Assessment of arteriovenous malformations with 3-Tesla time-resolved, contrast-enhanced, three-dimensional magnetic resonance angiography

Clinical article

KANAKO KUNISHIMA, M.D.,1 HARUSHI MORI, M.D.,1 DAISUKE ITOH, M.D.,1 SHIGEKI AKI, M.D., Ph.D.,2 HIROYUKI KABASAWA, Ph.D.,1 TOMOYUKI KOGA, M.D.,1 KEISUKE MARUYAMA, M.D., Ph.D.,2 TOMOHIKO MASUMOTO, M.D., Ph.D.,1 OSAMU ABE, M.D., Ph.D.,1 AND KUNI OHTOMO, M.D., Ph.D.1

Departments of 1Radiology and 2Neurosurgery, The University of Tokyo Hospital, Tokyo, Japan

Object. Although conventional catheter angiography is commonly used in the evaluation of intracranial arteriovenous malformations (AVMs), less invasive tools are more suitable for screening or follow-up. Older MR angiography techniques cannot provide high enough temporal and spatial resolution for assessing AVMs. Three-tesla time-resolved imaging of contrast kinetics (TRICKS)—a time-resolved, contrast-enhanced 3D MR angiography technique—achieves subsecond time resolution without sacrificing spatial resolution. The purpose of this study was to assess the accuracy of TRICKS at 3 T in the evaluation of AVMs.

Methods. Between November 2006 and November 2007, 31 patients who were known to have AVMs underwent evaluation in a 3-T unit with the TRICKS technique. The TRICKS images were then evaluated independently by 2 radiologists for nidus detection, early venous filling detection, and Spetzler-Martin classification, and these results were compared with the results of catheter angiography.

Results. Time-resolved imaging of contrast kinetics achieved 96% sensitivity and 100% specificity both in nidus detection and early venous filling detection. The Spetzler-Martin grades also showed excellent correlation with catheter angiography findings (κ = 0.89).

Conclusions. Although this is a preliminary study, the authors’ results indicate that time-resolved contrast-enhanced 3D MR angiography at 3 T is a good tool to assess AVMs, and has the potential to replace catheter angiography in screening or follow-up examinations of patients with AVMs. (DOI: 10.3171/2008.7.JNS08173)

Key Words • arteriovenous malformation • contrast-enhanced angiography • digital subtraction angiography • time-resolved angiography

Abbreviations used in this paper: AVM = arteriovenous malformation; FOV = field of view; MIP = maximum intensity projection; TRICKS = time-resolved imaging of contrast kinetics.
Assessment of AVMs with time-resolved 3D MR angiography

combined with a 3-T MR imaging unit. In this study, we investigate the accuracy of 3-T TRICKS in the assessment of AVMs compared with conventional catheter angiography.

Methods

Patient Population

We searched our hospital’s imaging records from the period between November 2006 and November 2007, and recruited 31 patients (14 men and 17 women; mean age 38.3 years, range 16–74 years) who were known to have or to have had AVMs (Table 1). All patients underwent conventional catheter angiography and TRICKS with the 3-T system at a time interval between modalities of < 1 month. All patients had an adequate glomerular filtration rate (> 30 ml/min/1.73 m²), and were referred for MR imaging according to the accepted clinical examination for AVMs at our institution. Informed consent was obtained from each patient or the patient’s guardian in the case of underage patients prior to MR angiography and conventional catheter angiography.

Twenty-three AVMs were located in the supratentorial circulation (2 frontal, 7 parietal, 6 temporal, 5 occipital, 1 basal ganglia/thalamus, and 2 in the corpus callosum) and 4 were in the infratentorial circulation (1 pons, 1 cerebellum, and 2 in the cerebellopontine angle). In the remaining 4 cases, the AVMs were angiographically obliterated after radiosurgery.

Magnetic Resonance Imaging

Magnetic resonance imaging was performed with a 3-T superconducting system (Signa 3.0T HDx System, GE Healthcare). Time-resolved imaging of contrast kinetics was performed in combination with conventional MR imaging sequences. The images were obtained in the sagittal plane including imaging of the internal carotid artery on the lesion side in all cases. The imaging parameters for TRICKS were as follows: TR 4.3 msec, TE 1.5 msec, flip angle 20°, 240 × 190–mm FOV, 384 × 256 acquisition matrix, 4.0-mm section thickness (resolution doubled using zero fill interpolation processing) to obtain 6.4-cm volume coverage, 83.3-kHz bandwidth, and a number of excitation value of 0.5. Parallel imaging with a reduction factor of 2 was applied. The TRICKS reconstruction generated 48 time-resolved phases with the frame rate of 0.8 seconds per volume. About 15 ml of gadoteridol (Prohance, Bracco) or gadodiamide (Omniscan, Nycomed) was injected at 4–10 ml/second with a power injector (Spectris Solaris EP). The first volume was subtracted from subsequent volumes to eliminate background nonvascular signal intensity and then the MIP was reconstructed.

Conventional Catheter Angiography

Conventional catheter angiography was performed with a 4 or 5 Fr catheter via the femoral artery with a filming rate of 2–3 images/second, a 1024 × 1024 matrix size, and a 20-cm FOV. Angiography included selective injection of the internal carotid, common carotid, or vertebral arteries in the frontal and sagittal views and additional views as necessary. For each projection, a 6–18-ml bolus of iodinated contrast material, iopamidol (Iopamiron, Japan Schering) or ioversol (Optiray, Yamanouchi Pharmaceutical), was injected at 2–6 ml/second using a power injector.

Image Evaluation

Two neuroradiologists (H.M. and D.I.), both blinded to the results of either study, independently reviewed the TRICKS results using source and MIP images. For the initial evaluation, observers checked whether there was a patent nidus. Next, in cases of patent nidi, the characteristics were evaluated according to the Spetzler-Martin classification. Nidi size was classified into 1 of 3 groups: small (<3 cm), medium (3–6 cm), and large (>6 cm). Venous drainage was categorized as superficial only or including the deep venous system, and the location was categorized as being in an eloquent or noneloquent area. The venous drainage was defined as superficial if the veins drained into the cortical venous system and as deep if the veins drain into the great vein of Galen, the straight sinus, or the cavernous sinus. After the evaluation of each factor, the grade was calculated according to the scoring system. In addition to the Spetzler-Martin classification, early venous filling was also evaluated in cases of patent nidi.

The conventional catheter angiograms were reviewed by 2 other neuroradiologists (K.K. and S.A.) as reference images. Each AVM on conventional catheter angiography was analyzed in a same manner as on TRICKS images.

Statistical Analysis

All statistical studies were performed with commercially available statistical software (JMP 6, SAS institute). Kappa values were calculated for Spetzler-Martin

TABLE 1: Summary of characteristics in 31 patients with AVMs*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVM location</td>
<td></td>
</tr>
<tr>
<td>supratentorial</td>
<td>23 (74)</td>
</tr>
<tr>
<td>frontal lobe</td>
<td>2 (6)</td>
</tr>
<tr>
<td>temporal lobe</td>
<td>6 (19)</td>
</tr>
<tr>
<td>parietal lobe</td>
<td>7 (23)</td>
</tr>
<tr>
<td>occipital lobe</td>
<td>5 (16)</td>
</tr>
<tr>
<td>corpus callosum</td>
<td>2 (6)</td>
</tr>
<tr>
<td>thalamus/basal ganglia</td>
<td>1 (3)</td>
</tr>
<tr>
<td>infratentorial</td>
<td>4 (13)</td>
</tr>
<tr>
<td>pons/medulla</td>
<td>1 (3)</td>
</tr>
<tr>
<td>cerebellum</td>
<td>1 (3)</td>
</tr>
<tr>
<td>cerebellopontine angle</td>
<td>2 (6)</td>
</tr>
<tr>
<td>angiographically occluded</td>
<td>4 (13)</td>
</tr>
</tbody>
</table>

* There were 14 men and 17 women with a mean age of 38.3 ± 12.5 years (range 16–74 years).
grade agreement of TRICKS between both observers, and correlation with the results of the corresponding conventional catheter angiograms evaluations. The Wilcoxon signed-rank test was used to analyze interobserver variability on nidus and early venous filling detection. Sensitivity and specificity were calculated to assess the diagnostic accuracy of TRICKS compared with that of conventional catheter angiography related to the detection of nidi and early venous filling. Kappa values of up to 0.4 indicated a positive agreement (but poor correlation), 0.41–0.6 was moderate, 0.61–0.8 was good, and values 0.81–1 indicated an excellent agreement or correlation. For Wilcoxon signed-rank tests, probability values < 0.05 were regarded as significant.

Results

No complications were observed during the MR procedures and conventional catheter angiography. We successfully obtained continuous serial hemodynamic images in all 31 cases. Of 31 patients, 4 had AVMs angiographically obliterated after the treatment. Embolization had previously been performed in 2 AVMs, and previous radiosurgery had been performed in 4 AVMs. In 2 cases, hematomas existed when TRICKS was performed.

Interobserver Agreement

There was complete agreement between 2 observers in nidus detection (p > 0.05). In regard to the early venous filling detection, disagreement was observed only in 1 case (p > 0.05). Interobserver agreement was good for Spetzler-Martin grade (κ = 0.61); there were discrepancies between the 2 observers in 3 cases for the nidus size, 3 cases for the location, and 3 cases for the visualization of venous drainage. In the cases with interobserver disagreement, an additional reading by both examiners was performed to reach a consensus.

Nidi and Early Venous Filling Detection

All 4 cases of occluded AVMs were correctly diagnosed on TRICKS (specificity of nidus detection 100%). In addition to these angiographically observed occluded AVMs, a very small nidus (< 10 mm) in the right occipital lobe without early venous filling was also correctly evaluated on TRICKS (specificity of early venous filling detection 100%). Sensitivity was 96% both in nidus detection (26/27) and in early venous detection (25/26) (Figs. 1 and 2). In 1 case, the nidus was not clearly visible, but a small dilated draining vein in the left cerebellopontine angle was demonstrated with early venous filling on conven-
Assessment of AVMs with time-resolved 3D MR angiography

We regarded this finding to represent a very small patent AVM. On TRICKS, however, this small dilated vein could not be detected.

Spetzler-Martin Classification

Two cases were excluded from assessment with the Spetzler-Martin classification. In the first case, mentioned in the previous section, the nidus could not be visualized clearly on conventional catheter angiography. In the other case the nidus existed in the temporal tip, and the setting of FOV by focusing on the nidus location excluded the great vein of Galen from the FOV.

Nidus Size and Location

Eleven nidi were classified as small, 12 as medium, and 2 as large on conventional catheter angiography. The results of TRICKS were matched to those of conventional catheter angiography in 24 cases (Table 2). It was difficult to measure the exact size of the nidus in the sagittal plane on source images in 1 case because a dilated draining vein lay over the nidus. In 1 case, the nidus size was 32 mm in diameter with a dilated draining vein overlaid in the sagittal view, which made it difficult to measure the exact size of the nidus in the sagittal plane even on source images; both observers regarded this nidus as small (< 3 cm).

Twelve nidi were located in the eloquent areas and 13 were in noneloquent areas on conventional catheter angiography. There was complete match between conventional catheter angiography and TRICKS determination of nidus location.

Venous Drainage

In 25 AVMs, conventional catheter angiography showed deep venous drainage in 14, and exclusively superficial drainage in 11 cases. In 24 cases, TRICKS diagnosed the drainage route correctly (Table 2). In 1 case, TRICKS incorrectly showed superficial venous drainage only, whereas conventional catheter angiography demonstrated deep venous drainage. The deep draining vein was too small to demonstrate the great vein of Galen in the arterial phase. This small deep draining vein could not be detected on TRICKS.

Arteriovenous Malformation Grades

Grades (range 1–5) were assessed according to the nidus size, location, and venous drainage route. There

Fig. 2. A and B: Conventional catheter angiograms of the right common carotid artery showing a nidus in the right temporocipital lobe and the early filled right transverse sinus. C–E: Maximum intensity projection images obtained with TRICKS. The nidus is easily detected, and the right transverse sinus and sigmoid sinus are demonstrated in the early phase.
was an excellent correlation between conventional catheter angiography and TRICKS; discrepancies were observed in only 2 cases (κ = 0.89, Table 3).

Discussion

In this study, 3-T TRICKS achieved 96% sensitivity and 100% specificity in both nidus detection and early venous filling detection. Characteristics of AVMs, assessed with the Spetzler-Martin classification, according to the TRICKS findings corresponded highly with those obtained with conventional catheter angiography.

Unenhanced MR angiograms or T2-weighted images are very valuable in the assessment of the angiarchitectural AVMs. However, these techniques with higher spatial resolution, however, lack the temporal resolution to evaluate the hemodynamic character of AVMs.

Two-dimensional MR digital subtraction angiography has proven its effectiveness in the evaluation of AVMs, with its capability to assess the hemodynamics of these lesions. However, the spatial resolution of this modality is restricted when subsecond temporal resolution is obtained. In a previous report of 2D MR digital subtraction angiography with a temporal resolution of 1.05 seconds per dynamic image, AVM detection sensitivity was 87%, which is lower than our results because of inferior spatial and temporal resolution. In some cases it was difficult to detect the deep draining vein on TRICKS MIP images because many vessels were overlaid in the sagittal view; however, the deep veins could be separated from the superficial ones on TRICKS source images (Fig. 3). This implies the limited ability to detect the vessel location in 2D MR digital subtraction angiography even with high in-plane spatial resolution.

It must be acknowledged, however, that both the temporal and spatial resolution of TRICKS is inferior to that on conventional catheter angiography (0.63 × 0.74 mm²). Time-resolved imaging of contrast kinetics with this level of in-plane spatial resolution and subsecond temporal resolution has not been reported on previously, and we achieved 96% sensitivity and 100% specificity of nidus detection and early venous filling detection, with excellent correlation of the Spetzler-Martin grade assessed on TRICKS and on conventional catheter angiography. In addition to the high temporal and spatial resolution, 3D acquisition also contributed to our results. In certain cases, however, the noninvasive, radiation-free, and iodinated contrast agent–free nature of MR digital subtraction angiography may justify its use over conventional catheter angiography, particularly in screening and follow-up. In the case of screening, such as for patients with small AVMs, the cost and time of a conventional angiography study may not be justified. TRICKS was able to detect the small draining veins in these cases.

It must be acknowledged, however, that both the temporal and spatial resolution of TRICKS is inferior to that on conventional catheter angiography. This resolution is not high enough to assess the short mean transit times of feeding arteries and draining veins in cerebral AVMs.

A new generation of 3-T scanners has been introduced in recent years. These units have several significant advantages, especially in MR angiography. First, the increased signal-to-noise ratio improves spatial resolution and has a shorter scan time. Second, these machines can give better background suppression of stationary tissues and greater flow enhancement, resulting in vessel-tissue contrast improvement.

Our 3-T sequence of TRICKS provided a 0.8-second time resolution while preserving the high spatial resolution (0.63 × 0.74 mm²). Time-resolved imaging of contrast kinetics with this level of in-plane spatial resolution and subsecond temporal resolution has not been reported on previously, and we achieved 96% sensitivity and 100% specificity of nidus detection and early venous filling detection, with excellent correlation of the Spetzler-Martin grade assessed on TRICKS and on conventional catheter angiography. In addition to the high temporal and spatial resolution, 3D acquisition also contributed to our results. In some cases it was difficult to detect the deep draining vein on TRICKS MIP images because many vessels were overlaid in the sagittal view; however, the deep veins could be separated from the superficial ones on TRICKS source images (Fig. 3). This implies the limited ability to detect the vessel location in 2D MR digital subtraction angiography even with high in-plane spatial resolution.

It must be acknowledged, however, that both the temporal and spatial resolution of TRICKS is inferior to that on conventional catheter angiography. This resolution is not high enough to assess the short mean transit times of feeding arteries and draining veins in cerebral AVMs.

A new generation of 3-T scanners has been introduced in recent years. These units have several significant advantages, especially in MR angiography. First, the increased signal-to-noise ratio improves spatial resolution and has a shorter scan time. Second, these machines can give better background suppression of stationary tissues and greater flow enhancement, resulting in vessel-tissue contrast improvement.

Our 3-T sequence of TRICKS provided a 0.8-second time resolution while preserving the high spatial resolution (0.63 × 0.74 mm²). Time-resolved imaging of contrast kinetics with this level of in-plane spatial resolution and subsecond temporal resolution has not been reported on previously, and we achieved 96% sensitivity and 100% specificity of nidus detection and early venous filling detection, with excellent correlation of the Spetzler-Martin grade assessed on TRICKS and on conventional catheter angiography. In addition to the high temporal and spatial resolution, 3D acquisition also contributed to our results. In some cases it was difficult to detect the deep draining vein on TRICKS MIP images because many vessels were overlaid in the sagittal view; however, the deep veins could be separated from the superficial ones on TRICKS source images (Fig. 3). This implies the limited ability to detect the vessel location in 2D MR digital subtraction angiography even with high in-plane spatial resolution.

It must be acknowledged, however, that both the temporal and spatial resolution of TRICKS is inferior to that on conventional catheter angiography. This resolution is not high enough to assess the short mean transit times of feeding arteries and draining veins in cerebral AVMs.

A new generation of 3-T scanners has been introduced in recent years. These units have several significant advantages, especially in MR angiography. First, the increased signal-to-noise ratio improves spatial resolution and has a shorter scan time. Second, these machines can give better background suppression of stationary tissues and greater flow enhancement, resulting in vessel-tissue contrast improvement.

Our 3-T sequence of TRICKS provided a 0.8-second time resolution while preserving the high spatial resolution (0.63 × 0.74 mm²). Time-resolved imaging of contrast kinetics with this level of in-plane spatial resolution and subsecond temporal resolution has not been reported on previously, and we achieved 96% sensitivity and 100% specificity of nidus detection and early venous filling detection, with excellent correlation of the Spetzler-Martin grade assessed on TRICKS and on conventional catheter angiography. In addition to the high temporal and spatial resolution, 3D acquisition also contributed to our results. In some cases it was difficult to detect the deep draining vein on TRICKS MIP images because many vessels were overlaid in the sagittal view; however, the deep veins could be separated from the superficial ones on TRICKS source images (Fig. 3). This implies the limited ability to detect the vessel location in 2D MR digital subtraction angiography even with high in-plane spatial resolution.

It must be acknowledged, however, that both the temporal and spatial resolution of TRICKS is inferior to that on conventional catheter angiography. This resolution is not high enough to assess the short mean transit times of feeding arteries and draining veins in cerebral AVMs.

A new generation of 3-T scanners has been introduced in recent years. These units have several significant advantages, especially in MR angiography. First, the increased signal-to-noise ratio improves spatial resolution and has a shorter scan time. Second, these machines can give better background suppression of stationary tissues and greater flow enhancement, resulting in vessel-tissue contrast improvement.

Our 3-T sequence of TRICKS provided a 0.8-second time resolution while preserving the high spatial resolution (0.63 × 0.74 mm²). Time-resolved imaging of contrast kinetics with this level of in-plane spatial resolution and subsecond temporal resolution has not been reported on previously, and we achieved 96% sensitivity and 100% specificity of nidus detection and early venous filling detection, with excellent correlation of the Spetzler-Martin grade assessed on TRICKS and on conventional catheter angiography. In addition to the high temporal and spatial resolution, 3D acquisition also contributed to our results. In some cases it was difficult to detect the deep draining vein on TRICKS MIP images because many vessels were overlaid in the sagittal view; however, the deep veins could be separated from the superficial ones on TRICKS source images (Fig. 3). This implies the limited ability to detect the vessel location in 2D MR digital subtraction angiography even with high in-plane spatial resolution.

It must be acknowledged, however, that both the temporal and spatial resolution of TRICKS is inferior to that on conventional catheter angiography. This resolution is not high enough to assess the short mean transit times of feeding arteries and draining veins in cerebral AVMs.

A new generation of 3-T scanners has been introduced in recent years. These units have several significant advantages, especially in MR angiography. First, the increased signal-to-noise ratio improves spatial resolution and has a shorter scan time. Second, these machines can give better background suppression of stationary tissues and greater flow enhancement, resulting in vessel-tissue contrast improvement.

Our 3-T sequence of TRICKS provided a 0.8-second time resolution while preserving the high spatial resolution (0.63 × 0.74 mm²). Time-resolved imaging of contrast kinetics with this level of in-plane spatial resolution and subsecond temporal resolution has not been reported on previously, and we achieved 96% sensitivity and 100% specificity of nidus detection and early venous filling detection, with excellent correlation of the Spetzler-Martin grade assessed on TRICKS and on conventional catheter angiography. In addition to the high temporal and spatial resolution, 3D acquisition also contributed to our results. In some cases it was difficult to detect the deep draining vein on TRICKS MIP images because many vessels were overlaid in the sagittal view; however, the deep veins could be separated from the superficial ones on TRICKS source images (Fig. 3). This implies the limited ability to detect the vessel location in 2D MR digital subtraction angiography even with high in-plane spatial resolution.

The case with small dilated draining vein only and the case in which TRICKS failed to include the great vein of Galen in the FOV were excluded from Spetzler-Martin classification assessment.

Table 2: Summary of conventional catheter angiography and TRICKS findings for the Spetzler-Martin classification of 25 patients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Catheter Angiography</th>
<th>TRICKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>size (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;3</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>3–6</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>&gt;6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>eloquent</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>noneloquent</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>venous drainage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>superficial</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>deep</td>
<td>14</td>
<td>13</td>
</tr>
</tbody>
</table>

* The case with small dilated draining vein only and the case in which TRICKS failed to include the great vein of Galen in the FOV were excluded from Spetzler-Martin classification assessment.

Table 3: Comparison of Spetzler-Martin grades as assessed with TRICKS and conventional catheter angiography in 25 patients

<table>
<thead>
<tr>
<th>Catheter Angiography Grade</th>
<th>TRICKS Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3</td>
</tr>
<tr>
<td>II</td>
<td>1</td>
</tr>
<tr>
<td>III</td>
<td>1</td>
</tr>
<tr>
<td>IV</td>
<td>0</td>
</tr>
<tr>
<td>V</td>
<td>0</td>
</tr>
</tbody>
</table>

κ = 0.89
the examination of young patients with intracranial hemorrhage, early venous filling is often the key diagnostic finding indicating the presence of an AVM.\textsuperscript{1} For follow-up, which requires repeated evaluations,\textsuperscript{18,20} assessment of patency and nidus character is necessary.\textsuperscript{15} In these cases, early venous filling assessment and the Spetzler-Martin classification are important, and the assessment of small vessels and the number of vessels is not as important as in the pretreatment evaluation. Although larger trials are still needed for prospective evaluation of the diagnostic accuracy of TRICKS at 3 T, our results show a high correlation of results with conventional catheter angiography in terms of Spetzler-Martin grade with 96% sensitivity and 100% specificity of nidus and early venous detection. This finding indicates that the TRICKS sequence could eventually replace the use of conventional catheter angiography in selected cases of screening and follow-up in patients with AVMs.

There are drawbacks to the implementation of TRICKS. First, artifacts may occur at the edge of enhancing vessels due to the technical character of TRICKS.\textsuperscript{8} Although this factor did not have great influence on early venous filling assessment and Spetzler-Martin classification in this study, an artifact may affect the assessment of small vessels. Second, the total thickness of 6.4 cm sometimes fails to include some of the main components, such as the superior sagittal sinus or sigmoid sinus, depending on the nidus location. Appropriate FOV setting can prevent misinterpretation until faster imaging techniques are developed that enable obtaining a greater slice thickness. Third, in MR digital subtraction angiography, basically only 1 plane of projected images can be obtained in a single contrast-injection sequence. The 3D acquisition technique TRICKS enables image reconstructions in any desired direction, but a 4.0-mm-slice thickness (with zero fill interpolation processing) is so inferior to the in-plane spatial resolution (0.63 × 0.74 mm) that the reconstructed images are rather rough compared with the original projected images. Although it is actually possible to assess the depth information from the TRICKS source images, or stereoscopic vision from the MIP images, if images are not acquired in the proper orientation, the observer might find the evaluation of detailed hemodynamic information more difficult. In the present study, we used the sagittal plane for image acquisition in all patients because previously obtained unenhanced MR images led us to judge that to be appropriate, and we were able to assess all AVMs well. To check the size and location of AVM nidus on unenhanced MR imaging sequences, such as T2-weighted images, before starting TRICKS might be necessary to prevent an inappropriate plane setting. Fourth, materials such as hematomas that have short signals on T1-weighted images are depicted as high intensity on “nonsubtracted” images of TRICKS, as on a T1-weighted image. These sometimes make the assessment of the vessel route difficult. On “subtracted” TRICKS images, however, high signal in the hematoma is subtracted together with the other background signals, and it would not affect the assessment of AVM.

A limitation to our study is that we did not conduct...
examinations of a control group of patients without AVMs to rule out observer bias. This bias, however, was reduced by including cases of occluded AVMs.

Conclusions

Time-resolved contrast-enhanced 3D MR angiography at 3 T can provide important information about AVM such as early venous filling and Spetzler-Martin classification, which highly correspond to those of conventional catheter angiography. Although this is a preliminary study, time-resolved contrast-enhanced 3D MR angiography at 3 T has the potential to replace conventional catheter angiography in screening or follow-up examinations of patients with AVMs.

Disclaimer

The authors do not report any conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Acknowledgments

We gratefully acknowledge Hiraku Kumamaru, M.D., of the Health Policy Institute, Japan, for his assistance with English proof-reading and statistical data analysis.

References

31. Türkşü PA, Korosec FR, Carroll TJ, Willig DS, Grist TM, Mistretta CA: Contrast-enhanced magnetic resonance angiography...
Assessment of AVMs with time-resolved 3D MR angiography


Accepted July 2, 2008.
Please include this information when citing this paper: published online December 1, 2008; DOI: 10.3171/2008.7.JNS08173.
Erratum: published online February 6, 2009; DOI: 10.3171/2008.7.JNS08173a.
Address correspondence to: Kanako Kunishima, M.D., Depart-ment of Radiology, The University of Tokyo Hospital, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan. email: kunishima-tky@umin. ac.jp.