram.



A B C

Fig. 5. Stenosis of the common and internal carotid artery.

A, A conventional angiogram shows a stenosis involving the distal segment of the left common carotid artery and narrowing of the proximal left internal carotid artery.

B, Multislab transverse 3-D acquisition, and *C*, two-slab oblique sagittal MR angiograms show the stenosis, which appears slightly exaggerated in both, but the two-slab oblique sagittal MR angiogram shows better correspondence with the conventional angiogram.

different, we cannot make a precise comparison between the results of the two sequences from our study. The multislab transverse 3-D acquisition minimizes saturation effects if the slab thickness is kept relatively small (6). As a result, we use this approach for all our carotid studies. Two problems are often encountered. First, nonrectangular slab profiles result in a linear artifact on projection images at the junctions of the slabs. Second, patient motion between or during acquisition of sequential slabs may cause a discontinuity artifact. The two-slab oblique 3-D acquisition does not suffer from either artifact, and a greater length of the vessel is seen for a given total scan time. Postprocessing of the oblique images also tends to be more straightforward than when one has to deal with multiple overlapping images with the multislab 3-D approach. On the other hand, flow contrast was slightly better for the multislab transverse acquisitions. A potential limitation of oblique acquisitions is that two gradients must be activated simultaneously for position encoding. Since the vectorial sum of two gradients is less than for a single orthogonal gradient, peak gradient capabilities may be exceeded for oblique acquisitions. This requires an increase in slice thickness or echo time. However, the required degree of obliquity was so slight for our studies that this problem was insignificant.

Finally, a limitation intrinsic to 3-D acquisition methods is saturation of slowly flowing blood. If a long segment of the common carotid artery is included in an oblique 3-D slab, then slow or recirculating flow distal to an ulceration or a critical stenosis might become saturated, causing loss of flow contrast. Slow flow is better imaged by multislice 2-D techniques.

Conclusion

Use of an oblique 3-D sequence seems to be an effective means for overcoming saturation effects for MR angiography of the extracranial carotid arteries when the body coil is used as transmitter. Extrapolating from the results of previous studies using direct sagittal acquisitions in a head coil for evaluation of the extracranial carotid arteries (4), it is likely that a single two-slab oblique acquisition will prove sufficient for detection and grading of carotid stenoses.

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