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Original Article

3D T2-Weighted Sampling Perfection with Application-Optimized Contrasts Using Different Flip Angle Evolutions (SPACE) and 3D Time-of-Flight (TOF) MR Angiography Fusion Imaging for Occluded Intracranial Arteries

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Objective: Determining the course of occluded vessels in advance will increase the success rate and safety of mechanical thrombectomy (MT). Herein, we evaluate the usefulness of MR fusion images created via 3D T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolutions (T2-SPACE) and 3D time-of-flight (TOF)-MRA for visualization of occluded vessels in patients with acute ischemic stroke (AIS) before MT.
Methods: We enrolled 26 patients with AIS caused by intracranial large vessel occlusion who presented at our hospital and underwent MRI with fusion images unaffected by motion artifacts in our study. All patients underwent T2-SPACE and TOF-MRA followed by MT. We created fusion images of the T2-SPACE and TOF-MRA by combining a translucent image of the occluded artery produced by the flow void effect in T2-SPACE with the same vessel in a TOF-MRA image. Fusion images were compared with post-recanalization angiography and post-recanalization MRA, respectively, and the degree of agreement in depiction of M1 runs and M2 branching beyond the occlusion on three levels was assessed. Imaging evaluations were performed independently by two endovascular specialists.
Results: The interobserver agreement of the MRI findings about the concordance of the occluded vessel's run was excellent (kappa was 0.87 [confidence interval: 0.61–1.12]). In all, 21 patients (80.8%) had excellent imaging, four (15.4%) had fair imaging, and one (3.8%) had a divided opinion of the rating between excellent and fair imaging. No cases were judged to be poorly drawn. Even if there was a localized signal loss, its distal portion could be delineated, so it did not affect the estimation of the entire vessel run, and we found that the anatomical structures of the occluded vessels were distinctly visible in the fusion images.
Conclusion: We demonstrated that MR fusion images derived using T2-SPACE and MRA methodologies could determine the courses of occluded vessels prior to MT performed for AIS. Fusion MR imaging may have potential as a preoperative test for ensuring effective and safe MT procedures.

Keywords acute ischemic stroke, mechanical thrombectomy, magnetic resonance imaging, T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolutions, intracranial artery occlusion

Introduction

Mechanical thrombectomy (MT) is a standard procedure for treating acute ischemic stroke (AIS) due to large vessel occlusion[1)] and is increasingly being used for a wider range of patients.[2)] To the best of our knowledge, only few studies of visualization of the occluded vessels prior to MT have been reported.[3–5)] Therefore, most interventionalists

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perform MT blindly. This may lead to hemorrhagic complications and incomplete recanalization. Vessel perforation is a rare yet drastic complication that may arise in such cases.[6] Hence, determining the course of occluded blood vessels in advance will enhance the effectiveness and safety of MT.

Novel high-resolution vessel wall imaging techniques have been developed for describing both wall characteristics and morphology. A previous study reported a technique for visualization of occluded middle cerebral arteries (MCAs) via T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolutions (T2-SPACE) in three patients.[7,8] 3D T2-SPACE is a useful sequence distinguishing between cerebrospinal fluid (CSF) signals and other signals including occluded vessels.[9] In the current study, we assess the usefulness of MR fusion images of the T2-SPACE and time-of-flight (TOF)-MRA techniques for visualization of the occluded arteries prior to MT.

Materials and Methods

Patients

Of the 55 patients with AIS occurring due to intracranial large vessel occlusion who presented at our hospital from October 2019 to September 2021, 26 patients who underwent 3 Tesla (T) MRI (MAGNETOM Verio Dot Ver. VE11D; Siemens Healthineers, Erlangen, Germany) with fusion images unaffected by motion artifacts and could compare the images before and after MT were enrolled in our study. Patients with AIS who were not eligible for MT (23 patients) and those who could not undergo MRI without sedation cause to motion artifacts (3 patients) or with MRI contraindications (3 patients) were excluded. Our research was approved by the ethics review board at our institution and was likewise conducted in accordance with the Declaration of Helsinki and its later amendments. All participants provided written informed consent prior to participation. All patients underwent T2-SPACE and TOF-MRA followed by MT.

Image parameters and evaluation

The imaging parameters for the T2-SPACE methodology were as follows: repetition time (TR), 2,400 ms; echo time (TE), 244 ms; field of view (FOV), 200 mm; matrix, 256 × 256; slice thickness, 0.8 mm; flip angle mode, T2 variable (standard); blood suppression; free gradient strength (100 mTms); and scan time, 2 min 30 s. The imaging parameters (TOF-MRA) were as follows: TR, 21 ms; TE, 3.76 ms; FOV, 180 mm; matrix, 160 × 320; slice thickness, 0.6 mm; and scan time, 2 min. The imaging range for T2-SPACE is limited to the area centered on the occluded branch origin, which covers one-third of the TOF-MRA image. While preparing for MT, a radiology technician constructed a fusion image of the T2-SPACE and TOF-MRA (approximately 5 min; minimum: 1 min 19 s, maximum: 9 min 3 s, average: 4 min 24 s) using SYNAPSE VINCENT Ver. 4.6 software (Fujifilm, Tokyo, Japan). Briefly, the fusion image was created by combining a translucent image of the occluded artery produced by the flow void effect in T2-SPACE with the same vessel in TOF-MRA. Imaging evaluations were performed independently by two neurosurgeons with 13 and 15 years of experience who were an endovascular specialist. This was a retrospective evaluation and reviewers did not blindly evaluate the images. Fusion images were compared with post-recanalization angiography and post-recanalization MRA, and assessed the degree of agreement in depiction of M1 runs and M2 branching beyond the occlusion on three levels (excellent, fair, poor). Excellent was defined as the occluded segment and all distal branches beyond the occlusion could be clearly depicted as well as post MT angiography or post MRA; fair was defined as the occluded segment and distal branches could be visible but some discrepancy from the post MT angiography or post MRA in the diameter, course, or branches; and poor was defined as the occluded segment or distal branch could not be depicted. The results were evaluated by Kappa values as the interobserver agreement using Easy R.

Results

All 26 enrolled patients (12 women and 14 men; average age: 74 ± 10 years [range, 37–88 years], mean National Institutes of Health Stroke Scale: 13 ± 8 points [1–30 points], and mean diffusion-weighted imaging–Alberta stroke program early computed tomography score: 7 ± 2 points [3–11 points]) were referred for MT. Of these, 18 were diagnosed with either cardiogenic or artery-to-artery embolism, seven were diagnosed with atherosclerotic thrombosis, and the other case presented with an unknown (undiagnosable) cause. In five cases, the internal carotid artery (ICA) leading to the MCA was occluded; the MCA segments were occluded in the other cases (M1, 9 patients; M2, 12 patients). Eighty-eight percent of the patients achieved thrombolysis in cerebral infarction (TICI) 2b–3

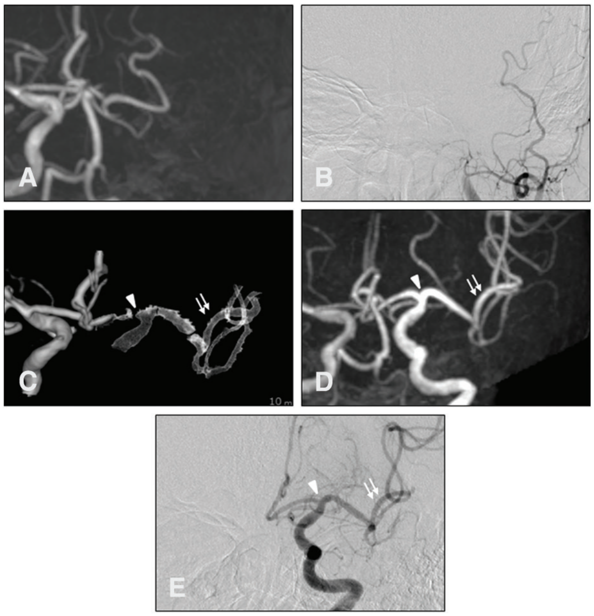

Fig. 1 Detection of blood vessels beyond the occluded sites in the left internal carotid artery occlusion case. This figure depicts images obtained in Case 1, with the occlusion point defined as the left ICA. Original 3D TOF-MRA images obtained at admission do not delineate the course of the MCA distal to the ICA (**A**). Angiography performed prior to MT (**B**) demonstrates a similar appearance as compared with 3D TOF-MRA at admission (**A**). Fusion images obtained from 3D T2-weighted SPACE and 3D TOF-MRA reveal the course of the MCA distal to the occlusion (**C**). The ICA in the petrous bone was difficult to delineate, but the intracranial MCA was well delineated, M1 showed a large run caudally, and the ensuing M2 was open vertically. Therefore, the image delineation was rated "excellent." MRA images (**D**) and angiography (**E**) acquired after MT match the fusion MR images (**C**) in terms of visualizing the MCA distal to the occlusion. Double arrows and arrowheads indicate the same point in the vessels. ICA: internal carotid artery; MCA: middle cerebral artery; MT: mechanical thrombectomy; SPACE: sampling perfection with application-optimized contrasts using different flip angle evolutions; TOF: time-of-flight

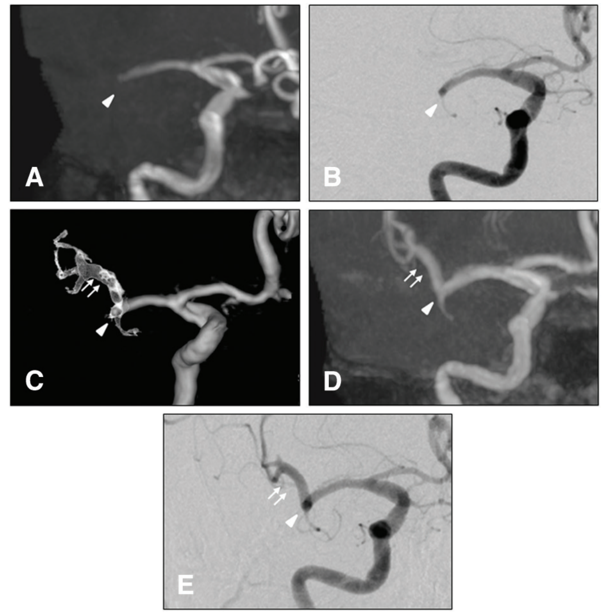

Fig. 2 Detection of blood vessels beyond the occluded sites in the right MCA M1 distal segment occlusion case. This figure depicts images obtained in Case 2, with the occlusion point defined as the right MCA M1 distal segment. Original 3D TOF-MRA images obtained at admission do not delineate the course of the MCA distal to the occlusion site (**A**: white arrowhead). Angiography performed prior to MT (**B**) demonstrates a similar appearance as compared with 3D TOF-MRA at admission (**A**). Fusion images obtained from 3D T2-weighted SPACE and 3D TOF-MRA reveal the course of the MCA distal to the occlusion (**C**: white double arrows). This case was a monofurcation branching type, and M1–M2 exhibited a steep branching angle. The image delineation was rated "excellent." MRA images (**D**) and angiography (**E**) acquired after MT match the fusion MR images (**C**) in terms of visualizing the MCA distal to the occlusion. Double arrows and arrowheads indicate the same point in the vessels. MCA: middle cerebral artery; MT: mechanical thrombectomy; SPACE: sampling perfection with application-optimized contrasts using different flip angle evolutions; TOF: time-of-flight

reperfusion. Seven patients presented with a small intracranial hemorrhage that did not affect their symptomology. None of these hemorrhagic events were related to MT procedural complications (i.e., wire perforation, vessel dissection, contrast extravasation).

Two endovascular specialists evaluated the images on the concordance of the occluded vessels' course and found that 21 patients (80.8%) had excellent imaging (**Figs. 1** and **2**), four (15.4%) had fair imaging (**Fig. 3**), and one (3.8%) had a divided opinion between excellent and fair ratings. No cases were judged to be poorly drawn. The interobserver kappa was 0.87 (confidence interval: 0.61–1.12).

Cases judged fair were those in which part of the occluded vessel had high signal internally in the T2-SPACE original image, as in Case 3 (**Fig. 3**), and therefore, a portion of the vessel could not be delineated. Even with a localized signal loss, the distal portion could be delineated; therefore, estimation of the entire vessel course was not affected in all images judged fair.

Discussion

Operation with a microcatheter beyond the occlusion site is performed blindly in MT. This may affect the incomplete recanalization rate and may cause complications such as blood vessels' perforation (which is associated with a high mortality rate).[6] Understanding the properties of the thrombus and the vascular architecture at the occluded site is crucial for performing successful MT. In this study, we easily confirmed the course and branching of occluded blood vessels prior to performing MT by using MR imaging to visualize the course of the blood vessels beyond the occluded area.

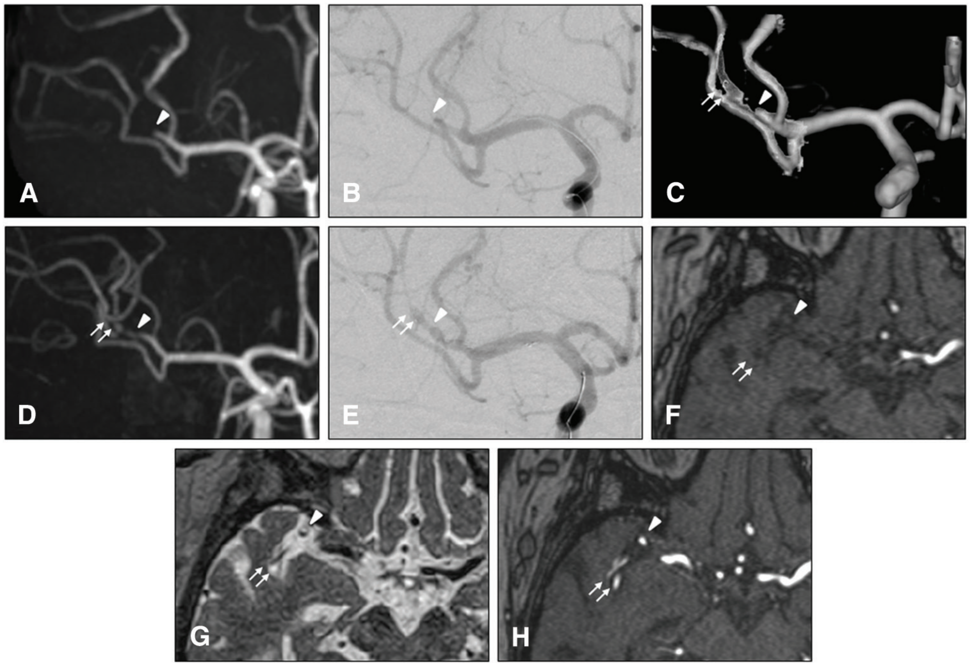

Fig. 3 Detection of blood vessels beyond the occluded sites in the right MCA M2 segment occlusion case. This figure depicts images obtained in Case 3, with the occlusion point defined as the right MCA M2 segment. Original 3D TOF-MRA images obtained at admission do not delineate the course of the MCA distal to the occlusion site (**A**: white arrowhead). Angiography performed prior to MT (**B**) demonstrates a similar appearance as compared with 3D TOF-MRA at admission (**A**). Fusion images obtained from 3D T2-weighted SPACE and 3D TOF-MRA reveal the course of the MCA distal to the occlusion (C: white double arrows). M2 runs linear, but part of the run is missing in the fusion image. Therefore, the image delineation was rated "fair." MRA images (**D**) and angiography (**E**) acquired after MT match the fusion MR images (**C**) in terms of visualizing the MCA distal to the occlusion. In the original MRA image before MT (**F**), the occluded vessels were not shown, but depicted as low signal in original T2-SPACE (**G**), and part of the occlusion was high signal internally (**G**: arrowhead). The original MRA after MT (**H**) showed no particular abnormality in the vascular signal of the occlusion site (**H**: arrowhead). Double arrows and arrowheads indicate the same point in the vessels. MCA: middle cerebral artery; MT: mechanical thrombectomy; SPACE: sampling perfection with application-optimized contrasts using different flip angle evolutions; TOF: time-of-flight

More specifically, in this case series, we mainly focused on MCA lesions with numerous flexion points and acute angles for the M1–M2 segments as related to hemorrhagic risk and the recanalization ratio.[10,11] The MCA typically branches into the superior and inferior trunk; however, various branching patterns have been observed, including monofurcation, trifurcation, pseudo-bifurcation, and early bifurcation. MCA anomalies include a twig-like MCA and fenestrated, duplicated, and accessory MCAs. Moreover, incidental, unruptured, and intracranial aneurysms are occasionally found in the MCA.[12,13] Knowledge of these characteristics enables safe and effective surgical treatment for AIS. The MCA can be followed by imaging the retrograde blood flow using cone-beam computed tomography[3] and 3D fast imaging.[4,5] Basi-parallel anatomical scanning, which uses heavy T2-weighted images, is a well-known technique for visualizing the arterial outer diameter within vertebral artery dissection; however, this technique is limited as it only provides two-dimensional description.[14] To the best of our knowledge, few comprehensive studies to date have predicted the course of an occluded vessel or discussed the most appropriate method for supporting the MT procedure.

T2-SPACE is a 3D fast spin-echo technique. This technique has proven valuable within high-resolution imaging and has a greater time efficiency as compared with the conventional 2D T2-weighted sequence.[15] The 3D-SPACE sequences employ a variable flip angle and high turbo factor to achieve a good vascular flow void, and it has been reported that even occluded vessels are shown as distinct low-signal areas within high-signal emitting areas in the CSF.[9] High-resolution vessel wall imaging techniques, including SPACE, have been developed for clinical use in various types of intracranial artery disease, especially within intracranial atherosclerosis.[16] Because these sequences are mainly meant to evaluate wall features, suppressing CSF signals is essential.[16)]

Herein, we employed T2-weighted images, in which the contrast between the low-intensity flow void of the vessels and the high-intensity CSF permits vessel identification without requiring a contrast medium. A previous study reported successful fusion imaging within T2-SPACE and TOF-MRA implemented for intracranial cerebral aneurysm.[17)] However, to the best of our knowledge, there are no previous reports regarding the use of this technique for occluded cerebral arteries within AIS, with the exception of two case reports.[7,8)] We reviewed a larger number of cases in the current study and focused on imaging the occluded artery using T2-SPACE and SYNAPSE VINCENT software to produce translucent images of the occluded artery almost instantaneously. We identified the angles and directions of branching within the MCA prior to performing MT in all of the reported cases. We used the T2-SPACE imaging method within 3T MRI as provided by Siemens; however, it is entirely possible that similar fast spin-echo imaging methods provided by other companies could produce comparable images.[4,5)]

The fusion image using T2-SPACE presented herein is simple to generate, requiring imaging and reconstruction times of approximately 2.5 min and 5 min, respectively. The scanning time was slightly longer than that reported by Sato et al.[5)] However, the total scanning time with the addition of evaluating MRA is less than 5 min, which is comparable to their report.[5)] A manual is in place at our medical center so that the technician on duty can produce images even at night and/or without optimal support from their clinical team.

We consider that this technique has potential as a preoperative examination tool within AIS necessitating MT, especially in facilities that allow MR images to be acquired quickly (i.e., prior to other diagnostic imaging examinations). When limiting our evaluation to cases using the dedicated hotline, we demonstrate that the entirety of this procedure takes approximately 74 ± 8 min from door to puncture and approximately 38 ± 13 min from puncture to recanalization, even while taking an MR image. Eighty-eight percent of patients achieved TICI 2b–3 reperfusion, and there were no hemorrhagic events related to the MT procedure (as represented by the perforation of blood vessels).

In five cases where the agreement of the fusion image was judged to be fair, there was a localized signal loss in the depiction of the occluded vessels because of lack of flow void effect, for example, as shown in **Fig. 3**. Luminal clots are reported to be identified as hyperintense or isointense signals on high-resolution MRI,[18)] but not all in our case series. The reasons for this were considered to be the nature of the thrombus, but due to the small number of cases, it is difficult to determine the properties of the thrombus using this method alone. Further investigation is needed to determine which cases are more likely to have delineation defect.

The limitations of fusion imaging include challenges in acquiring MR images among patients who present with intense body movements in the MRI scanner as well as the long preparation time necessary in facilities where an MR image cannot be obtained quickly. However, recent studies have suggested that MRI may be associated with a decreased risk of futile recanalizations.[19)] Hence, more cases may be selected for MRI prior to implementing MT in the future. This technique will be useful for facilities where an MRI is the first choice for AIS diagnoses, and will likely contribute to reducing complications and enabling successful recanalization in MT for AIS. While this case series focuses mainly on MCA lesions, previous studies have reported that blind catheterization may be more dangerous in the posterior circulation as compared with the anterior circulation.[20)] Future research is necessary to verify the utility of this technique with respect to posterior circulation.

Conclusion

MR fusion images obtained through T2-SPACE and MRA appear to be a simple and effective tool for determining the course of occluded vessels prior to performing an MT for AIS. We conclude that fusion MR imaging may have potential as a preoperative test for ensuring an effective and safe MT procedure.

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Disclosure Statement

The authors declare that they have no conflicts of interest.

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