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Technical Note

Usefulness of the Preoperative Images Supporting Mechanical Thrombectomy Based on Susceptibility-Weighted Image for Stroke

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Objective: This is a report on the usefulness of 3D fusion imaging with susceptibility-weighted imaging (SWI) as preoperative imaging for mechanical thrombectomy (MT) for acute ischemic stroke (AIS).
Case Presentations: Among 17 cases of patients who underwent MT in AIS between March 2021 and April 2022, 14 patients who underwent MRI with SWI (shortened SWI for stroke) and 3D T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolution were targeted in the study. Three cases with motion artifacts due to body movement were excluded from the images. After imaging, 3D fusion images were constructed to visualize thrombi and occluded vessels. SWI for stroke obtained thrombus information in 11 of the 14 cases (78.5%) and 3D images of the thrombi could be created in all 11 cases. 3D fusion images could be created in nine of the 14 cases (64.2%).
Conclusion: 3D fusion images, using SWI for stroke, can visualize thrombi and occluded vessels and may be effectively used as preoperative images for MT.

Keywords acute ischemic stroke, mechanical thrombectomy, magnetic resonance imaging, susceptibility weighted image, susceptibility vessel sign

Introduction

The use of mechanical thrombectomy (MT) has become prevalent as the standard treatment for acute ischemic stroke (AIS) since its efficacy for this disease was verified.[1)] Nevertheless, this treatment requires technical skill and experience to be safely performed because it necessitates the use of an endovascular device. Technical skill is also required, as it is impossible to confirm the presence of thrombus, vessels, and other structures that are distal to the occlusion during surgery and requires a blind operation.[2)] Therefore, obtaining information on the thrombus and occluded vessels prior to surgery is important to predict stent deployment location during treatment and to reduce the risk of intraoperative complications, such as vascular perforation or rupture.

Previously, we have visualized occluded vessels using MRI to create 3D T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolution (T2-SPACE) and created 3D fusion images with MRA.[3,4)] We have now created images with thrombi in a short amount of time using susceptibility-weighted imaging (SWI) for stroke to obtain 3D images with vascular information for both the occluded vessels and other vessels, making this information accessible to surgeons prior to MT.

Herein, we report on the imaging parameters for SWI for use in cases of stroke, methods of creating fusion images, and their usefulness as pre-MT assistive images.

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Table 1 List of patients for whom fusion images were created and MT was performed

Patient no	Age	Sex	Occlusion site	NIHSS	DWI-ASPECTS	SVS	3D image of thrombus	3D fusion image	TICI	Thrombus
1	85	M	Lt. M2	9	5	+	+	+	2b	+
2	67	M	Rt. M1	16	7	–	–	–	1	–
3	80	F	Lt. ICA	30	10	+	+	+	3	+
4	77	F	Rt. ICA	1	10	–	–	–	2b	+
5	73	F	Rt. M1	14	9	+	+	–	3	+
6	76	F	Rt. M1	19	9	+	+	–	3	+
7	85	F	Rt. ICA	4	7	+	+	+	3	+
8	81	M	Lt. M2	27	9	+	+	+	3	+
9	69	M	Rt. ICA	10	6	+	+	+	2b	+
10	87	F	Lt. M1	26	4	+	+	+	2a	+
11	87	F	Rt. M1	17	3	+	+	+	2a	+
12	86	F	Rt. ICA	12	4	+	+	+	1	+
13	83	F	Rt. M1	3	7	–	–	–	2b	+
14	92	F	Rt. M2	24	9	+	+	+	2b	+

DWI-ASPECTS: diffusion-weighted imaging-Alberta stroke program early CT score; F: female; ICA: internal carotid artery; Lt.: left; M: male; M1: middle cerebral artery horizontal segment; M2: middle cerebral artery insular segment; MT: mechanical thrombectomy; NIHSS: National Institutes of Health Stroke Scale; Rt: right; SVS: susceptibility vessel sign; TICI: thrombolysis in cerebral infarction

Case Presentation

The participants of this study were 14 cases (excluding three cases of poor imaging due to artifacts caused by body movements) selected from among 17 cases that underwent MT for AIS between March 2021 and April 2022, for whom we created SWI for stroke and T2-SPACE images using MRI (**Table 1**).

After imaging, we created 3D fusion images to visualize thrombi and occluded vessels. SWI for stroke provided information on thrombi in 11 of the 14 cases (78.5%). 3D images of the thrombi could be created for all 11 cases for which thrombus information was obtained. 3D fusion images could be created in nine of the 14 cases (64.2%) (**Table 1**).

The MRI device utilized was a MAGNETOM Verio Dot 3.0T, ver. VE11D (Siemens Healthineers, Erlangen, Germany). The image analysis workstation utilized was a SYNAPSE VINCENT, ver. 6.4 (Fujifilm, Tokyo, Japan), and the analysis software utilized was Multi-3D and 3D View (Fujifilm). The imaging parameters were as follows:

1. SWI for stroke: (repetition time [TR]: 18 ms, echo time [TE]: 10 ms, field of view [FOV]: 220 mm, matrix: 320×168, accel factor: 2, slice thickness: 1.6 mm, slices per slab: 88, band width [BW]: 280, and time of acquisition [TA]: 1 min 20 s).
2. T2-SPACE: (TR: 2400 ms, TE: 244 ms, FOV: 200 mm, matrix: 250 × 250, flip angle mode: T2 variable (standard), turbo factor: 150, blood suppression: free [170 mTms], TA: 2 min 30 s).
3. MRA: (TR: 21 ms, TE: 3.76 ms, FOV: 180 mm, matrix: 160×320, slice thickness: 0.6 mm, BW: 170, flip angle (FA): 18, TA: 3 min 56 s).

The study was approved by the ethics review board at our institution.

Case 1

History of present illness: An 85-year-old man discovered lying indoors in a prone position was transported on an emergency basis to this hospital (**Table 1**, Patient No. 1). His score on the National Institutes of Health Stroke Scale (NIHSS) was 9 and he had aphasia and right hemiparesis.

Imaging findings: A head MRI was done upon arrival at the hospital. Diffusion-weighted imaging (DWI) indicated high-intensity zones in the left deep white matter and insular cortex (diffusion-weighted imaging-Alberta Stroke Program Early CT Score [DWI-ASPECTS]: score of 9). The MRA images were suggestive of occlusion of the middle cerebral artery, and occlusion was observed in the M2 segment (**Figs. 1A**–**1C** and **2A**). We performed imaging using SWI for stroke and T2-SPACE. The original SWI for stroke images showed the susceptibility vessel sign (SVS) and confirmed the site of the thrombus (**Fig. 1D**–**1F**). To create 3D fusion images after these imaging studies, we forwarded the original SWI for stroke, T2-SPACE, and MRA images to the analysis workstation and performed co-registration. The 3D fusion images were created by extracting the SVS from the SWI for stroke as the

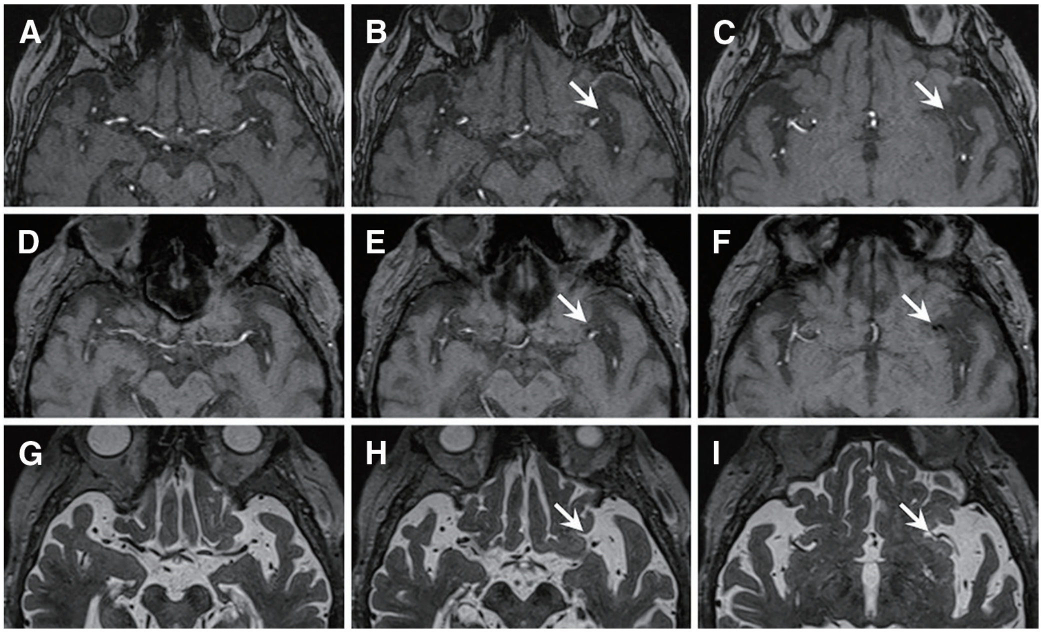

Fig. 1 Original preoperative MRI image obtained for Case 1. Although it was possible to confirm that there was a high-intensity signal zone in the M1 segment of the left middle cerebral artery (**A**), there was a low-intensity signal zone in the M2 segment (**B**–**C**: arrow). The original SWI for stroke imaging allowed confirmation of the high-intensity signal zone in the M1 segment of the left middle cerebral artery (**D**). A low-intensity signal zone corresponding to the occlusion site was indicated, which allowed for the identification of the SVS (**E**–**F**: arrow). T2-SPACE allowed confirmation of the left middle cerebral artery M1 segment (**G**) and the flow-void effect from the occlusion site to the distal artery as a low-intensity signal zone (**H**–**I**: arrow). SWI: susceptibility-weighted imaging; SVS: susceptibility vessel sign; T2-SPACE: 3D T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolution

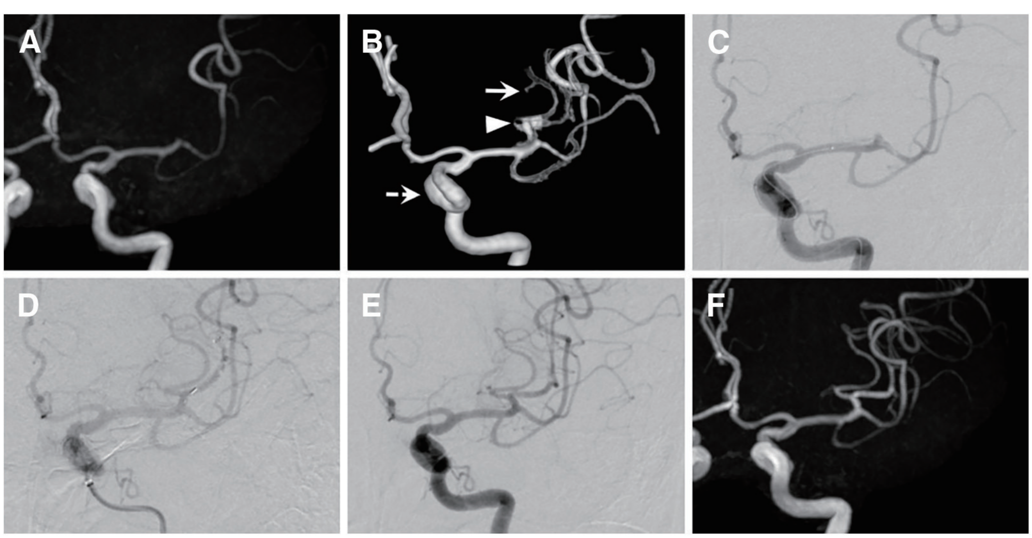

Fig. 2 Images obtained in Case 1. The preoperative MRA MIP image led to suspicion of occlusion of the superior trunk (**A**). We created a 3D fusion image (**B**: arrow [occluded vessel: T2-SPACE]), an arrowhead (thrombus: SWI for stroke), and a dotted arrow (artery structure: MRA). A preoperative cerebral angiogram showed occlusion of the superior trunk, which was consistent with the preoperative MRA. The postoperative cerebral angiography allowed for confirmation of the reestablishment of blood flow. This was consistent with the artery structure created using the 3D fusion image (**C**: preoperative, **D**: after stent placement, **E**: postoperative). Postoperative MRA MIP image aided in the confirmation of the reestablishment of blood flow to the superior trunk (**F**). MIP: maximum intensity projection; SWI: susceptibility-weighted imaging; T2-SPACE: 3D T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolution

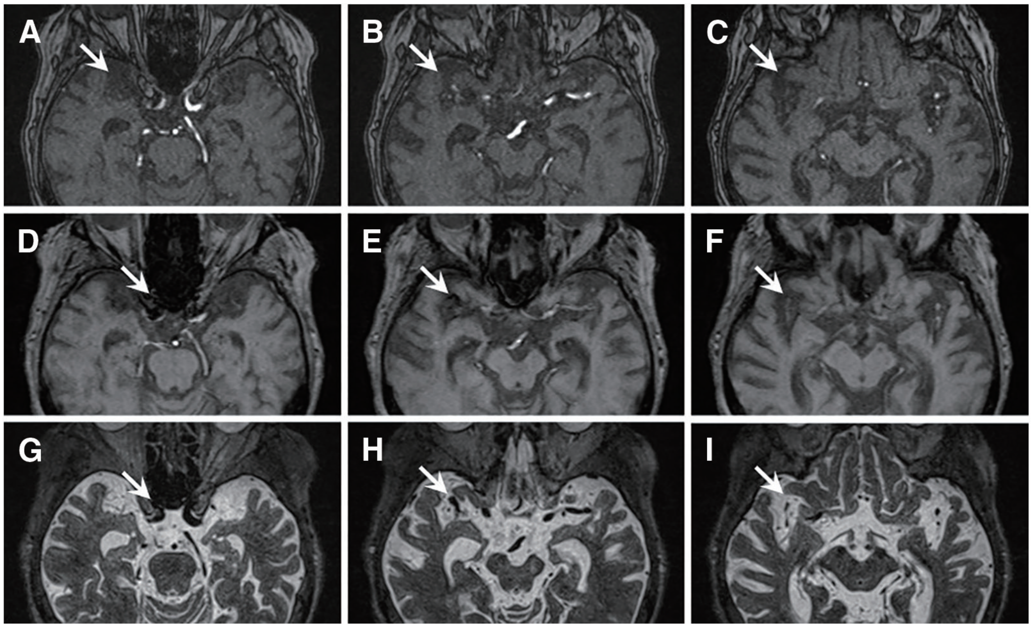

Fig. 3 The original preoperative MRI image was obtained for Case 2. MRA showed the M1 segment of the left middle cerebral artery as a low-intensity signal zone, which led to the suspicion of occlusion (**A**–**C**: arrow). Assessment of the thrombus in the ICA within the pyramidal bone was difficult using the original SWI for the stroke image (**D**: arrow). SVS was confirmed at M1–M2 of the right middle cerebral artery (**E**–**F**: arrow). The depiction of the ICA within the pyramidal bone was also difficult with T2-SPACE (**G**: arrow). However, it was possible to confirm the flow-void effect for the M1 segment of the right middle cerebral artery and the artery distal to the occlusion as low-intensity signal zones (**H**–**I**: arrow). ICA: internal carotid artery; SWI: susceptibility-weighted image; SVS: susceptibility vessel sign; T2-SPACE: 3D T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolution

thrombus and overlapping the occluded vessel obtained from the flow-void results on the T2-SPACE image (**Fig. 1G**–**1I**) with the vessels shown on the MRA. The process required approximately 8 min and allowed visualization of the vessels and the occluded vessels (**Fig. 2B**).

Cerebral angiography: The cerebral angiography performed involved confirmation of the occlusion in the left middle cerebral artery and carrying out of the MT (**Fig. 2C**).

MT: Using the 3D fusion images as a reference, we introduced a microguidewire into the left middle cerebral artery, which was the expected location of the thrombus, the M2-segment, and the central artery. We deployed a Tron FX (Terumo, Tokyo, Japan) of 4 mm × 20 mm and achieved reperfusion swiftly (**Fig. 2D**). While applying suction using a 5 Fr SOFIA Flow (Terumo), we removed the Tron FX and confirmed thrombus adhesion. Postoperative cerebral angiography showed thrombolysis in the cerebral infarction (TICI) scale of 2b, and the MT was concluded (**Fig. 2E**).

Postoperative course: The postoperative course was satisfactory and without complications. Right hemiplegia and aphasia were both observed to be improving. MRA performed on the following day indicated that the blood flow in the left middle cerebral artery had been reestablished (**Fig. 2F**).

Case 2

History of present illness: A 92-year-old woman was discovered after a fall in the bathroom and was transported on an emergency basis to this hospital (**Table 1**, Patient No. 14). Her NIHSS score was 24 and she had right conjugate deviation and left upper and lower extremity paralysis.

Imaging findings: An MRI was performed upon arrival at the hospital. DWI showed a right lentiform nucleus and a high-intensity zone in the deep white matter (DWI-ASPECTS: 9). MRA showed occlusion in the right middle cerebral artery in the M1 segment (**Figs. 3A**–**3C** and **4A**). Thus, using the same method as described above in the section on Case 1, we created 3D fusion images (**Figs. 3D**–**3I** and **4B**–**4C**). This allowed us to visualize the thrombus and occluded blood vessels in a region from the M1 segment to the superior trunk. The time required to create the image was approximately 8 min.

Cerebral angiography: Occlusion in the right middle cerebral artery was indicated, as was the case with MRA, as the artery was not visible past the M1 segment (**Fig. 4D**). Subsequently, we performed MT.

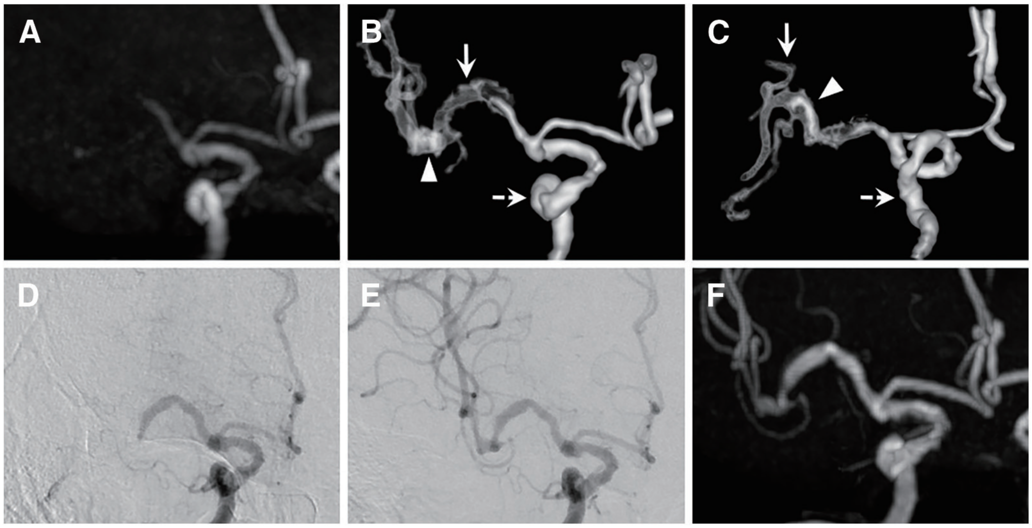

Fig. 4 Images obtained in case 2. It was possible to confirm occlusion in the M1 segment of the right middle cerebral artery on the preoperative MRA MIP image (**A**). We created a 3D fusion image (**B**–**C**: arrow [occluded vessel: T2-SPACE]), an arrowhead (thrombus: SWI for stroke), and a dotted arrow (artery structure: MRA). The depiction of the occluded vessel was satisfactory, and we were able to confirm the presence of the thrombus from the M1 segment to the superior trunk (**C**). Preoperative cerebral angiography was consistent with the preoperative MRA (**D**). Postoperative cerebral angiogram allowed for the confirmation of the reestablishment of blood flow (**E**). This was consistent with the artery structure created using the 3D fusion image. The MRA MIP image taken on the day following surgery confirmed the reestablishment of blood flow (**F**). MIP: maximum intensity projection; SWI: susceptibility-weighted Image; T2-SPACE: 3D T2-weighted sampling perfection with application-optimized contrasts using different flip angle evolution

MT: Using the 3D fusion image as a reference, a microguidewire was introduced to a position beyond the thrombus in the superior trunk. A Tron FX of 4 mm × 20 mm was introduced and reperfusion was swiftly confirmed. While applying suction using a 5 Fr SOFIA Flow, we removed the Tron FX and identified a small amount of thrombus affixed to it. As an additional blood vessel occlusion was identified in a distal location, a microguidewire was introduced into the M3 segment. A Tron FX 1.5 mm × 15 mm was introduced, and the stent was recovered. A cerebral angiogram showed a TICI scale of 2b, and the MT was concluded (**Fig. 4E**).

Postoperative course: The conjugate deviation disappeared following surgery. The patient was able to engage in conversation, and the left upper and lower extremity paralysis improved. An MRA performed on the following day indicated that the blood flow had been restored to the right middle cerebral artery (**Fig. 4F**).

Discussion

SWI is an imaging method that was advocated by Haacke et al.[5] Using phase data, it emphasizes the difference in the magnetic susceptibility of intravenous deoxyhemoglobin and the oxyhemoglobin within tissues. Normally, images reconstructed using minimum intensity projection (min IP) are used for diagnosis. It has been reported that the SVS,[6] which depicts thrombi within major arteries during the acute phase (that are conventionally identified using T2-weighted images), detects thrombi in a more sensitive manner.[7] While there are various views regarding the SVS, it is believed to allow easier identification of the target for extraction, i.e., the thrombus, during MT procedures.[8,9]

The SWI used in this study (SWI for stroke) allowed images to be obtained in a short period, as the entire brain could be imaged in 1 min 20 s. In addition, venous signals were suppressed by reducing the TE to 10 ms; therefore, the recognition of the SVS was facilitated.

3D images of the thrombi were created from the SVS using original images that were not subjected to min IP processing. After sending the data to the image analysis workstation, a template for the purpose of creating thrombi was used to obtain an image in approximately 20 s. By suppressing the venous signal and reducing the slice thickness to 1.6 mm, good 3D images of the thrombi could be obtained. In addition, even when the creation of a 3D fusion image that included the occluded vessel was included, the process took approximately 10 min and could be concluded prior to the start of the MT procedure. This allowed the surgeon to confirm the morphology of the thrombus prior to the MT procedure and gain an accurate understanding of the extent of the thrombus and the vessel in which it is located.

Since MT is performed blindly with a microguidewire that is inserted past the occlusion site, complications such as incomplete reopening of the vessel and vascular perforation are risks. As a result, several different methods of visualization have been reported. Ohara et al.[10] created T1- and T2-weighted images using a 3D-turbo spin-echo sequence to identify the thrombus and arterial anatomy. It has been reported that in cases involving branches of the middle cerebral artery, multiplanar reconstruction has been used to assess the location and size of thrombi and intramural hematomas; additionally, the effectiveness of the 3D-turbo spin-echo sequence has been advocated. Preoperative understanding of the characteristics of the thrombus and visualization of the structure of the occluded vessels are important for the success of MT. It has also been reported that 3D fast spin-echo sequence T2-weighted images are useful in ascertaining the spatial relationships of the periarterial structures in cases of craniotomy as well as in cases of intravascular treatment.[11]

In the present study, the SVS was detected in 11 of the 14 cases (78.5%) in whom the method described in this study was performed. However, the SVS was not detected in three cases. In two of the three cases in which the SVS was not detected, the thrombi were removed using MT. The fact that SWI had difficulty identifying these thrombi may be because the main component of the thrombi may not have been deoxyhemoglobin. In the remaining case, it was impossible to extract the thrombus using MT; additionally, an atherothrombotic cerebral infarct was suspected. Moreover, confirmation of the thrombus was difficult due to the magnetic susceptibility artifacts in the internal carotid artery (ICA) within the pyramidal bone.

It was possible to create 3D images of thrombi in all 11 cases in which the SVS was detected. Although it is difficult to create 3D images of the ICA within the pyramidal bone, it is important to confirm the distal side of a thrombus when predicting the location of stent placement. Therefore, images are created even in cases in which the proximal side of the thrombus reaches the pyramidal bone.

In nine out of 14 cases (64.2%), it was possible to create 3D fusion images. Difficulty was encountered in five cases, and in three of these cases, it was impossible to detect SVS using SWI for stroke, making it difficult to create 3D images of the thrombi. In the remaining two cases, the occluded vessels could not be imaged using T2-SPACE, which made it difficult to create 3D images of the occluded vessels. In such cases, images are created using the flow-void effect of the T2-SPACE, in accordance with the report on the creation of 3D images of occluded vessels by Ozaki et al.[12] The T2-SPACE used in the present study utilized a variable flip angle. Modulation of the flip angle increases the dispersion of the blood phase, and as a result, a strong flow-void effect is obtained. In these two cases, the main reason for the inability to create images was the loss of the flow-void effect of the blood. In cases in which a blood vessel within the cerebrospinal fluid signal presents with an equal or higher intensity signal, it can be difficult to create preoperative images as it is difficult to identify the occluded vessel. Changes in the signal strength of the occluded vessel are believed to be related to the properties of the thrombus. It has been reported[13] that the thrombus can be differentiated as an equal or higher signal on a high-resolution MRI, but further investigation of this is necessary. Visualization of the occluded vessel using T2-SPACE allows visualization of the vessels and other structures beyond the middle cerebral artery M2 segment up to their peripheral, but as is the case with SWI for stroke, it was difficult to visualize the ICA within the pyramidal bone.

Image fusion processing is carried out automatically on the SWI for stroke and the T2-SPACE images individually, with the MRA image as the starting point. Registration was successfully observed in all nine cases in which 3D fusion image creation was possible. This was likely because SWI for stroke images the entire brain, and the fact that the original images depict the major arteries other than the occluded vessel in high intensity made highly accurate fusion processing possible.

To the best of our knowledge, there have been no reports of cases in which 3D fusion images of thrombi and occluded vessels have been made from individual preoperative MRI images. When imaging is performed using both SWI for stroke and the T2-SPACE sequences, the process takes 3 min 50 s longer; however, we believe that an accurate diagnosis of the extent of the region the thrombus has affected and the occluded vessel in the preoperative evaluation are important in the determination of a therapeutic strategy. In particular, we believe that detecting thrombi in lesions with complicated vessel courses, such as lesions in the M1–M2 branches of the middle cerebral artery and tortuous blood vessels, contributes to increased safety.

Conclusion

3D fusion images of SWI for stroke and T2-SPACE are an effective method that allows the visualization of thrombi and occluded vessels in a short period prior to the MT procedure. This method is effective as it reduces complications and assists in the safe performance of MT.

Disclosure Statement

The authors declare that they have no conflicts of interest.

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