Preoperative Evaluation of Collateral Venous Anastomoses in Meningioma Involving Cerebral Venous Sinus by Susceptibility Weighted Imaging

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Abstract: Precise preoperative identification of the collateral venous anastomoses is critical for proper surgical management of patients with meningioma involving sinus. This study was to assess the feasibility of susceptibility weighted imaging (SWI) to delineate the collateral venous anastomoses before surgery.

Twenty-five patients with meningiomas that were involved in sinuses underwent surgery and the collateral anastomoses were evaluated with SWI and phase-contrast magnetic resonance venography (MRV) before surgery. The results obtained with SWI were compared with those obtained with MRV. Intraoperative findings were used as the gold standard.

By surgery, a total of 98 collateral anastomotic veins were identified in the 25 patients. SWI depicted 85 collateral anastomotic veins close to the meningioma with a sensitivity of 87%, whereas MRV showed 57 collateral anastomotic veins with a sensitivity of 58%. The detectability of collateral anastomotic veins in SWI images was superior to MRV.

The results suggest that SWI is superior to MRV and could provide more reliable information on the collateral venous anastomoses in patients with meningioma.

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Abbreviations: FA = flip angle, FOV = field of view, MinIP = minimum intensity projection, MRA = magnetic resonance angiography, MRI = magnetic resonance imaging, MRV = magnetic resonance venography, PACS = picture archiving and communication system, PC = phase-contrast, SWI = susceptibility weighted imaging, TE = echo time, TOF = time of flight, TR = repetition time.

INTRODUCTION

Meningioma typically arises from the meninges along the intradural venous sinuses, and involvement of the sinus poses a challenge for surgery. Understanding of the relationship between the tumor and the adjacent venous structure is crucial for precise surgical planning, especially for the meningiomas involving venous sinuses.[1,2] Currently, magnetic resonance angiography (MRA) is the technique of choice to display the intracranial venous circulation. However, the routinely used MRA is limited in this respect because of the saturation (time of flight [TOF]) and encoding velocity (phase-contrast [PC]) artifacts. Susceptibility weighted imaging (SWI) is a rapidly evolving technique that utilizes both the magnitude and phase information to demonstrate the susceptibility changes between tissues.[3] SWI is sensitive to the paramagnetic effects of deoxyhemoglobin and shows good performance in the evaluation of cerebral venous sinus thrombosis by demonstrating the cortical veins and collateral slow flow. Low-flow vascular malformation that is not visualized well on magnetic resonance venography (MRV) could be depicted in exquisite detail along with the venous components on SWI. SWI has also been used for noninvasive imaging of trauma, tumors, multiple sclerosis, poststroke changes, and occult vascular disease, and for the quantification of brain iron.[4–8] This study was to assess the performance of SWI in the preoperative evaluation of collateral venous anastomoses in patients with meningiomas involving cerebral venous sinus by comparing with MRV and intraoperative findings.

MATERIALS AND METHODS

Patients

This study was approved by the ethics committee of Qilu Hospital. Informed consent was obtained from all patients before enrollment in the study. Twenty-five consecutive patients (10 men and 15 women) with a diagnosis of meningioma involving the major dural sinus were prospectively evaluated within a period of 9 months. The age of patients ranged from 31 to 77 years (mean, 58 years). The meningiomas were in the direct vicinity of superior sagittal sinus in 11 patients, transverse sinus in 7 patients, confluence sinus in 3 patients, and sigmoid sinus in 4 patients. All patients underwent conventional magnetic resonance imaging (MRI), SWI, and PC MRV before surgery.

MRI and MRV

MRI was performed using a Siemens 3T scanner (Magnetom Trio; Siemens Medical Solutions, Erlangen, Germany) with a standard head coil. Routine T1-weighted spin-echo imaging and T2-weighted turbo spin-echo imaging were performed with repetition time (TR) of 2000 and 3000 ms and echo time (TE) of 13 and 80 ms, respectively. All images were obtained with a 22-cm field of view (FOV) and a 192×256 matrix. Section thickness was 6 mm. Gadobutrol (1.0 mol/L, Shering, Berlin, Germany) was administered in a dose of 0.1 mmol/kg by an automatic power injector (Medrad Spectris, Indianola, PA) at a rate of 4.0 mL/s. Three-dimensional (3D) PC

MRV was performed with the following parameters: TE, 4.8 ms; TR, 15 ms; flip angle (FA), 15°; FOV, 260 mm; matrix, 208 × 180; slice thickness, 2 mm; number of slices, 60; acquisition, sagittal; velocity encoding, 15 cm/s; acquisition time, 6 minutes 33 seconds. Source images from MRV sequences were transferred to a workstation for image elaboration. Two sets of 12 images (1 every 15°) from rotation in the 2 orthogonal planes were obtained.

Susceptibility Weighted Imaging

SWI was performed with a 3D fast low-angle gradient-echo sequence. This sequence consisted of a strongly T2*-weighted low-bandwidth 3D fast low-angle shot sequence with flow compensated in all 3 orthogonal directions. The parameters of SWI were as follows: $TR = 28$ ms; $TE = 20$ ms; $FA = 20°$. Thirty two partitions of 2 mm were acquired by using a matrix size of 282×512 and a rectangular FOV of 256 mm, which resulted in a voxel size of $0.6 \times 0.5 \times 2$ mm^3. SWI images were constructed with raw data of the magnitude and phase. A phase mask was generated by setting all positive phase values (between 1° and 180°) to unity and normalizing the negative phase values ranging from 0° to 180° to a gray-scale of values ranging linearly from unity to zero, respectively. The normalized phase mask was multiplied 4 times against the original magnitude image, and images that enhanced the hypointensity of the region containing susceptibility properties (such as deoxygenated venous blood) were generated. Finally, a minimum intensity projection (MinIP) over 2 sections was performed to display the processed data by using contiguous sections of 4-mm thickness in the axial plane.[9–11] Finally, a MinIP technique was used to display the processed magnitude data. The effective MinIP thickness is determined by the number of series of images put together from the original combined SWI processed magnitude image, which is a combination of the magnitude and phase data. The MinIP reconstructions are arbitrary and may be created with thinner or thicker sections. Generally speaking, the thicker the reconstructions are, the better depiction and delineation of vein continuity are obtained. However, this may also lead to apparent false representation because of the presence of multiple contiguous slices put together and is a potential pitfall for accurate localization. In addition, a higher thickness of the MinIP may lead to partial voluming and misregistration of the vessels. On the other hand, a thinner thickness of MinIP may lead to misinterpretation of veins from focal lesions such as microbleeds. In this study, we used 2 sections of 4-mm slice thickness for the processed magnitude image based our experience and manufacturer's recommendation; this thickness of MinIP image could maintain the continuity of veins, minimize partial volume effects, and prevent misinterpretation of the localization of vessels versus focal lesions.[9–12] The processing was automatically performed by the Magnetom Vision software (Siemens Medical System, Erlangen, Germany).

Image Analysis

The SWI and MRV images were archived to a picture archiving and communication system (PACS) for interpretation. The reading sessions were done on a PACS workstation (Impax Version 4.5 PACS; Agfa HealthCare, Mortsel, Belgium). Two radiologists (with 13 and 10 years of experience in interpreting vascular imaging, respectively) who were unaware of patients' clinical data reviewed the images independently. Disagreement was resolved by consensus. The number of collateral vessels close to the sinus was counted. Surgery was used as the gold standard. The χ^2 test was used to evaluate the ability of SWI and MRV in the depiction of collateral vessels.

RESULTS

All patients underwent surgery in our institution. A summary of patients' information is presented in Table 1. Neurosurgeons evaluated the number of collateral veins bridging the neoplasm and sinus or running close to it. All of the 25 meningiomas showed sinus involvement and a total of 98 collateral anastomotic veins (average 4 for each tumor) were observed at surgery. SWI identified 85 collateral anastomotic veins close to the meningioma, whereas MRV depicted 57 collateral anastomotic veins. The anastomotic veins identified on SWI and MRV were all confirmed by surgery. The sensitivities of SWI and MRV were 87% and 58%, respectively. The difference was statistically significant ($P < 0.01$).

SWI demonstrated all collateral veins in 13 patients, whereas MRV depicted all collateral veins in only 2 patients (Figure 1). In 1 patient with a meningioma involving the superior sagittal sinus, SWI clearly depicted all of the 3 collateral veins; in contrast, none of the collateral veins was detected by MRV (Figure 2).

DISCUSSION

Meningioma involving the cerebral venous sinus represents a challenge for complete resection of the tumor.[13]

TABLE 1. Characteristics of 25 Men With Meningiomas Involving Cerebral Venous Sinus and Collaterals Showed by MRV, SWI, and Surgery

Case No./Age, y	Location	MRV	SWI	Surgery
1/77	Superior sagittal sinus	2	3	4
2/65	Transverse sinus	4	6	6
3/67	Confluence sinus	0	3	3
4/54	Superior sagittal sinus	0	1	1
5/71	Transverse sinus	3	5	7
6/66	Confluence sinus	2	5	5
7/58	Superior sagittal sinus	2	4	5
8/52	Superior sagittal sinus	3	3	3
9/53	Transverse sinus	1	3	3
10/58	Confluence sinus	3	2	4
11/67	Superior sagittal sinus	1	2	2
12/38	Transverse sinus	5	7	7
13/47	Sigmoid sinus	2	2	3
14/46	Sigmoid sinus	3	3	3
15/59	Superior sagittal sinus	3	4	4
16/67	Sigmoid sinus	4	4	5
17/65	Sigmoid sinus	2	3	5
18/62	Superior sagittal sinus	1	2	2
19/53	Transverse sinus	4	5	5
20/50	Superior sagittal sinus	5	6	7
21/59	Transverse sinus	0	1	1
22/31	Transverse sinus	0	2	3
23/45	Superior sagittal sinus	1	2	2
24/49	Superior sagittal sinus	3	4	4
25/55	Superior sagittal sinus	3	3	4

MRV = magnetic resonance venography, SWI = susceptibility weighted imaging.
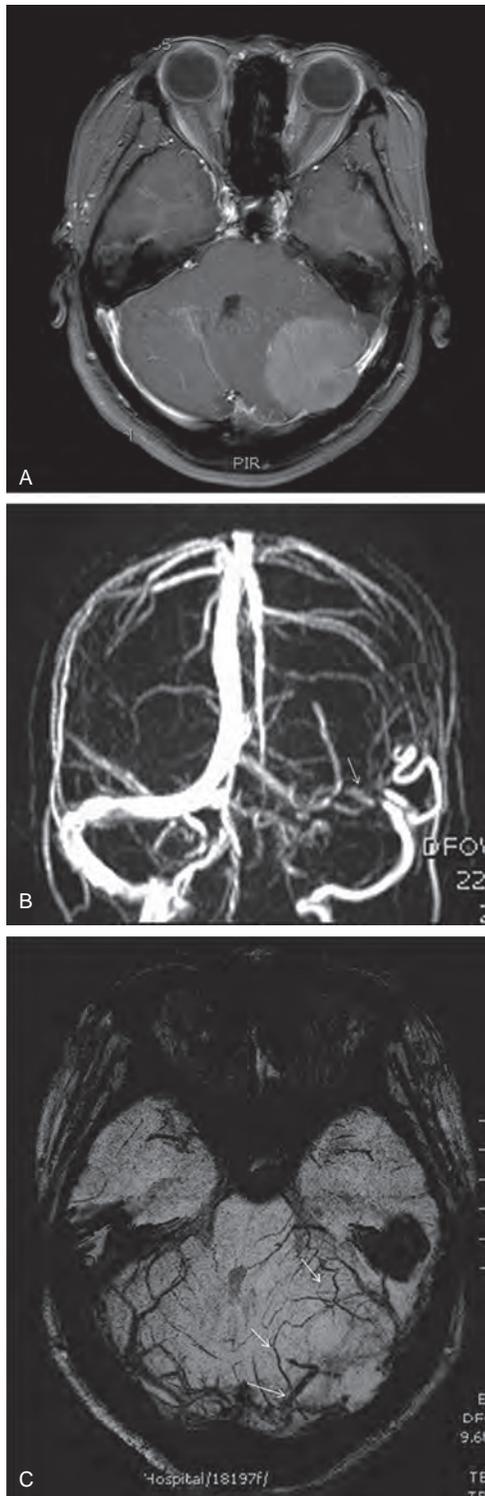
FIGURE 1. Meningioma invading the left transverse sinus in a 58-year-old woman. (A) Conventional MRI showed that the tumor infiltrated the left transverse sinus. (B) MRV shows that the left transverse sinus was occluded and only 1 collateral venous anastomose was demonstrated (arrow). (C) SWI clearly depicts all the 4 collateral veins confirmed by surgery (arrow). MRI = magnetic resonance imaging, MRV = magnetic resonance venography, SWI = susceptibility weighted imaging.

When a meningioma is located near the sinus, total resection may require removal of a portion of the sinus and thus identification of collateral venous pathways is a major concern. In the case of a completely occluded sinus, progressive occlusion by the tumor usually results in the formation of collateral venous anastomoses and thus total removal is advisable. Reports have emphasized the importance of collateral venous pathways, especially end-to-end anastomoses of the superficial veins at a site distal to the obstruction of the cerebral venous sinus, and surgeons should take care in preserving these alternative pathways, which constitute an important collateral circulation.[14] Therefore, preoperative assessment on the sinus occlusion and collateral veins is fundamental for correct surgical planning.

Catheter angiography is considered the standard technique for the evaluation of arterial and venous vasculature of brain. However, its invasiveness and periprocedural and postprocedural complications are well known. The MRA techniques used most frequently to image intracranial vessels are 2D TOF and 3D PC. Signal loss because of in-plane blood flow remains a limitation of this technique, which is essentially related to a very slow flow. TOF-MRV has been shown to have limited value in the pathological conditions involving the intracranial venous system such as stenosis, occlusion, and thrombosis.[14,15] In the case of meningioma involving the cerebral venous sinus, sinus patency is represented by residual slow flow, hence making TOF-MRV unsuitable to study this pathology.[15–20] 3D phase-sensitive MRV is able to demonstrate slow or diminished flows, but its accuracy depends on velocity-induced phase shift and requires a prior estimate of blood flow velocity. Despite our efforts to choose a supposedly appropriate PC velocity, PC could not depict all the collateral vessels mainly owing to the wide range of velocity seen within these venous vessels, especially in the cases with impaired flow in the collateral veins by the meningioma. The accuracy of PC in detecting collateral venous anastomoses was not higher than 60%, indicating that this sequence may not be the most appropriate one to evaluate the collateral veins for meningiomas infiltrating a dual sinus.

SWI uses a fully velocity-compensated high-resolution 3D-GE(Gradient Echo) sequence that uses magnitude and filtered phase information.[5,10] It was originally referred as high-resolution blood oxygenation level dependent venography. SWI permits extremely sensitive analysis of venous vasculature and hemorrhage.[7,8] During the past decade, SWI has been shown to be able to provide additional useful information on various neurologic disorders, which is often complementary to conventional MRI sequences.[3–10] Lee and coworkers[17] studied 10 patients and concluded that SWI is ideal for screening patients with high clinical suspicion of low-flow vascular malformation such as cavernomas.[20] Reichenbach et al[4] have also shown similar results for developmental venous anomaly. Saini et al[22] reported a patient with a dural arteriovenous fistula with delayed cerebral venous drainage, and the fistula was imaged with SWI in addition to conventional MRI.[21] The investigators have concluded that SWI is helpful in the detection of abnormal venous vessels.[23]

Our study showed that small and very slow-flowing veins might not be detectable with PC MRV. In contrast, SWI clearly showed these veins because of its increased spatial resolution and strong susceptibility contrast. Although the number of patients in this study was limited, side-by-side comparison between SWI and MRV with surgery as the gold reference clearly suggested that SWI is superior to MRV in the detection of collateral venous anastomoses in patients with meningiomas
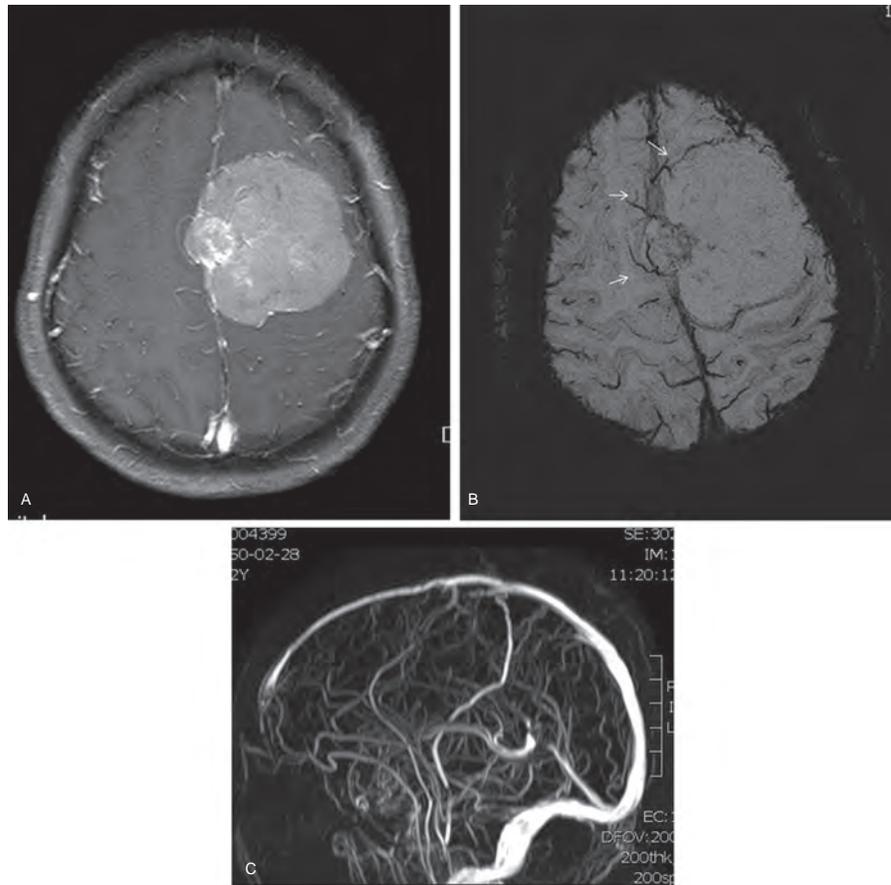
FIGURE 2. Meningioma involved the superior sagittal sinus in a 67-year-old woman. (A) Conventional MRI showed that the tumor invaded the superior sagittal sinus. (B) SWI clearly depicts 3 collateral veins (arrow). (C) No collateral vein detected by MRV. MRI = magnetic resonance imaging, MRV = magnetic resonance venography, SWI = susceptibility weighted imaging.

involving cerebral venous sinus. Further studies in a larger patient population will help to confirm the results obtained in this study.

In conclusion, we investigated the performance of SWI in the evaluation of collateral anastomoses in patients with meningioma and compared it with MRV with surgery as the gold reference. Our results showed that SWI could provide more reliable information on the collateral anastomoses compared with MRV, which is critical for operative planning for patients with meningiomas involving venous sinuses.

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