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# A Pitfall in Detection of Intracranial Unruptured Aneurysms on Three-dimensional Phase-Contrast MR Angiography

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**Summary: We report three cases of intracranial unruptured aneurysm evaluated with MR angiography using both three-dimensional time-of-flight and three-dimensional phase-contrast techniques. It has been said that the phase-contrast technique has advantages over the time-of-flight technique in the detection of intracranial aneurysms. However, in our three cases, three-dimensional time-of-flight MR angiography clearly showed the intracranial unruptured aneurysms, but three-dimensional phase-contrast MR angiography failed to show them.**

**Index terms: Aneurysm, intracranial; Magnetic resonance angiography (MRA)**

Identifying intracranial unruptured aneurysms has been a critical clinical problem because the morbidity and mortality associated with subsequent subarachnoid hemorrhage are extremely high. Magnetic resonance (MR) angiography has become a major modality for detecting unruptured aneurysms. Two techniques are commonly available, time-of-flight and phase-contrast techniques.

A recent report systematically comparing three-dimensional time-of-flight and 3-D phase-contrast MR angiography said that the 3-D phase-contrast technique was superior to the 3-D time-of-flight technique in the detection of intracranial aneurysms (1). However, we encountered three cases with intracranial unruptured aneurysm in which the aneurysms were more apparent on 3-D time-of-flight MR angiography than on 3-D phase-contrast MR angiography.

## Case Reports

*Case 1*

A 63-year-old woman was admitted to our hospital because of loss of consciousness lasting several minutes after taking a bath. She was nauseated after the episode. On admission, she was suspected of having cerebrovascular disease and MR angiography was performed. MR examination was performed with a 1.5-T superconductive scanner (GE Signa, Advantage) using a circumferential, transmit-and-receive head coil. Three-dimensional time-of-flight MR angiography used a 3-D spoiled gradient-echo sequence, spoiled gradient-recalled acquisition in a steady state (spoiled gradient-echo) with 34/4.6/2 (repetition time [TR]/echo time [TE]/excitations), 20° flip angle, 256 × 128 matrix, 14-cm field of view, and a 60-mm volume with a 1-mm section thickness. Total examination time was approximately 9 minutes. Three-dimensional phase-contrast MR angiography used a 3-D gradient-recalled acquisition in a steady state sequence with the following parameters: 24/8.2/1, flip angle of 20°, field of view of 18 cm, maximum velocity encoding of 45 cm/sec, and a volume of 60 mm with 1-mm-thick partitions with a matrix of 256 × 192. The total examination time was approximately 20 minutes. On both 3-D time-of-flight and 3-D phase-contrast techniques, the center of the imaging volume was slightly above the circle of Willis.

The 3-D time-of-flight MR angiography demonstrated an unruptured aneurysm at the trifurcation of the right middle cerebral artery (Fig 1A). However, the 3-D phase-contrast MR angiography did not show the aneurysm (Fig 1B). Cerebral angiography confirmed the aneurysm, whose size was 4.4 × 4.9 × 4.9 mm (Fig 1C). The patient underwent clipping of the aneurysm, and was discharged without complication.

*Case 2*

A 59-year-old woman was admitted to the hospital for removal of a gallstone. During the admission, she experienced vertigo and was suspected of having vertebrobasilar arterial insufficiency. MR angiography was performed with parameters similar to those in case 1. Three-dimensional time-of-flight MR angiography showed an unruptured aneurysm at the trifurcation of the right middle cerebral artery (Fig 2A). However, 3-D phase-contrast MR angiography barely showed the aneurysm (Fig 2B). Conventional angiography confirmed the aneurysm

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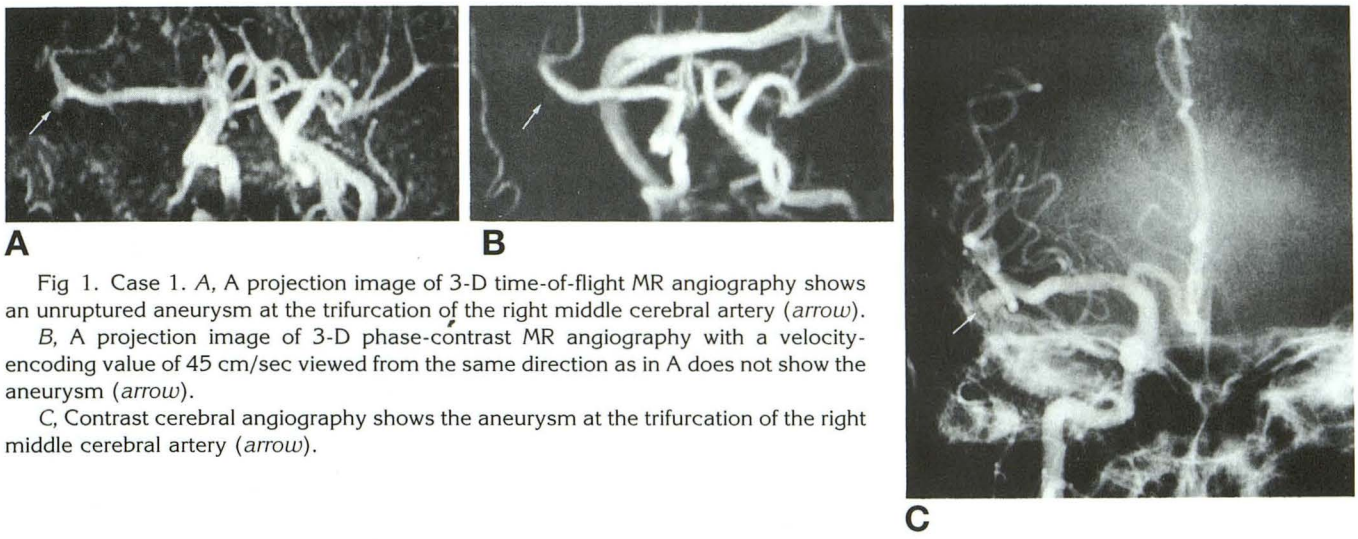


Fig 1. Case 1. *A*, A projection image of 3-D time-of-flight MR angiography shows an unruptured aneurysm at the trifurcation of the right middle cerebral artery (*arrow*).

*B*, A projection image of 3-D phase-contrast MR angiography with a velocity-encoding value of 45 cm/sec viewed from the same direction as in A does not show the aneurysm (*arrow*).

*C*, Contrast cerebral angiography shows the aneurysm at the trifurcation of the right middle cerebral artery (*arrow*).

(Fig 2C). The patient underwent clipping of the aneurysm without complication.

*Case 3*

A 41-year-old man had a 1-year history of severe headaches, and a recent episode of loss of consciousness. A conventional MR examination revealed an abnormal structure in the suprasellar cistern. MR angiography was performed similarly to the previous cases. The 3-D time-of-flight angiogram showed an aneurysm at the top of the basilar artery (Fig 3A,B). The maximum intensity projection images of the 3-D phase-contrast angiogram showed only an outline of an aneurysm with central signal loss. The structure was initially misdiagnosed as the normal left posterior cerebral artery (Fig 3C). The collapse images barely confirmed the aneurysm (Fig 3D), but the magnitude images of this phase-contrast sequence correctly revealed the aneurysm (Fig 3E).

Next a 3-D phase-contrast angiogram using a very low maximum velocity encoding of 10 cm/sec was performed. By necessity, this phase-contrast angiogram with a low maximum velocity encoding had increased TR, TE, and total examination time. A TR of 28 milliseconds and a TE of 10 milliseconds were used, and the total examination time was approximately 22 minutes. The other parameters were the same as for the study with the 45 cm/sec velocity-encoding value. This phase-contrast angiogram obviously showed the aneurysm, but intracranial arterial structures were lost (Fig 3F,G).

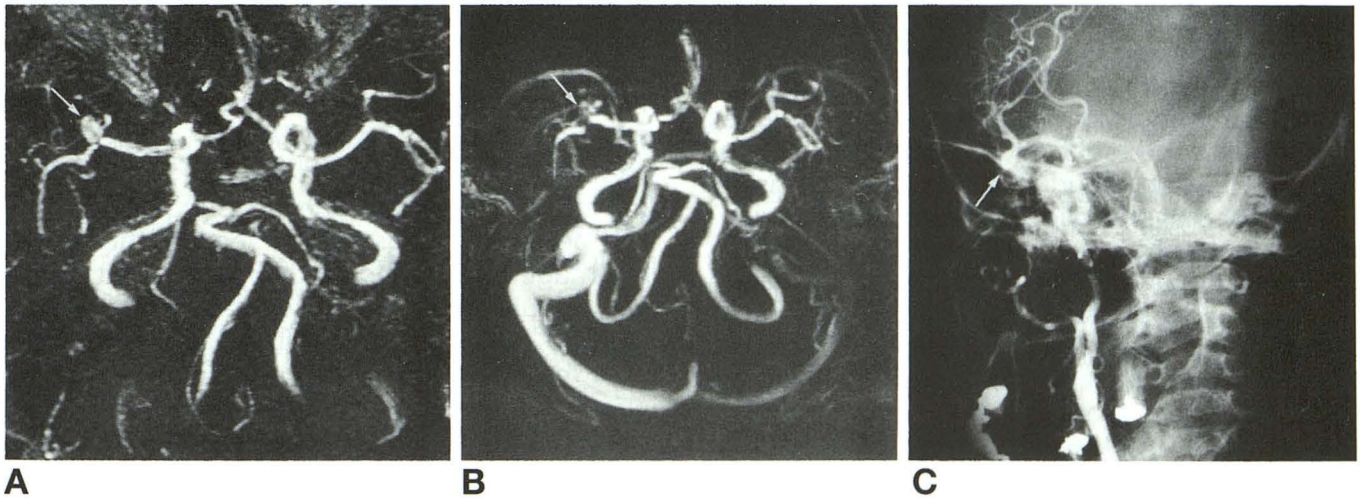


Fig 2. Case 2. *A*, A collapsed image of 3-D time-of-flight MR angiography shows an unruptured aneurysm at the trifurcation of the right middle cerebral artery (*arrow*).

*B*, A collapsed image of 3-D phase-contrast MR angiography with a velocity-encoding value of 45 cm/sec faintly shows the aneurysm at the trifurcation of the right middle cerebral artery (*arrow*).

*C*, Contrast cerebral angiography shows the aneurysm at the same region (*arrow*).

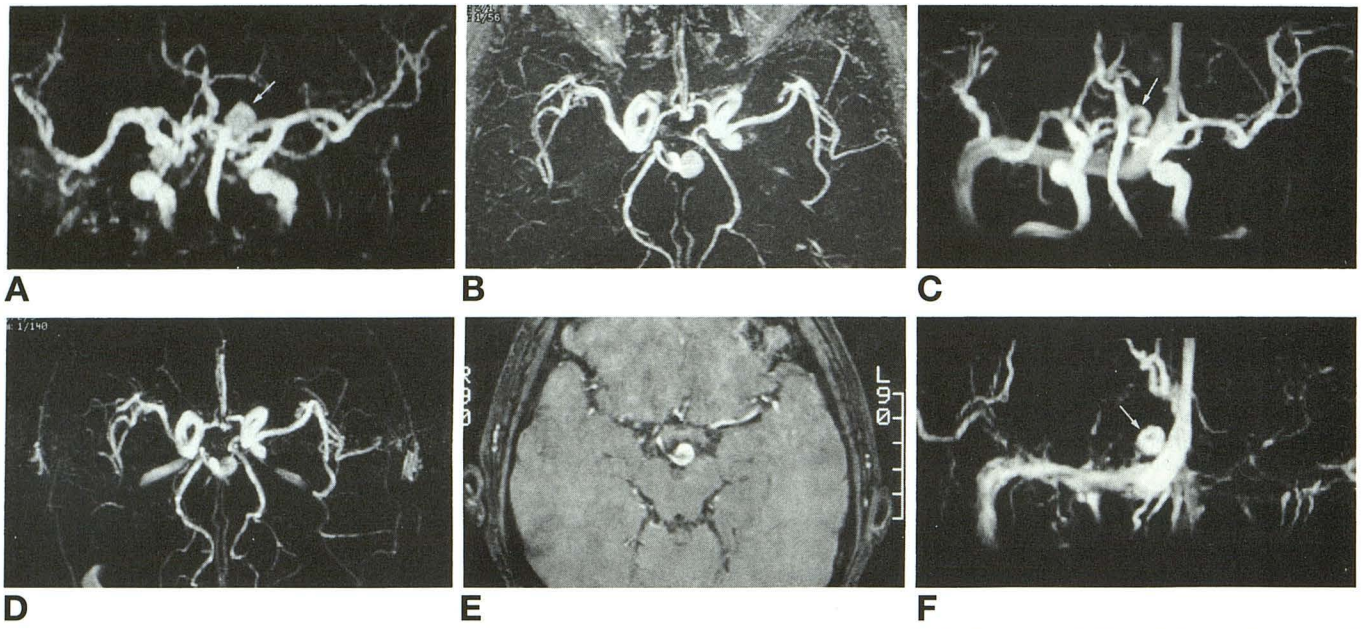


Fig 3. Case 3. *A*, A projection image of the 3-D time-of-flight angiogram shows an unruptured aneurysm at the top of the basilar artery (*arrow*).

*B*, A collapsed image of the 3-D time-of-flight angiogram also shows the aneurysm.

*C*, A projection image of the 3-D phase-contrast angiogram with a velocity-encoding value of 45 cm/sec shows the aneurysm with a central signal loss caused by slow flow (*arrow*), which was confused with the normal left posterior cerebral artery.

*D*, A collapsed image of the 3-D phase-contrast angiogram with a velocity-encoding value of 45 cm/sec barely shows the aneurysm.

*E*, A source magnitude image from the 3-D phase-contrast angiogram with a velocity-encoding value of 45 cm/sec obviously shows the aneurysm.

*F*, A projection image of the 3-D phase-contrast angiogram with a velocity-encoding value of 10 cm/sec shows the aneurysm, but arterial structures have disappeared.

*G*, A collapsed image of the 3-D phase-contrast angiogram with a velocity-encoding value of 10 cm/sec clearly shows the aneurysm.

## Discussion

To evaluate blood flow, 3-D phase-contrast and 3-D time-of-flight MR images are obtained quite differently. Three-dimensional phase-contrast MR angiography uses velocity-induced phase shifts with subtraction techniques to distinguish flowing blood from surrounding tissue (1–3). For this purpose, phase-contrast angiography uses bipolar flow-encoding gradient pulses to encode a spin's velocity as a change of phase. The phase-shift accumulation is expressed as the following equation: $\phi = \gamma VTA$, where $\phi$ is the phase shift induced by flow in the transverse spin magnetization, $\gamma$ is the gyromagnetic ratio of the spin, V is the component of the spin's velocity in the applied gradient's direction, T is the center-to-center time interval between the two gradient lobes, and A is the area of each gradient lobe. The phase shift is directly proportional to a spin's velocity; stationary tissue shows no phase shift. In the phase-contrast pulse sequence, the polarity of the bipolar gradient is inverted on alternative acquisitions (odd/even) for each phase-encoding step. For the second acquisition, the inverted bipolar pulse induces a phase shift, $\phi = -\gamma VTA = -\phi$. Also for this acquisition, a stationary spin shows no net phase shifts. When the image data from the first acquisition are subtracted from those of the second, the resulting image reflects signal that is different in the two acquisitions. Because stationary tissues yield no phase shifts, a subtraction of the first from the second acquisition results in cancellation of stationary tissue signal. Nonzero contributions to voxel intensity result only from moving spins. Strictly speaking, the resultant contribution to voxel values in the magnitude image from each moving spin is proportional to $\sin \phi$. However, the parameters T and A are usually small enough so that $\sin \phi = \phi$. So the voxel values (signal intensity) are roughly pro-

portional to flow velocity. However, it should be noted that this principle is effective only when blood flow moves with constant velocity. As described later, nonlaminar turbulent or vortex flows may cause a significant loss of signal on the phase-contrast angiogram. Inflow enhancement (flow-related enhancement) also plays an important and fundamental role in signal intensity in the phase-contrast angiogram.

The information from the data set of a 3-D phase-contrast sequence can be displayed as individually reconstructed 3-D Fourier transform partitions, which are called *source images.* These source images are of great value in evaluating aneurysms. To approximate a conventional cerebral angiography, the individual source images can be projected onto a 2-D planar view at any viewing angle using a maximum intensity projection ray-tracing technique. This procedure yields a collapse view and reprojected views but, at the same time, may result in apparent signal loss from moving spins in vessels.

On the other hand, 3-D time-of-flight MR angiography directly uses flow-related enhancement to identify moving spins (1, 4–11). The 3-D data sets obtained by a 3-D time-of-flight sequence are also subjected to a maximum intensity projection ray-tracing technique to create projection and collapse images of vessels. A major limitation of 3-D time-of-flight angiography is its relative inability to cancel signal from stationary spins. In particular, short-T1 material such as fatty tissues and subacute hematomas containing methohemoglobin appear bright, simulating flow enhancement. However, 3-D time-of-flight MR angiography has a critical advantage of using a shorter TE than 3-D phase-contrast MR angiography. This may be the most important factor allowing 3-D time-of-flight MR angiograms to provide better visualization of the aneurysms in our cases.

There have been several reports on the study of intracranial aneurysms with MR angiography (1, 4, 7–11). One report systematically evaluated a series of intracranial aneurysms with both 3-D phase-contrast and 3-D time-of-flight MR angiography (1). Huston et al (1) noted that 3-D phase-contrast angiography permitted detection of all 14 aneurysms, whereas 3-D time-of-flight angiography failed to detect 2 aneurysms because of saturation effects of slow blood flow in the larger aneurysms. They concluded that the advantages of 3-D phase-contrast imaging included variable velocity sensitivity, superior ability to depict the patent lumina of vessels, low sensitivity to saturation effects, superior background suppression, and functional flow information. At present, this opinion is generally accepted (1–3).

In our three cases, however, 3-D time-of-flight MR obviously detected the aneurysms, whereas 3-D phase-contrast MR hardly depicted them. The blood flow in an aneurysm is remarkably complicated and changes during the cardiac cycle. Gonzalez et al presented a report of a computer analysis (12) showing that flow direction in an aneurysm completely reverses during one cardiac cycle when vortex flow arises inside the aneurysm. Shear stresses caused by a distribution of flow velocities perpendicular to the aneurysm wall results. In addition, the flow velocity in the aneurysm is much slower than that in the parent artery. Therefore, these complex, variously laminated and vortex flows with to-and-fro motions must greatly influence the signal (loss) of the 3-D phase-contrast technique. Other mechanisms described below may also contribute to the phenomena observed in our cases.

The major mechanisms of signal loss with the phase-contrast angiogram are slow and disturbed flows with resultant spin dephasing. Signal loss from higher-order motions of moving spins within an aneurysm occurs because most MR angiography methods are signed to generate high signals in voxels containing protons that have moved with constant velocity. The gradient of velocities perpendicular to the aneurysm wall which is created by vortex flow within an aneurysm is another mechanism of intravoxel dephasing.

Additional potential deficiencies of 3-D phase-contrast angiography related to data acquisition, image processing, and display acquisition parameters should be considered. It is well known that the TE is a major factor relating to signal loss from complex and vortex flows. Phase dispersion is roughly proportional to the square of the TE. The 3-D phase-contrast technique has the disadvantage of having a longer TE than the 3-D time-of-flight technique because the former needs the inclusion of a bipolar flow-encoding gradient. In our cases, the TE of the 3-D phase-contrast technique was approximately twice as long as in the 3-D time-of-flight technique. The longer TE in the 3-D

phase-contrast technique contributes to the complex flow phase dispersion, leading to signal loss within aneurysms. However, the TE used on the 3-D phase-contrast angiogram in our studies was not sufficiently long to explain the complete signal loss of the aneurysm in case 1. Other mechanisms that may influence the intravoxel dephasing include total gradient area and voxel size. The 3-D phase-contrast pulse sequence requires a wide total gradient area compared with the 3-D time-of-flight pulse sequence because of the bipolar flow-encoding gradients. The wide total gradient area is said to increase complex flow-induced phase dispersion. It is well known that the smaller the voxel size, the less intravoxel dephasing will occur. However, in our study, voxel sizes were approximately comparable between the two techniques.

Another possible mechanism causing signal loss within an aneurysm is the velocity encoding with the phase-contrast technique. Saturation effects caused by slow flow are less problematic with the phase-contrast angiogram. However, with the phase-contrast angiogram, poor image contrast caused by slow flows within an aneurysm is related to the fact that the amount of detectable phase shift or signal intensity is proportional to velocity. In areas of slow flow, the degree of phase shift is reduced and may be difficult to resolve with the routinely used flow-encoding gradient of 45 cm/sec in our institute. As seen in case 3, this problem can be dramatically overcome by using a lower velocity encoding of 10 cm/sec. However, the very low velocity encoding can not be used for routine phase-contrast MR angiography because the higher velocities in arterial structures will be aliased and appear as low signal intensities, causing a disappearance of intracranial arteries (Fig 3). There are additional problems encountered with phase-contrast angiography using slow velocity encoding, including longer TRs and increased acquisition times.

Finally, the maximum intensity projection algorithm yielding collapsed and reprojected views sometimes causes a distortion of vascular anatomy (13, 14). Because the ray-tracing technique is designed to depict only the maximum intensity encountered as the ray passes through the imaging volume, the intensity of the vessel should be on average at least 2 standard deviations above background intensity. If signal intensity from an aneurysm decreases below that level because of a complex flow, partial voluming, or saturation effects, signal loss within the aneurysm will occur. This problem may be overcome by referring to individual source images. In our case 3, the aneurysm could be correctly appreciated only on the magnitude images. Unfortunately in cases 1 and 2, we could not reevaluate the magnitude images because the source images had been lost.

There is also the possibility that an aneurysm filled with a subacute thrombus with shortened T1 may cause high signal intensity on 3-D time-of-flight MR and no signal on 3-D phase-contrast MR. However, in our cases, conventional angiography confirmed blood flow in the aneurysms.

MR angiography has now become the most useful screening modality for the detection of unruptured aneurysms. It has been suggested that 3-D phase-contrast MR angiography should be the most suitable technique for this purpose because of its excellent sensitivity to aneurysms (1–3). However, our cases illustrate that 3-D phase-contrast angiography has pitfalls arising from complex flow within aneurysms. These problems may be overcome by a careful reading of the phase-contrast source magnitude, reprojection, and collapse images. However, we conclude that 3-D time-of-flight MR angiography may have a role in diagnosing unruptured aneurysms.

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