Intracranial MR Angiography: A Direct Comparison of Three Time-of-Flight Techniques

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During the past few years, several time-of-flight MR angiographic techniques have been described for rapid, reliable, noninvasive vascular evaluation. This investigation was performed to directly compare three time-of-flight methods in imaging the intracranial vasculature: a single-volume method, a sequential two-dimensional slice technique, and a technique using the sequential acquisition of multiple thin volumes. Thirty-two normal volunteers were imaged, and direct comparisons of the three techniques were performed in 20 subjects. Analysis of the resulting images revealed optimal depiction of large vessels with the single-volume and multiple thin-volume methods, small vessels with the multiple thin-volume technique, and venous structures with the sequential two-dimensional slice acquisition. The effects of progressive spin saturation in time-of-flight MR angiography are discussed along with the individual benefits and disadvantages of each method.

We conclude that the diagnostic value of intracranial time-of-flight MR angiography can be maximized through tailoring the angiographic method to the suspected abnormality based on the requirements for spatial resolution and slow-flow sensitivity, as suggested by the clinical history or prior imaging studies.

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Intracranial MR angiography based on both time-of-flight (TOF) and phase-sensitive methods has been described for the noninvasive evaluation of many vascular abnormalities, including aneurysms, arteriovenous malformations, occlusions, and venous thromboses [1–10]. Each of the techniques used in these investigations displayed advantages and limitations. The single-volume three-dimensional Fourier transformation (3DFT) TOF technique has demonstrated rapid, reliable visualization of the intracranial circulation in many of these applications [1, 2, 4, 10]. However, the effects of progressive saturation of inflowing spins present a major limitation to this method, limiting visualization of venous anatomy, slow-flow lesions, and distal vasculature in thick imaging volumes [6, 9]. Several TOF methods have been proposed to reduce the manifestations of spin saturation based on the acquisition of thinner slices or volumes [3, 5, 9] (Lewin JS et al., presented at the annual meeting of the Radiological Society of North America, November 1989; Parker DL et al., presented at the annual meeting of the Society for Magnetic Resonance in Medicine, August 1990). The purpose of this study was to directly compare three intracranial TOF MR angiographic techniques under equivalent imaging conditions to evaluate vessel visualization, the effects of progressive spin saturation, and the strengths of each technique in the diagnosis of vascular disease.

Subjects and Methods

The study population consisted of 32 healthy volunteers. Imaging parameters and volume-excitation RF pulses were evaluated and adjusted in the first 12 volunteers, and comparison of the three techniques was made under equivalent imaging conditions in the final 20 subjects.

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Informed consent was obtained from each subject after the nature of the examination was fully explained.

All studies were performed on a standard superconducting 1.5-T whole-body system (Siemens Magnetom, Erlangen, Germany) with a 10-mT/m gradient capability and a transmit/receive, circularly polarized head coil. Postprocessing with a maximum-intensity-projection (MIP) algorithm was done to provide an angiographic display. The three TOF techniques that were compared included a single-volume technique, a multiple thin-volume technique, and a sequential two-dimensional (2-D) slice technique (Fig. 1).

The single-volume method used a 3DFT gradient-echo sequence, fast imaging with steady precession (FISP), with velocity-compensation gradients in the read and slice-select directions, 40/7/1 (TR/TE/excitations), a 15° flip angle, a 256 × 256 matrix with a 200-mm field of view, and a single 64-mm excitation volume divided into 64 1-mm-thick partitions [1]. Total examination time was 11 min.

The multiple thin-volume method used a similar 3DFT gradient-echo FISP sequence with velocity-compensation gradients in the read and slice-select directions, 25–40/7/1 (TR/TE/excitations), 25° flip angle, and 256 × 256 (12 subjects) or 192 × 256 (eight subjects) matrix with a 200-mm field of view. The volume of interest was covered by acquiring sequential thin 16-partition volumes: either five 24-mm volumes with a 1.5-mm partition thickness (11 subjects) or six 16-mm volumes with a 1.0-mm partition thickness (nine subjects). Adjacent volumes were overlapped three partitions at each end (3.0–4.5 mm) [9] (Lewin et al., RSNA, November 1989). Total examination time was 9–12 min.

The sequential 2-D slice method consisted of a two-dimensional Fourier transformation (2DFT) gradient-echo sequence, fast low-angle shot (FLASH), with velocity-compensation gradients in the read and slice-select directions, 25/10/1 (TR/TE/excitations), a 60° flip angle, and a 256 × 256 (13 subjects) or 192 × 256 (seven subjects) matrix with a 200-mm field of view. Sequential 3-mm slices were obtained with 1 mm of overlap to cover the region of interest [3, 5]. Total examination time was 8–10 min.

For the comparison portion of the study, axial three-dimensional data sets were obtained with each method, covering equivalent 64-mm-thick volumes centered slightly above the circle of Willis. A direct axial MIP reconstruction of each of the three techniques was compared for each subject, with assessment of image quality with respect to several factors.

Large vessel definition was determined by examination of the supraclinoid carotid bifurcation, primary bifurcation of the middle cerebral artery, and anterior limb of the carotid siphon for evidence of signal loss from motion-induced dephasing (flow voids).

Small vessel resolution was evaluated by inspection of cortical vascular branches in the anterior, middle, and posterior cerebral artery distributions and by visualization of the ophthalmic, posterior communicating, and superior cerebellar arteries. Note was made of the technique revealing the largest number of uninterrupted opercular branches of the middle cerebral arteries and the longest segments of posterior temporal, parietooccipital, and calcarine branches of the posterior cerebral arteries in each volunteer.

The venous system was evaluated through examination of the internal cerebral veins and the straight, sphenoparietal, and transverse venous sinuses.

Results

The best definition of large-vessel bifurcations was observed with the volume inflow studies, with both the single-volume and multiple thin-volume techniques equivalent at providing reliable large-vessel images with a minimum of flow voids or vascular discontinuities (Figs. 2A and 2B). The number of bifurcations and carotid siphons imaged without artifactual narrowing or interruption is presented in Table 1.

Small-vessel detail was best provided with the multiple thin-volume method (Fig. 2B). The number of examinations providing visualization of multiple small cortical branches of the anterior, middle, and posterior cerebral arteries, and the number of ophthalmic, posterior communicating, and superior cerebellar arteries demonstrating definite flow, are detailed in Table 2. Posterior communicating arteries were included in this table only when seen in their entirety on the axial MIP reconstruction, even though many other partial posterior communicating arteries were observed.

Examination of the individual partitions or slices from the data sets prior to postprocessing supplied better definition of small communicating arteries than any of the postprocessed angiograms, supporting previous reports suggesting that information is lost in the MIP postprocessing technique [11] (Fig. 3).

While the number of examinations revealing the presence of small cortical branches is noted in Table 2, the best definition of small uninterrupted middle cerebral artery branches was obtained with the multiple thin-volume method

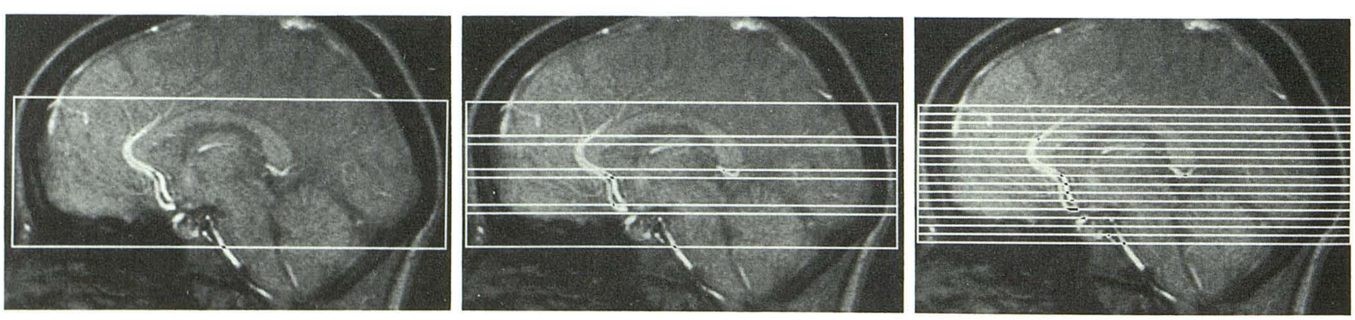
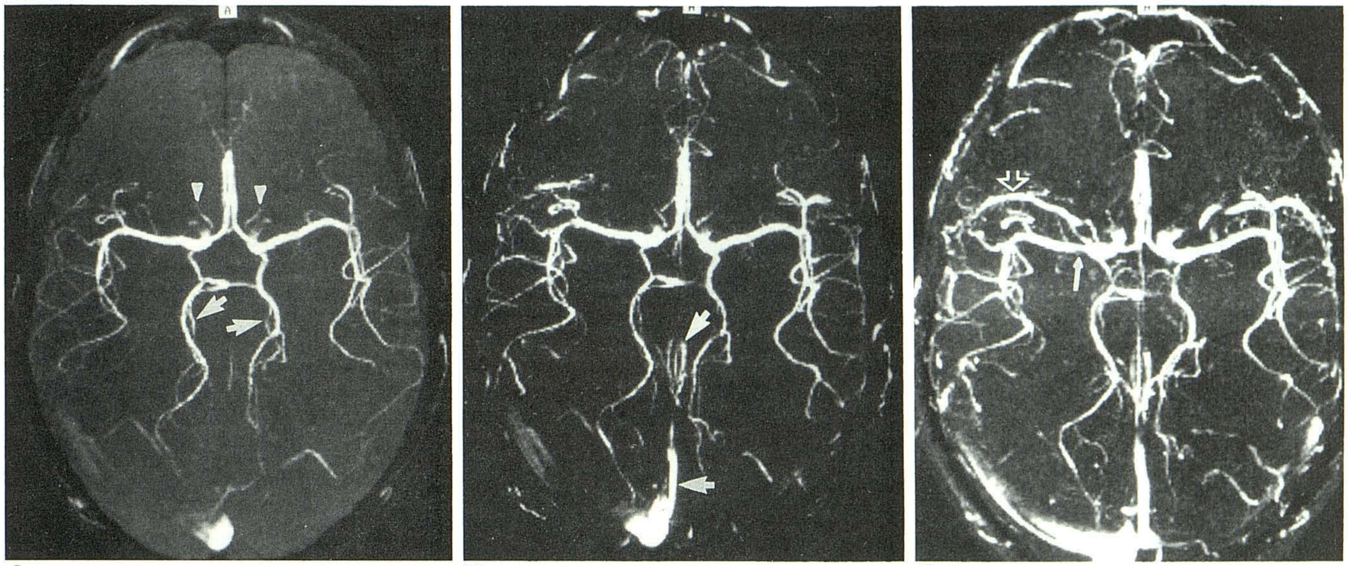

A B C

Fig. 1.—Three different time-of-flight MR angiographic techniques.

A, Single-volume technique. Region of interest (*box*) is acquired with a single 3DFT acquisition.

B, Multiple thin-volume technique. Equivalent region of interest is covered by several overlapping thin 3DFT acquisitions (only four volumes shown for clarity, either five or six 16-partition volumes used in study).

C, Sequential 2-D slice technique. The same region of interest is covered by multiple thin, overlapping 2DFT slices (not to scale). Thirty-one 3-mm-thick slices with 1 mm of overlap were used in the study.



A B C

Fig. 2.—Axial maximum-intensity-projection reconstructed angiograms.

***A*, Single-volume method. Good signal is noted in proximal portions of anterior, middle, and posterior cerebral arteries. Many cortical branches in middle and posterior cerebral distributions are noted, along with bilateral posterior communicating arteries, proximal ophthalmic arteries (*arrowheads*), and superior cerebellar arteries (*arrows*).**

***B*, Multiple thin-volume method. Again, proximal portions of anterior, middle, and posterior cerebral arteries are well visualized, along with posterior communicating arteries and portions of ophthalmic and superior cerebellar arteries. More small cortical branches are noted as compared with single-volume technique. Signal within internal cerebral veins and straight sinus is also noted (*arrows*).**

***C*, Sequential 2-D slice method. Slight artifactual narrowing is noted in region of right supraclinoid carotid bifurcation (*solid arrow*), but remainder of proximal large arteries are well visualized. Numerous cortical vessels, posterior communicating arteries, and portions of ophthalmic and superior cerebellar arteries are seen. In addition to internal cerebral veins and straight sinus, sphenoparietal (*open arrow*) and right transverse sinus are much better visualized than with other methods. However, more slowly flowing in-plane spins in left transverse sinus are not visualized owing to persistent spin saturation.**

(Note.—Anterior limb of carotid siphon is not entirely included in region of interest, precluding adequate evaluation for flow void in this region in this subject.)

TABLE 1: Large-Vessel Visualization with Three Different Time-of-Flight MR Angiographic Techniques

Structure	No. Visualized Satisfactorily		
	Single-Volume Method	Multiple Thin-Volume Method	2-D Slice Method
Supraclinoid bifurcation	38/40	38/40	16/40
Middle cerebral artery bifurcation	34/40	33/40	26/40
Anterior limb of siphon	16/20	15/20	14/20

Note.—The anterior limb of the carotid siphon was not included in the imaging volumes in 10 subjects (20 carotid siphons).

TABLE 2: Small-Vessel Visualization with Three Different Time-of-Flight MR Angiographic Techniques

Structure	No. Visualized Satisfactorily		
	Single-Volume Method	Multiple Thin-Volume Method	2-D Slice Method
Anterior cerebral artery branches	8/20	18/20	18/20
Middle cerebral artery branches	19/20	19/20	17/20
Posterior cerebral artery branches	20/20	19/20	11/20
Ophthalmic artery	26/40	30/40	15/40
Posterior communicating artery	15/40	15/40	9/40
Superior cerebellar artery	17/40	20/40	15/40

in 13 subjects, single-volume technique in four subjects, and sequential 2-D slice method in three subjects. The best uninterrupted visualization of small branches of the posterior cerebral artery was provided with the single-volume method in 13 subjects and the multiple thin-volume technique in the remaining seven cases.

Venous sinuses and subependymal veins were best visualized with the sequential 2-D slice method (Fig. 2C), as noted in Table 3. While the multiple thin-volume method also demonstrated flow in many venous structures, in no case was a vein or sinus seen on the multiple thin-volume method and not on the sequential 2-D slice technique. The single-volume technique did not demonstrate venous structures smaller than the transverse sinus in any examination.

Motion artifacts causing widespread vessel discontinuity were seen in one case each with the sequential 2-D slice and multiple thin-volume techniques. No significant artifacts were noted with the single-volume technique.

Discussion

TOF MR flow effects are based on the macroscopic motion of spins having longitudinal magnetization. Typically, the magnetization of a bolus of blood is modified, or tagged, often through relaxation or inversion, allowing protons flowing into

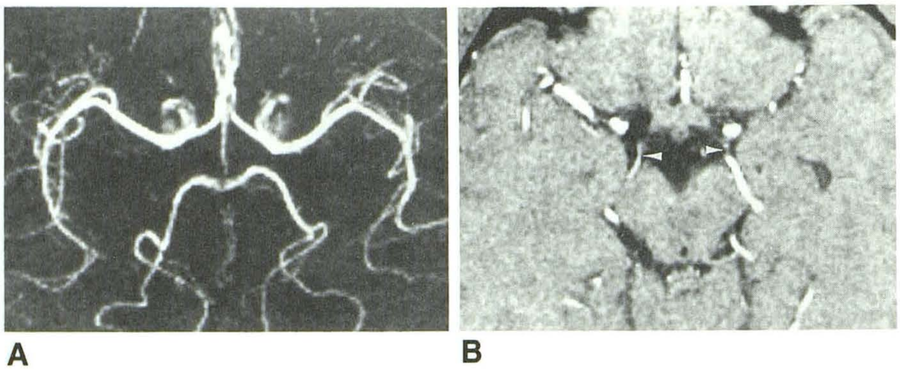


Fig. 3.—Visualization of posterior communicating artery.

A, **Axial maximum-intensity-projection reconstruction of single-volume technique. No definite signal is noted in posterior communicating arteries.**

B, **On a single partition from original 3-D data set, both right and left posterior communicating arteries are clearly visualized (*arrowheads*). Remaining portions of right artery were seen on adjacent partitions.**

TABLE 3: Venous Delineation with Three Different Time-of-Flight MR Angiographic Techniques

Structure(s)	No. Delineated		
	Single-Volume Method	Multiple Thin-Volume Method	2-D Slice Method
Internal cerebral veins	0/20	16/20	20/20
Straight sinus	0/20	19/20	20/20
Sphenoparietal sinus	0/40	18/40	25/40
Transverse sinus	1/22	12/22	15/22

Note.—The transverse sinuses were not included in the imaging volumes in nine subjects (18 sinuses).

the imaging volume to be distinguished from surrounding stationary tissue [12–17] (Sardashti M et al., presented at the annual meeting of the Society of Magnetic Resonance in Medicine, August 1989).

The contrast between blood and stationary tissue in the inflow-based methods described in this study results from one type of TOF effect termed flow-related enhancement, which occurs when partially saturated spins within the imaging slice are replaced by inflowing unsaturated or fully magnetized spins. If the TR is short compared with the longitudinal relaxation rate (T1), the signal from stationary material is attenuated, while the signal from fully relaxed inflowing spins remains high. Thus, the bright vessels seen with flow-related enhancement result from relative attenuation of the stationary tissue rather than from an intrinsic quality of the inflowing spins [12, 13].

Flow-related enhancement was observed and described early in MR imaging, initially referred to as *paradoxical enhancement* with spin-echo sequences [12, 13, 18, 19], and was subsequently exploited for vascular imaging with low-flip-angle 2DFT gradient-echo sequences by Wehrli et al. [16, 17]. This technique was modified by Laub et al. [1, 20] with implementation of a 3DFT acquisition method in which a thick volume of tissue was excited, encompassing the entire region of interest. These data were subsequently postprocessed by using an MIP ray-tracing algorithm, projecting the three-dimensional data set onto a 2-D plane to facilitate interpretation.

While rapidly flowing arterial blood was well visualized with this single 3DFT volume method, loss of visualization of more slowly flowing blood was noted. Two TOF methods were subsequently described that allowed improved slow-flow sensitivity. The first technique resembled the earlier cross-sectional vascular imaging of Wehrli et al. [16, 17] in its use of very thin 2DFT gradient-echo slices, allowing negligible saturation of even the slowest inflowing blood within the imaging slice. The application of MIP postprocessing to a series of contiguous or slightly overlapping slices was first described by Edelman et al. [3] and Keller et al. [5], allowing evaluation of the data in an easily interpretable angiographic format, equivalent to that described for the volume technique, and demonstrating improved visualization of slowly flowing venous blood [3, 6]. The second TOF method with improved slow-flow sensitivity was the multiple thin-volume approach, initially described in the head by Marchal et al. [9]. This technique used multiple sequentially acquired thin 3DFT volumes, approximately 32 mm in thickness, to cover the region of interest, allowing visualization of more slowly flowing blood than possible with the single thick-volume technique.

Two factors that are important for the successful production of MR angiograms with inflow MR angiographic techniques have been described by Ruggieri et al. [1]. First, flow-related enhancement must be maximized through use of an imaging volume oriented perpendicularly to the inflowing blood and through optimization of the TR and flip angle. Second, signal loss from intravoxel phase dispersion must be minimized by using constant-velocity flow-compensation gradients combined with the shortest available TEs to reduce signal loss from flow-induced phase cancellation. The small voxels resulting from the extremely thin slices available with volume image acquisition further reduce signal loss from phase effects by limiting the effective range of motion-induced phase shifts across the smaller voxel.

The result of our investigation support this earlier work, demonstrating excellent visualization of the larger intracranial arteries with the thick single-volume approach (Fig. 2A). Unfortunately, as described in previous reports [6, 9], this study also revealed limited visualization of the smaller, more distal arterial structures, with venous detail almost absent with the single-volume technique. These findings are primarily related to the effects of progressive spin saturation. While the flow-related enhancement obtained with this method is very high at the point that a vessel enters the imaging volume, the inflowing spins undergo saturation as the blood traverses the region of excitation, resulting in progressively diminishing contrast. A total loss of flow-related enhancement occurs after the flowing spins have been present within the imaging volume for a time period on the order of magnitude of the longitudinal relaxation time (T1) of blood (Fig. 4). The distance into the imaging volume in which contrast remains sufficient to visualize a vessel depends on the TR, flip angle of excitation, blood velocity, and T1 of blood. Thus, with a thick-volume acquisition, only rapid arterial blood flow retains sufficient flow-related enhancement to be successfully imaged throughout the volume, with more slowly moving venous or pathologically slowed arterial flow unable to span the entire volume before becoming sufficiently saturated to prevent visualization.

Several methods can be used to minimize this progressive saturation of inflowing spins in TOF MR angiography. Decreasing the flip angle and increasing the TR both serve to increase the depth that inflowing spins penetrate the imaging volume before saturation [1]. However, an increased TR results in longer examinations and T1 relaxation of stationary tissue, while a decreased flip angle decreases the signal-to-noise ratio and reduces the degree of spin saturation of the stationary material, resulting in decreased contrast of inflowing blood to stationary tissue. In practice, the TR of 40 msec and flip angle of 15° used with the 64-mm single-volume technique in this investigation allowed arterial blood to reach the small, distal vessels with a relatively small degree of progressive spin saturation (Fig. 2A).

Loss of visualization of more slowly flowing blood can be prevented by decreasing the slab thickness, allowing the slowly flowing spins to cross the entire volume before becoming saturated. The most effective use of this strategy is the acquisition of thin slices with the sequential 2-D slice technique. The primary advantage of this method, its high sensitivity to slow flow, was demonstrated in our study in the excellent visualization of venous structures this method provided (Fig. 2C). The diminished progressive spin saturation observed with these thin slices also allowed the use of a higher flip angle, which increased contrast between the inflowing blood and stationary tissue, and a shorter TR, which decreased the length of the examination. Unfortunately, although spin saturation is greatly reduced, it cannot be eliminated entirely. Its persistent effects may still be observed when imaging slow, in-plane blood flow (Fig. 2C).

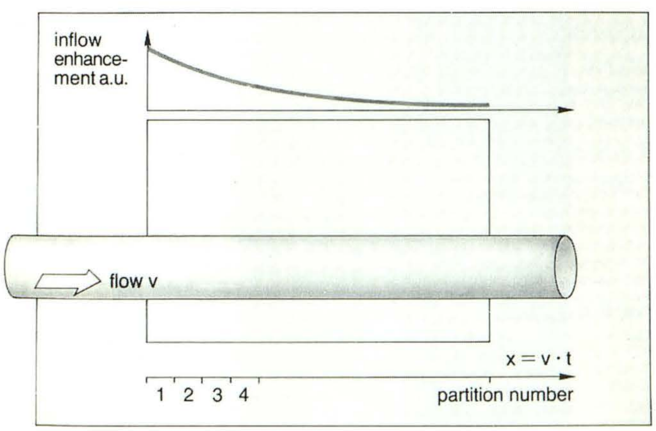


Fig. 4.—Spin saturation in volume techniques: inflow enhancement in arbitrary units (a.u.) vs partition number for perpendicular flow. While inflow enhancement is high in partition 1, level of enhancement decreases within each subsequent partition. The amount of time blood retains sufficient signal to be visualized (t) depends on the longitudinal relaxation time of blood (T1), TR, and flip angle of excitation. The distance (x) into volume that blood can travel during this period depends on the velocity of inflowing spins (v), with rapidly flowing spins traveling farther than slowly flowing spins during the same time.

Although an excellent method for displaying venous flow, several disadvantages of the sequential 2-D slice technique can be noted when compared with the volume acquisition method. The first important distinction is the relative thickness of the 2DFT imaging slice (3 mm in this investigation) compared with the individual partition of the volume method (1 mm). This results in a decrease in spatial resolution in the slice-select direction, most notable when MIP processing is performed parallel to the slices (Figs. 5A and 5B). The increased slice thickness also results in an enlarged voxel, which will theoretically increase the vulnerability of this method to signal loss from intravoxel phase dispersion in regions of nonuniform flow, and from magnetic susceptibility artifact [21]. These effects most likely explain the difficulty this technique demonstrated, as compared with the volume acquisition methods, in visualizing the supraclinoid carotid and primary middle cerebral artery bifurcations.

Although the use of this technique with slices of 1.5–2 mm in thickness has been reported [5], achieving a thin rectangular slice profile can be difficult. To excite a thin slice with a reasonably rectangular profile, the slice-selective RF and gradient pulse combination must be applied over a longer time period. This longer pulse increases the time for flow-induced phase dispersion to occur in the slice-select direction, and prolongs the minimum attainable TE. Although gradients for compensation of constant-velocity flow are used to decrease phase dispersion, similar to those described for the volume method, the longer TE of the 2DFT acquisition results in a geometric increase in signal loss from higher-order motion (acceleration, jerk), further contributing to the areas of signal void in regions of nonuniform flow at the major vascular bifurcations observed in this study.

The visualization of intracranial vasculature with the multiple thin-volume method in this investigation suggests that slow flow is imaged almost as well as with the sequential 2-D slice technique. Furthermore, the use of multiple thin volumes retains the benefits of the 3DFT acquisition scheme such as shorter TE, higher spatial resolution with thin partition thickness, and better signal-to-noise ratio than with the 2DFT sequential 2-D slice method, providing many of the advantages of these other two techniques without their limitations. The individual volumes must be overlapped to avoid volume aliasing or wraparound artifact in the slice-select direction, requiring increased imaging times as compared with the single 3DFT volume and sequential 2-D slice techniques. Insufficient overlap can cause loss of vascular information between volumes (Fig. 5C), while higher degrees of overlap further increase total examination time (Fig. 5D). The potential exists for misinterpretation at the site of the junctional artifact that may occur at these boundaries owing to loss of vessel definition and artifactual vascular discontinuity, especially

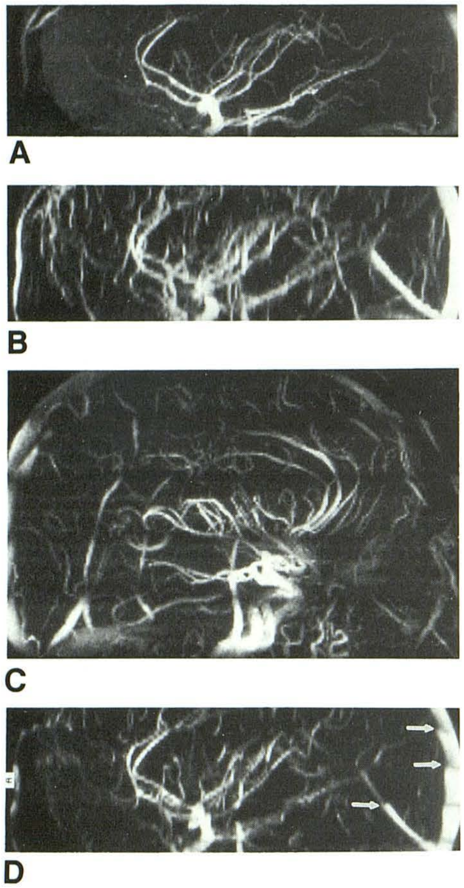


Fig. 5.—Lateral maximum-intensity-projection reconstruction.

A, Single-volume method. The 1-mm partition thickness results in smooth-appearing, sharply defined vessels.

B, Sequential 2-D slice method. Thicker slices of this technique, with effective 2-mm resolution in slice-select direction, result in somewhat blurred vessels with staircase appearance of oblique vessels.

C, Multiple thin-volume method (different subject, five 32-mm-thick volumes). Slightly different technique with inadequate overlap between adjacent volumes reveals a junctional artifact with variation in background and vascular signal where contiguous volumes meet.

D, Multiple thin-volume method (same subject as in *A* and *B*). With 35% overlap, minimal variation in arterial and background signal is noted at junctions of adjacent volumes. Junctional artifact is still noted within venous structures owing to spin saturation effects (*arrows*; see text). Use of 1.5-mm partition thickness in this subject results in some blurring of vessels as compared with single-volume technique (*A*).

when small structures such as aneurysms are being sought. This source of error can best be minimized by reconstructing and evaluating each thin volume separately when an area of clinical interest or apparent abnormality falls at the junction of two volumes. While an overlap of approximately 35% was necessary in this investigation owing to a nonrectangular volume excitation profile, the appropriate degree of overlap will vary with optimization of the RF profile (Lewin et al., RSNA, November 1989; Parker et al., SMRM, August 1990).

The effects of persistent spin saturation in the multiple thin-volume method were still noted in this investigation as a difference in contrast of slowly flowing blood at the junction of adjacent volumes, where the entry slice partition of one volume meets the exit slice partition of the next (Fig. 5D). Progressive spin saturation can also be seen with slowly flowing blood in vessels coursing for a distance within the thin volume, observed in the slightly poorer visualization of venous structures when compared with the sequential 2-D slice technique. This effect may be noted with the draining veins of a vascular malformation as well [9].

Better visualization of the small, distal branches of the posterior cerebral artery with the single-volume technique than with the multiple thin-volume method, noted in 13 subjects in this study, can be explained by examining the effects of progressive spin saturation in these vessels. Unlike the middle cerebral arteries, which course through several volumes in the multiple thin-volume technique, the basilar and posterior cerebral arteries reside almost entirely in the lowermost volume of the multiple-volume technique in the majority of subjects. Thus, no decrease in spin saturation would be expected with the acquisition of multiple volumes. Furthermore, the shorter TR and higher flip angle of the multiple thin-volume method act to increase the effects of spin saturation within each individual thin volume. These findings suggest that the use of a longer TR and lower flip angle may be justified with this technique when a large component of in-plane flow is anticipated.

The findings of this study suggest that artifacts in TOF MR angiography depend on the method used. When motion occurs between the sequential acquisitions of the sequential 2-D slice or multiple thin-volume techniques, a discontinuity in the vessels at that level can be seen (Fig. 6), as was noted in one study with each of these two methods. When motion occurs during a 3DFT acquisition, it is spread throughout the entire volume during the 3DFT and results in an overall degradation in image quality without a focal artifact. Although

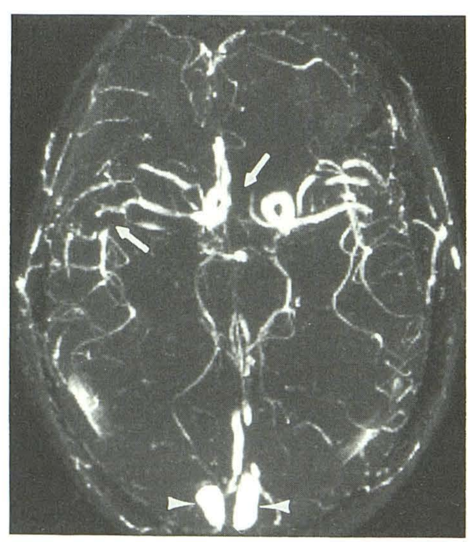


Fig. 6.—Discontinuity artifact. Motion occurring between slices in a sequential 2-D slice acquisition results in misregistration during reconstruction. Multiple artifactual discontinuities are noted (*arrows*), along with appearance of two superior sagittal sinuses (*arrowheads*).

this was not noted in this study population of healthy volunteers, the motion encountered with less cooperative patients in the clinical setting may result in this type of reduction in image quality.

In summary, signal loss from progressive saturation of inflowing spins is a general problem of TOF MR angiographic techniques that cannot be eliminated. The results of this effect on image quality, however, can be partially controlled through use of thinner imaging volumes or 2-D slices, with further reduction through the appropriate selection of flip angle, TR, and slice or volume orientation. The available TOF MR angiographic methods demonstrate different imaging characteristics, with high-resolution depiction of the proximal arterial circulation without discontinuity or signal void best provided with both the single thick-volume and multiple thin-volume methods, small-vessel visualization best obtained with the improved inflow of the multiple thin-volume technique, and venous structures best displayed with the sequential 2-D slice technique. The direct comparison in this investigation was limited by the use of a 1-mm partition thickness for the single three-dimensional volume, 1- or 1.5-mm thickness for the multiple thin-volume, and 3-mm slice thickness for the sequential 2-D slice technique. However, as these different thicknesses reflect those often present in the clinical application of these methods, the findings of this study nonetheless suggest that the evaluation of large vessels at the base of the brain, as might be necessary for investigation of a circle of Willis aneurysm or large vessel occlusive disease, can best be performed with the single-volume or multiple thin-volume technique. The examination of more distal arterial vasculature or somewhat slower flow, as required for evaluation of an arteriovenous malformation or the search for a peripheral aneurysm, can best be performed with the multiple thin-volume technique. Evaluation of venous sinus thrombosis, draining veins of an arteriovenous malformation, or other venous disease can best be performed with the sequential 2-D slice technique.

While trials in the clinical setting are necessary to further delineate the differential characteristics of these techniques in the presence of disease, our preliminary findings suggest that the diagnostic value of intracranial TOF MR angiography can be maximized through tailoring the angiographic method to the suspected abnormality based on the requirements for spatial resolution and slow-flow sensitivity, as suggested by the clinical history or prior imaging studies.

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The reader's attention is directed to the commentary on this article, which appears on pages 1141–1142.