Technical Innovation

Three-Dimensional Time-of-Flight Subtraction Angiography of Subacute Cerebral Hemorrhage

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Three-dimensional (3D) time-of-flight (TOF) MR angiography has been adopted as a technique for routine assessment of stenosis and occlusion of intracranial blood vessels. Difficulties in making a diagnosis arise when patients present with subacute hemorrhage in the region of interest [1, 2] because methemoglobin is hyperintense on 3D TOF MR angiograms. Incorporation of this signal hyperintensity to the maximum-intensity-projection reconstructed images may mask the arteries of interest or mimic vascular abnormalities. This study aimed to design an MR digital subtraction technique capable of removing hyperintense hematoma from 3D TOF MR angiograms.

Subjects and Methods

All MR imaging was performed using a 1.5-T whole-body MR scanner (Signa Horizon, Echospeed, software version 5.8, General Electric Medical Systems, Milwaukee, WI) equipped with high-speed gradients. Maximal gradient strength was 23 mT/m and slew rate was 120 T/m/ per second. A circularly polarized head coil was used.

Five adult patients (three men, two women; mean age, 53.5 years) with findings of subacute hemorrhage around the circle of Willis on conventional MR imaging were selected for the study. After completion of conventional MR imaging using the standard brain protocol, 3D TOF MR angiography was performed with a thick axial slab centered on the circle of Willis. The imaging parameters for the 3D TOF MR angiogram pulse sequence were TR/TE, 36/6.9; flip angle, 20°; number of partitions, 64; partition thickness, 1.2 mm; matrix size, 512 × 224; field of view, 22 × 16.5 cm; receiver bandwidth, ± 15.6 kHz; and number of excitation, 1. Flow compensation and magnetization transfer saturation techniques were used. A second set of MR angiograms was then acquired by repeating the data acquisition using the same pulse sequence, imaging parameters, and identical slice locations except that superior and inferior spatial saturation (i.e., presaturation) slabs were added. The purpose of applying presaturation slabs was to create flow voids of all intracranial blood vessels in the second set of MR angiograms.

After data acquisition, all the angiographic base images were transferred to the Advantage Windows workstation (software version 2.0, General Electric Medical Systems) for postprocessing. The first set of MR angiographic base images was subtracted from the second set of images on a pixel-by-pixel basis, thus producing a third set of subtracted base images. Multiplanar angiograms were obtained by maximum-intensity-projection reconstructions of the first set of base images and the third set of subtracted base images. The two resulting sets of MR angiograms were qualitatively assessed and compared.

Results

All patients had typical MR features of subacute hematoma, which appeared hyperintense on both T1- and T2-weighted MR images. In two patients, the site of hemorrhage was remote from the circle of Willis. Hence, the blood vessels were not masked by hyperintense hematoma on MR angiography. In the other three patients, the site of hemorrhage was close to the circle of Willis. Therefore, part of the area of the blood vessels on the MR angiograms was obscured by the hyperintense hematoma. In all patients, the hyperintense hematoma was completely removed from the MR angiograms in the third set of subtracted base images.

As an illustrative case, 3D TOF MR angiograms of a 44-year-old man with a history of hypertension who presented with sudden onset of right-sided weakness showed a large hematoma obscuring the M2 and M3 segments of the left middle cerebral artery (Fig. 1A). A left vertebral artery aneurysm was displayed. The hematoma was removed on subtracted 3D TOF MR angiograms, and the M2 and M3 segments were clearly visible. No evidence was seen of an aneurysm (Figs. 1B and 1C). The left middle cerebral artery was slightly attenuated. The left vertebral artery aneurysm was well shown and was not affected by the subtraction technique.

Received October 24, 2001; accepted after revision January 2, 2003.

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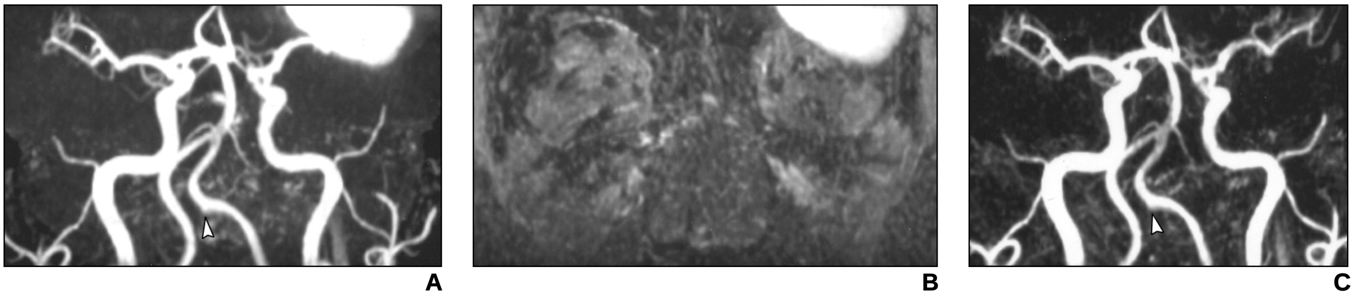

Fig. 1.—44-year-old hypertensive man with sudden onset of right-sided weakness.
A, Coronal maximum intensity projection of three-dimensional (3D) time-of-flight (TOF) MR angiogram of circle of Willis shows large subacute hematoma obscuring M2 and M3 segments of left middle cerebral artery. Note left vertebral artery aneurysm (*arrowhead*).
B, Coronal maximum intensity projection of 3D TOF MR angiogram of circle of Willis acquired with spatial saturation slabs placed immediately above and below acquisition volume shows blood vessels as dark. Note that subacute hematoma still appears bright.
C, Subtracted coronal maximum intensity projection of 3D TOF MR angiogram clearly shows M2 and M3 segments after removal of hematoma. Note lack of evidence of circle of Willis aneurysm. Left vertebral artery aneurysm (*arrowhead*) remains easy to see.

Another patient with no clinical history of hypertension was suspected of having an arteriovenous malformation. The 3D TOF MR angiograms showed a hematoma (Figs. 2A and 2B) obscuring the M2 and M3 segments of the right middle cerebral artery. After the high signal of the hematoma had been removed, no sign of arteriovenous malformation or aneurysm was seen (Fig. 2C) except for some attenuation in the distal right middle cerebral artery branches.

A 41-year-old woman with no known history of hypertension presented with an acute onset of mental confusion and disorientation. On MR imaging, a large subacute hematoma was found at the circle of Willis. A 3D TOF MR axial source angiogram showed a large hematoma and two adjacent small suspicious lesions (Fig. 3A). These lesions were present on multiple source images and could represent parts of the hematoma or abnormal vessels such as a vascular malformation. On subtracted axial maximum-intensity-projection (collapsed) images, the two suspicious lesions disappeared, indicating that they were indeed part of the hematoma (Fig. 3B).

Discussion

Three-dimensional TOF MR angiography makes use of a TR that is much shorter than the T1 relaxation time of stationary tissue. As a result, there is signal saturation of the stationary tissue. In contrast, the fresh, unexcited moving blood entering the excitation volume between pulse sequence repetitions is not saturated and thus has high signal intensity compared with that of the surrounding stationary tissue.

The main blood product of a subacute hematoma is either intracellular or extracellular methemoglobin. Methemoglobin is paramagnetic, resulting in very short T1 relaxation time. Thus, the longitudinal magnetization of the subacute hematoma can substantially recover, even though the TR used with the 3D TOF pulse sequence is short. This accounts for the signal hyperintensity of a subacute hematoma on the 3D TOF MR angiograms. When superior and inferior spatial saturation slabs are placed immediately above and be-

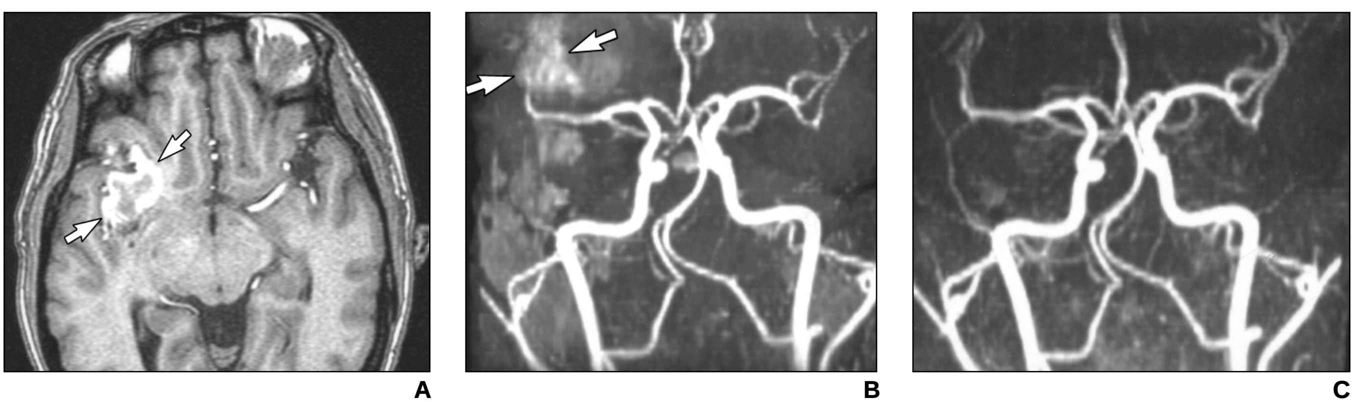

Fig. 2.—35-year-old woman with no clinical history of hypertension who presented after frequent episodic unilateral headaches.
A, Axial three-dimensional (3D) time-of-flight (TOF) MR angiogram shows subacute hematoma (*arrows*) near distal end of right middle cerebral artery. Such findings cannot be excluded on postprocessing.
B, Coronal maximum intensity projection of 3D TOF MR angiogram of circle of Willis shows subacute hematoma (*arrows*) obscuring M2 and M3 segments of right middle cerebral artery.
C, Subtracted coronal maximum intensity projection of 3D TOF MR angiogram shows M2 and M3 segments after removal of hematoma. Note lack of arteriovenous malformation or aneurysm, although distal middle cerebral artery branches are attenuated.

low the acquisition volume to saturate the fresh unexcited blood spins entering the acquisition volume, all blood vessels are made to appear dark (i.e., flow voids) on MR angiograms. The subacute hematoma, however, still appears bright. Digital subtraction between the 3D TOF MR angiograms acquired without spatial saturation slabs and those acquired with superior and inferior spatial saturation slabs gives rise to a third set of MR angiograms with bright blood vessels but with the subacute hematoma removed [3]. When digital subtraction is used between the 3D TOF MR angiograms and the avascular 3D TOF MR angiograms, patient movement should be kept to the minimum needed to obtain useful information. Apart from patient education and firm fixation of the head in the head coil by straps, the 3D TOF MR angiogram sequence should be immediately followed by the avascular 3D TOF MR angiogram sequence so as to minimize the time gap between the two sequences.

Another MR angiographic technique, the 3D phase contrast method, may also be used to eliminate signal hyperintensity of the subacute hematoma. Its principle of action depends on the velocity-induced phase shift, and there is no blood flow within the hematoma. However, the 3D TOF method possesses a number of unique advantages over the 3D phase contrast method. For example, the 3D TOF method is more useful than the 3D phase contrast method for revealing an aneurysm because of its greater spatial resolution using a larger matrix size (512 × 512). Furthermore, because the data acquisition time of the 3D phase contrast method is long, a low-resolution matrix (256 × 128) is commonly used. Consequently, the larger voxel size of the 3D phase contrast method results in a greater intravoxel phase dispersion, leading to a larger signal loss from turbulent flow [4]. The total time for acquiring two sets of 3D TOF MR angiograms is comparable to that for acquiring one set of 3D phase contrast MR angiograms, in the range of 10–12 min. The processing time for maximum-intensity-projection reconstruction is identical for 3D TOF MR angiography and 3D phase contrast MR angiography, and the time for the digital subtraction process is less than 30 sec. One trade-off of this technique is that any thrombus will also be removed even though the aneurysm remains intact. Conventional 3D TOF MR angiography is helpful in this regard.

In conclusion, 3D digital subtraction TOF MR angiography can be used to remove the subacute hematoma from the MR angiograms, and hence improve visualization of the underlying blood vessels.

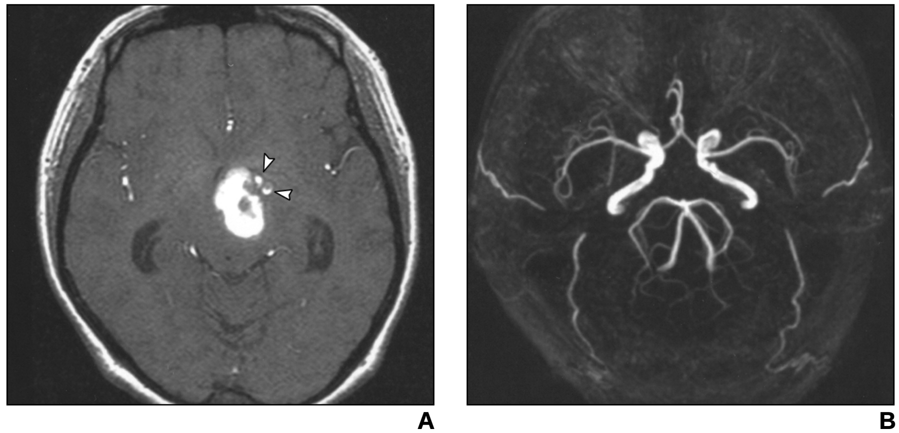

Fig. 3.—41-year-old woman with no clinical history of hypertension who presented with sudden onset of mental confusion and disorientation.
A, Axial three-dimensional (3D) time-of-flight (TOF) MR angiogram shows large subacute hematoma and two small lesions (*arrowheads*) that are suspected to be parts of either hematoma or aneurysm.
B, Subtracted axial maximum intensity projection of 3D TOF angiogram shows that suspicious lesions have disappeared, indicating that they were parts of hematoma.

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