Acta Neurochirurgica (2023) 165:1717–1725
https://doi.org/10.1007/s00701-023-05589-4

ORIGINAL ARTICLE

Utility of MRI in surgical planning for parasagittal meningiomas

John S. Winestone[1,2] · Halen Baker Erdman[2] · Musa Khweis[1] · Eliel Ben David[2,3] · Nevo Margalit[1,2]

Received: 14 November 2022 / Accepted: 7 April 2023 / Published online: 8 May 2023

Abstract

Background Surgical resection is the standard treatment for parasagittal meningioma (PSM), but complete resection may be challenging due to superior sagittal sinus (SSS) involvement. The SSS may be partially or completely obstructed, and collateral veins are commonly present. Thus, knowing the status of the SSS in PSM cases prior to treatment is essential to a successful outcome. MRI is utilized prior to surgery in order to determine SSS status and to check for presence of collateral veins. The objective of this study is to evaluate the reliability of MRI in predicting both SSS involvement and presence of collateral veins in subsequent comparison to actual intra-operative findings, and to report on complications and outcomes.

Methods 27 patients were retrospectively analyzed for this study. A blinded radiologist reviewed all pre-operative images, noting SSS status and collateral vein presence. Intraoperative findings were obtained from hospital records to similarly categorize SSS status and collateral vein presence.

Results Sensitivity of the MRI to SSS status was found to be 100% and specificity was 93%. However, sensitivity and specificity of MRI to collateral vein presence was only 40% and 78.6%, respectively. Complications were experienced by 22% of patients, the majority neurologic in nature.

Conclusion MRI accurately predicted SSS occlusion status, but was less consistent in identification of collateral veins. These findings suggest MRI should be used with caution prior to PSM resection surgery particularly with regards to the presence of collateral veins which may complicate resection.

Keywords Collateral veins · Meningioma · MRI · Superior sagittal sinus

Abbreviations

CE	Contrast enhanced
CI	Confidence interval
GTR	Gross total resection
ICG-VA	Indocyanine green video angiography
SWI	Susceptibility weighted imaging
SSS	Superior sagittal sinus
MRI	Magnetic resonance imaging
MRV	Magnetic resonance venography
NPV	Negative predictive value
PSM	Parasagittal meningioma
PPV	Positive predictive value

Introduction

Meningiomas occur next to major venous drainage sinuses 13–22% of the time [10]. A common subtype includes parasagittal meningiomas (PSM) along the superior sagittal sinus (SSS). Though these tumors are usually benign, complete resection may be challenging due to SSS involvement. The SSS may be partially or completely obstructed, and collateral venous channels are common in the PSM. Thus, knowing the status of the SSS in PSM cases prior to surgery is crucial to a successful outcome. Pre-operative imaging is utilized to determine the surgical approach, clarifying tumor location, size, and level of blood vessel invasion/obstruction.

Venous infarctions are one of the more serious complications that may occur following PSM resection. Clinical symptoms of venous infarctions vary, and may result in severe neurological deterioration [16]. Hence, particular care must be taken to define the venous network in the region of the tumor before surgery. Both the SSS and subsequent compensatory collateral veins must be considered.

✉ John S. Winestone
Winestone@szmc.org.il

[1] Department of Neurosurgery, Shaare Zedek Medical Center, Shmuel Bait 12, Jerusalem, Israel

[2] Faculty of Medicine, Hebrew University, Shmuel Bait 12, Jerusalem, Israel

[3] Department of Neuroradiology, Shaare Zedek Medical Center, Jerusalem, Israel

According to Sindou, "detailed radiological anatomy of the venous system has to be investigated preoperatively." [22] The imaging commonly used in pre-operative planning is structural magnetic resonance imaging (MRI) and when circumstances allow, magnetic resonance venography (MRV) may also be performed. Various MRI sequences have been developed in a quest to better image venous anatomy, however there is no established optimal imaging sequence for PSM surgery. Moderate success has been shown with magnets from 1.5–7 Tesla in strength [8, 9, 14, 17]. This report aims to retrospectively compare pre-surgical SSS and collateral vein status based on MRI to intraoperative observation in order to evaluate the degree of reliability of such tools for parasagittal meningioma resection surgery.

Methods

Subjects

27 consecutive patients who underwent surgery between 2017 and 2021 by the senior author Dr. Nevo Margalit at three Israeli medical centers (Shaare Zedek Medical Center, Assuta Medical Center of Tel Aviv, and Herzliya Medical Center) were included in this study. Surgery was primarily conducted in Shaare Zedek (a teaching hospital); a minority of operations were conducted at nearby hospitals due to insurance reasons. Twenty-four preoperative MRI images were available for analysis. Patient intraoperative findings, including SSS occlusion status and presence of collateral veins, were retrospectively gathered from surgical records and corresponding patient MRI data were analyzed as described in 'MRI Analysis'. Ethics approval was obtained for this study (ethics number 0407–21-SZMC) and due to the retrospective nature, patient consent was waived.

MRI analysis

MRI images were obtained on either 1.5 or 3 Tesla magnets. Image evaluation was performed using the following sequences – T1, T2, FLAIR, DWI, SWI, post contrast T1 (MPRAGE) and post-contrast MRV images (performed on 4 patients). A blinded radiologist reviewed all preoperative images, noting the following parameters: The status of the superior sagittal sinus was categorized as either occluded, partially occluded, open, or inconclusive; Collateral vein presence was categorized as either present or absent.

Intraoperative analysis

Intraoperative findings were analyzed from surgical records for comparison to MRI findings. Similarly, the status of the SSS was categorized as either occluded, partially occluded, open, or inconclusive. Collateral vein and residual tumor were categorized as either present or absent. Sindou classification was documented [23]. Operative notes further include: anterior, middle, or posterior third (1,2, or 3), whether resection of the sinus was conducted (yes or no), and extent of tumor resection (partial or full).

Nuances of surgical technique

We use a traditional coronal incision centered over the tumor, safely exposing the SSS and then starting ipsilateral and lateral to the PSM, working towards midline. Tumor resection can be divided into 2 stages: the cortical and sinus stage. The tumor is first debulked and then separated from the underlying cortex, attempting to preserve the integrity of the arachnoid and the cortical veins contained within.

Following resection of the cortical component, attention is turned to the tumor involving the SSS. Anterior third SSS segment tumors are resected with the sinus. In middle or posterior third SSS segment tumors, resection is guided by several key principles. Whenever there is flow in the sinus, we do not pursue complete resection or sinus reconstruction. Residual tumor is peeled off the walls of the sinus and bipolar coagulation is usually sufficient to control bleeding. In cases where we have attempted to remove tumor from the sinus itself, the limitation is the danger of limiting sinus flow by aggressive packing, rather than blood loss.

In cases where the sagittal sinus is occluded, we attempt a complete resection of the tumor and the affected SSS. The tumor resection may transition to subtotal when collateral veins are found at the tumor. These veins are preserved and not resected in any case. The identification of these veins is done carefully intraoperatively. After tumor resection, a dural patch is used to replace the resected dura and the bone is replaced. Any bone affected with tumor is drilled away until normal bone is noted.

Statistical analysis

Sensitivity, specificity, negative and positive predictive values, and negative and positive likelihood ratio were performed in order to assess the diagnostic accuracy of MRI for occluded SSS and the occurrence of collaterals. Quantitative variables were described using median and range. Qualitative variables were presented by frequencies and percentage.

Results

Patient demographics

27 patients were included in this study. Twenty-four of those patients had data for all parameters, specifically availability

of pre-operative MRI for review. Average age was 58.5 years with 48:52% male:female ratio. In 7% of patients, PSM location was in the anterior SSS, 78% in the middle SSS, and 15% in the posterior SSS. Six patients were repeat operations, one of whom also had previously undergone radiation (Table 1).

Intraoperative and MRI results

Superior sagittal sinus (SSS)

As shown in Table 1, MRI showed that 42% ($n = 10/24$) of the available images had an occluded SSS, 33.3% ($n = 8/24$) were partially occluded, and 25% ($n = 6/24$) were completely open. In surgery, 38% (9/24) of the patients were found to have an occluded SSS, and 63% ($n = 15/24$) had flow. Of the 10 patients with complete SSS occlusion on MRI, 9 patients did indeed present a fully occluded SSS; 1 patient had some degree of flow; the patient is presented in Fig. 1. There were no patients with a pre-operative MRI showing an open sinus that had a fully occluded sinus in surgery. Sinus involvement was also noted according to the Sindou classification of sinus invasion [23].

Thus, considering a occluded versus open (even if only partially open) SSS, the sensitivity of the MRI for detection of SSS occlusion was 100% (95% confidence interval [CI]: 62.88–100%) and specificity of the MRI for detection of open sinus was 93% (95% CI: 66.03–99.65%) (Table 2). The MRI was shown to have a positive predictive value (PPV) of 90% (95% CI: 54.11–99.47%) and a negative predictive value (NPV) of 100% (95% CI: 73.23%-100%). The positive likelihood ratio that the SSS was occluded intraoperatively compared to having some flow, if the MRI showed the SSS was occluded was 15 (95% CI: 2.25–99.6). The negative likelihood ratio that the SSS was open or partially open intraoperatively compared to occluded intraoperatively when the MRI showed the SSS was open or partially open was 0 (95% CI: 0–0).

Zero patients were noted to have an open sinus on MRI and were found to be occluded intraoperatively, noting that there were no false negatives. Furthermore, in only one patient did the MRI show the patient to have an occluded sinus but was found to have an open sinus in surgery (false positive).

Collateral veins

MRI image analysis for the presence of collateral veins showed that 29% ($n = 7/24$) of the images indicated collaterals, while 71% ($n = 17/24$) indicated no collaterals. Intraoperatively, 42% ($n = 10$) of the patients had collaterals and 58% ($n = 14$) exhibited none. In patients with MRIs showing collaterals (seven patients), three were false positives, that is, they did not have collaterals in surgery; four were true positives, meaning the MRI correctly predicted presence of collaterals (Table 3).

Conversely, when reviewing the 10 patients that had collaterals in surgery, only four were detected on MRI; the remaining six were not detected on MRI, a false negative. Thus, the sensitivity and specificity of the MRI to detect collaterals was only 40% (95% CI: 54.11%-99.47%) and 78.6% (95% CI: 48.55%-94.29%), respectively (Fig. 3). The chance that collateral veins indicated by MRI would be intraoperatively confirmed (PPV) was 57% (95% CI: 20.23%-88.19%). The chance that no collateral veins indicated by MRI would be intraoperatively confirmed (NPV) was 64.7% (95% CI: 38.62%-84.74%). The positive likelihood ratio was 1.87 (95% CI: 0.53–6.56) and the negative likelihood ratio was 0.76 (95% CI: 0.44–1.31).

4 patients with MRV

Only 4 patients had a formal MRV available for review (see Table 4). In patients 2,10, 12, and 23, the SSS was predicted to be occluded, but in surgery, patient 10 was found to have an open sinus. In these four patients, the MRV accurately predicted collateral vein status only once (patient 10; Fig. 1); in 2 patients there was a false negative, i.e. collaterals were found (2,12), and in patient 23 there was a false positive (see Table 4; Fig. 2). Ironically, in patient 10, although MRV accurately predicted collateral vein status, MRI incorrectly predicted a closed sinus (Fig. 1).

The radiologist's perspective

It should be noted the radiologist who interpreted all imaging of 24 patients rated different MRI modalities to determine what was most helpful to him. On a scale of 1–3, with 1 referring to good and 3 referring to poor, T2 and T1 + Gadolinium had the lowest average scores (both being 1.29) and was most beneficial in visualizing SSS occlusion and presence of collateral veins. In contrast, the score for FLAIR was higher (1.42) and T1 had the worst score (1.54).

Complications and outcomes

There were six (22%) complications within the entire group ($n = 27$). In a review of 24 patients for whom preoperative imaging data was available, five patients experienced complications (21%). Of these complications, four were classified as a significant neurologic deficit, and one was an infection that required re-operation. One complication occurred

Table 1 Patient demographics, pre-operative imaging expectations versus intraoperative observation of SSS patency/occlusion and collateral vein presence

#	M/F	Age (y)	First op (0), Rep (1) First op (0); Rep (1)	MRI SSS Occlusion (occluded-1, partly-2, open-3, inconcl-4, no data-NA)	MRI Collateral veins (yes-1, no-2, no data-NA)	MRV (Yes/ No = 0)	Sindou Grade (1–6)	Intra-Op SSS Occlusion (occluded-1, partly-2, open-3, inconcl-4)	Intra-Op Collateral veins (yes-1, no-2)	Compli-cations (none-0, venous infarct-1, bleed-2, infect-3, neuro-4, other-5)
1	M	78	1	1	2	0	6	1	1	0
2	M	51	0	1	2	Yes	6	1	1	0
3	M	40	0	3	2	0	4	2	2	0
4	F	80	0	1	2	0	6	1	2	0
5	F	70	0	1[a]	2	0	5	1	2	0
6	M	37	0	2	2	0	3	2	1	3
7	F	68	0	2	2	0	3	2	2	0
8	M	36	0	2[b]	2	0	4	3	1	4
9	F	75	0	1	2	0	6	1	1	4
10	M	63	0	1	1	Yes	6 or 4*	2	1	0
11	M	65	0	3	2	0	1	3	2	0
12	F	43	1	1	1	Yes	6	1	1	0
13	M	55	1	1	2	0	6	1	2	0
14	M	79	0	NA	NA	0	1	3	2	0
15	F	38	0	2	1	0	4	3	1	0
16	F	48	0	NA	NA	0	6	1	1	0
17	F	38	0	2	2	0	3	2	2	0
18	F	57	0	3	2	0	2	3	2	0
19	M	70	1	1	2	0	6	1	2	0
20	F	50	0	3	1	0	3	3	1	0
21	M	71	1	3	1	0	3	3	2	4
22	F	60	0	NA	NA	0	6	1	1	4
23	F	64	1	1	1	Yes	5	1	2	0
24	M	81	0	3	2	0	1	3	2	0
25	M	55	0	2	2	0	1	2	1	0
26	F	34	0	2	2	0	2	4	2	0
27	F	73	0	2	1	0	4	3	2	4

[a]Radiologist observed multiple meningiomas; the number here refers to the intrasinusoidal meningioma

[b]Radiologist observed tributary occlusion, not SSS occlusion

*Upon MRI, the SSS presented as occluded; In the OR, the sinus presented as open, but all walls and roof displayed involvement. Thus, the Sindou classification can fall under either grade 4 or 6

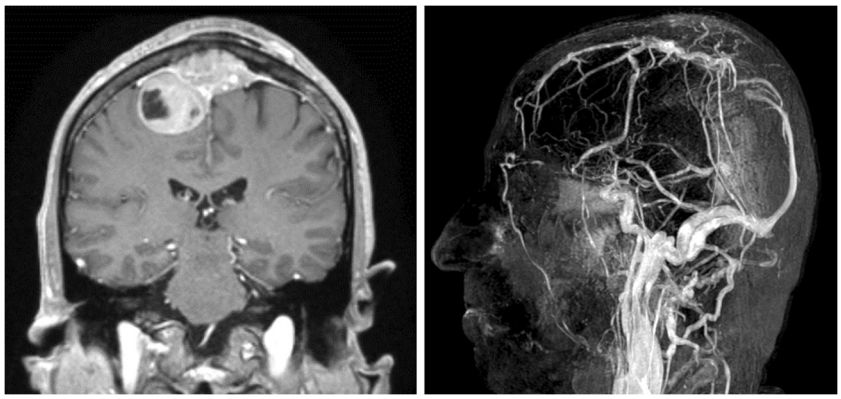

Fig. 1 Patient 10: Initial MRI (T1 with contrast and MRV) suggested an occluded SSS, Sindou Grade 6. During surgery the SSS was found to be patent, i.e. Sindou grade 4. Collateral veins were noted on the MRI and confirmed in surgery. This patient was one of four with a formal MRV available pre-operatively

in a patient without preoperative imaging data. This was transient lower extremity weakness that worsened following surgery but later improved beyond preoperative status (see Table 5).

The five complications for the 24 patients who had preoperative imaging included one infection that required re-operation, one severe postoperative hemiparesis that was worse than preoperative status and did not resolve, and two others had persistent unilateral lower extremity weakness that did not improve after surgery, and one had worsened unilateral leg weakness after surgery. It should be noted that of patients with neurologic deficits, 2 patients did not have collateral veins visualized on MRI, but did in surgery (e.g. Figure 3); additionally, 2 patients were anticipated to have collateral veins based on MRI, but in surgery it was determined they did not.

When reviewing the group with collateral vessels for correlation with complications, the false negatives (MRI showing no collaterals only to find collaterals in surgery) had three complications, including one infection and two neurologic complications. While only accounting for 25% of the total group (6/24) they accounted for (3/5) 60% of the total complications, specifically 2/4 (50%) neurologic complications, and one infection. In both cases of neurologic complications, the sinus was patent. One example is patient 9, presented in Fig. 3.

Table 2 MRI vs. Intra-operative Findings of SSS Status

	Intraoperative Occluded	Intraoperative Open	Total
MRI Occluded	9	1	10
MRI Open	0	14	14
Total	9	15	24

Occluded indicates full occlusion. Open indicates some flow, whether normal or partial stenosis

**After reviewing Sindou grade, we judge patient 19 to truly be occluded in surgery, leaving only patient 10 to be SSS occluded on MRI and open in surgery

17/27 total, or 15/24 for whom imaging was available, patients had either confirmed or suspected (e.g. non conclusive) residual tumor. The reason noted in the operative note was proximity to sinus (11), critical vein (4), or other (2).

83.3% of the false negative group did not have a complete resection, perhaps because of the surprise presence of collateral veins within the tumor. (9/27) patients underwent resection of the involved SSS, two of which sustained a neurologic complication, one patient was part of the 24 patients with pre-operative imaging. Four complications occurred in the remaining 16 patients.

Discussion

This study retrospectively examined the performance of various MRI sequences compared to true intraoperative findings in 27 PSM cases. We found that MRI accurately predicted SSS occlusion status, but was less consistent in identification of collateral veins. This study is limited by the small number of patients, heterogenous MRI techniques, and the retrospective nature. Nevertheless, the findings suggest MRI should be used with caution prior to PSM resection surgery, particularly with regards to the presence of collateral veins which may complicate resection.

In general, sacrifice of the SSS is considered safe for lesions located at the anterior third of the SSS or in a completely occluded sinus. Exceptions include cases in which collateral veins in or around the tumor have developed and provide compensatory venous drainage. In these cases, sacrifice of collateral veins may have devastating consequences including brain swelling and venous infarction. DiMeco et al. [4] stress the importance of collateral vein preservation in their review of 108 PSM resections invading the SSS, while others suggest major collateral vein resection in these cases may not be necessary at all [18]. Other classic sources, including Rhoton [19], Sindou, Alvernia [23], and Auque [22], support this assertion.

Table 3 MRI vs. Intra-operative findings of collateral veins

	Intraoperative Collateral	Intraoperative Absent	Total
MRI Collateral	4	3	7
MRI Absent	6	11	17
Total	10	14	24

Maximal safe resection is a key factor in treatment of PSM, but the surgeon must consider preservation of eloquent structures and their supporting venous drainage [12, 18]. Patients and families insist on optimal outcomes. Complications may have greater impact in meningioma surgery, given the relatively benign biology and long survival even with subtotal resection; patients live longer and thus with the consequences of our decisions. In 2001, Sindou et al. [21] published data of 80 meningiomas with aggressive resection, favoring gross total resection (GTR) with sinus reconstruction via patch or bypass. While 87.5% showed satisfactory outcome, 8.7% developed venous infarction and there was a 3.6% mortality rate. Two decades later this data may be viewed differently. A further series published in 2006 established the 6 Type Sindou classification scale to guide strategy for GTR including how to address the involved sinus based on patency and anatomic involvement, including planning vascular reconstruction. At the time, the low recurrence and complications rates lead the authors to support aggressive initial resection [23]. Most recently, Chen et al. reinforces the utility of the Sindou grading scale, with higher Sindou grades correlating with increased complications and recurrence [2]. Recent data has also emphasized the importance of residual neoplastic cells, as detailed by the Copenhagen grading scale in follow-up and patient management. Ultimately, tumor biology, and not singularly extent of resection, plays a critical role in recurrence [13].

Other groups favor prioritizing preservation of venous drainage over extent of resection. Komotar's case series reported in 2020 shows safe outcomes in a group of 58 patients, and emphasizes radiosurgery or laser interstitial therapy for management of residual tumor. The average follow up was only 7.7 months; longer follow up must be considered for residual tumor impact on long term neurologic performance [6]. Byrne's case series of 76 parasagittal meningiomas with a mean of 43 months follow up similarly prioritizes preservation of functional veins, e.g. patent sinus and or cortical veins in a "venous sparing approach," leaving residual tumor to be dealt with adjuvant therapies [15]. Our clinical strategy is more similar to these groups, prioritizing venous drainage over extent of resection in the hopes of better neurologic outcomes, at least in the acute phase. Earlier data favoring more aggressive surgery may be viewed differently in light of advances in adjuvant therapies as noted above. This is particularly true with higher grade tumors. Time will tell if this strategy will yield durable neurologic function.

Table 4 Findings in 4 patients with both MRI and MRV

	SSS Occlusion		Collateral Veins	
Patient	MRI	Intra-op	MRV	Intra-op
2	Yes	Yes	No	Yes
10	Yes	No	Yes	Yes
12	Yes	Yes	No	Yes
23	Yes	Yes	Yes	No

Due to the retrospective nature of this paper, and given our tertiary referral pattern, the MRI images analyzed were rather heterogeneous, produced from a variety of sequences, software, and machines. There are various opinions in the literature with regards to the optimal preoperative imaging sequence. Contrast enhanced MRV was found to be superior to phase contrast MRV in a series of 23 patients, and was superior in preoperative collateral vein detection (87 vs 58%) [1]. Most of the images used in this study did not use contrast enhanced MRV and this could have contributed to the low collateral detection rate. Phase contrast MRI also had 100% sensitivity for SSS occlusion and 50% specificity [1]. Sahoo et al. [20] reported CE MRV to be useful in detecting both SSS and collateral veins, and its utilization led to good outcomes in six patients where a novel double contrast technique was used. However, Wang et al. prospectively evaluated 3D Fast Spin-Echo T1 Black-Blood MR imaging to detect sinus invasion by meningiomas and found that it had a diagnostic accuracy of 94.74%, significantly higher than the accuracy of CE MRV (68.4%) [25]. In more recent studies, Wang's group have found MRV useful for building a resection strategy with respect to peritumoral or collateral veins [26].

Susceptibility weighted imaging (SWI) has been suggested to be superior to MRV in a review of 25 cases, finding 87% vs 58% sensitivity, respectively [27]. The increased spatial resolution and strong susceptibility contrast may provide for better detection of small and slow flowing veins making it superior to phase contrast MRV. The slow flow nature of the collateral veins is problematic when using time of flight sequences, and the variable nature of velocity limits the sensitivity of phase contrast MRV to less than 60%. Formal four and six vessel arteriography has also been documented. It is less commonly used given the invasive nature and the small but real risk of complication [3, 5].

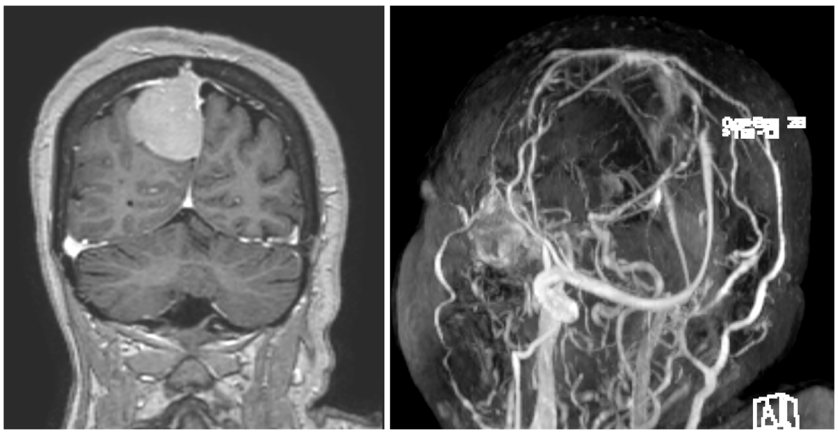

Fig. 2 Patient 23: MRI (T1 with contrast, left, and MRV right), predicted an occluded SSS with present collateral veins, Sindou 5 as the contralateral wall was spared. Surgery confirmed an occluded sinus, but collateral veins were not noted

Table 5 Intraoperative findings and post-operative evaluation

Patient no	SSS Resection	MRI Collateral veins	Intra-Op Collateral veins	Residual Tumor	Cause for Partial Tumor Removal	Complications
	(yes-1, no-2)	(yes-1, no-2, no data-NA)	(yes-1, no-2)	(no-0, yes-1, inconcl-2)	(sinus-0, vein-1, cortex-2, other-3, none reported-4)	(none-0, venous infarct-1, bleed-2, infect-3, neuro-4, other-5)
1	Y	2	1	2	1	0
2	Y	2	1	2	4	0
3	N	2	2	1	0	0
4	Y	2	2	0	3	0
5	N	2	2	1	0	0
6	N	2	1	1	0	3
7	N	2	2	1	0	0
8	N	2	1	1	0,1	4
9	Y	2	1	1	1	4
10	N	1	1	1	0	0
11	N	2	2	0	4	0
12	Y	1	1	1	3	0
13	Y	2	2	2	0	0
14	N	NA	2	0	4	0
15	N	1	1	0	4	0
16	N	NA	1	1	0	0
17	N	2	2	1	0	0
18	N	2	2	0	4	0
19	Y	2	2	0	4	0
20	N	1	1	0	4	0
21	N	1	2	2	4	4
22	Y	NA	1	1	1	4
23	N	1	2	2	0	0
24	N	2	2	0	4	0
25	N	2	1	1	0	0
26	Y	2	2	0	4	0
27	N	1	2	0	4	4

Patients 6, 8, 9, 21, 22, and 27 are those that experienced complications within the sample

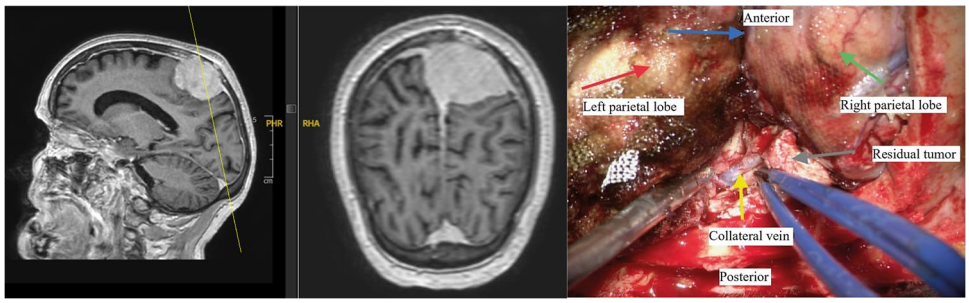

Fig. 3 Patient 9. Initial MRI demonstrated an occluded sinus, T1 with contrast sagittal, left, and coronal, center, with yellow orientation line on sagittal image, and Sindou grade 6. Collateral veins were not seen on MRI. A yellow arrow marks the intraoperative photograph showing a surprise collateral vein, right photograph. The vein was identified, and a small rim of tumor was left to preserve the vein. The falx and SSS were resected. Nevertheless, the patient did experience a neurologic deficit post-op. Right photo: intraoperative microscope photograph from vertex view of interhemispheric approach, (Zeiss Pentero Microscope Red arrow = left parietal lobe; Green arrow = right parietal lobe; Blue arrow = midline location of resected superior sagittal sinus; Gray arrow = residual tumor; Yellow arrow = collateral vein

Indocyanine green video angiography (ICG-VA) is an imaging technique that allows blood vessels to be better visualized during neurovascular surgery. This can be helpful in identifying and avoiding collateral veins in PSM resection surgeries. Various papers have looked into ICG-VA and found it to provide useful information both pre- and post-resection, above and beyond the information provided by MRV [7, 24]. One group reviewed 113 patients in which ICG was used to intraoperatively evaluate peritumoral draining veins and found that its use enabled higher resection rates. They show that 86.6% were the same or better neurologically and recurrence rates were low.

New MRI sequences and higher strength MRI machines may improve MRI reliability. There are also techniques using MRI and MRV to make 3-dimensional reconstructions to utilize prior to surgery with good outcome [11]. Various forms of intraoperative imaging, such as near infrared imaging and MRI, and intraoperative electrophysiological monitoring are becoming more and more common as well which could help guide surgeons to assess the tumor and avoid collaterals in real-time.

Conclusion

This paper retrospectively examined 27 patients who underwent surgery for PSM, comparing MRI findings of SSS status and presence of collateral veins to intraoperative findings. The results suggest that although MRI accurately predicted SSS occlusion status, MRI should be used with caution, especially for collateral vein detection. False negative MRI exams with regards to collateral veins accounted for a disproportionate number of complications (including the one infection requiring re-operation, and 50% of the neurologic complications), supporting the need to better identify collateral veins in future studies. Further study is needed to identify optimal imaging techniques for venous anatomy to best tailor resection and optimize outcome.

Acknowledgements We thank Anat Daskal for her expertise and efforts in the statistical analysis of this paper, and thanks to Halen Baker and Shira Nouriel for assistance in editing the manuscript.

Data Availability The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

Declarations

Research involving human participants Regarding ethical approval, all procedures performed in this study involving human participants was in accordance with the ethical standards of the institution in which this study was conducted and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Due to the retrospective nature of the study, informed consent was waived.

Disclosure of potential conflicts of interest The authors declare there are no relevant conflicts of interest.

References

1. Bozzao A, Finocchi V, Romano A, Ferrante M, Fasoli F, Trillò G, Ferrante L, Fantozzi LM (2005) Role of contrast-enhanced MR venography in the preoperative evaluation of parasagittal meningiomas. Eur Radiol 15(9):1790–1796. https://doi.org/10.1007/s00330-005-2788-8
2. Chen WW, Wang Y, Hu YC, Zhao YL (2023) Analysis of the common complications and recurrence-related factors of superior

parasagittal sinus meningioma. Front Surg 9:1023021. https://doi.org/10.3389/fsurg.2022.1023021
3. Dabus G, Linfante I, McDermott MW (2020) Angiography and embolization of meningiomas. Handb Clin Neurol 169:193–202. https://doi.org/10.1016/B978-0-12-804280-9.00013-5
4. DiMeco F, Li KW, Casali C, Ciceri E, Giombini S, Filippini G, Broggi G, Solero CL (2004) Meningiomas invading the superior sagittal sinus: surgical experience in 108 cases. Neurosurgery 55(6):1263–72; discussion 1272–4. https://doi.org/10.1227/01.neu.0000143373.74160.f2
5. Dowd CF, Halbach VV, Higashida RT (2003) Meningiomas: the role of preoperative angiography and embolization. Neurosurg Focus 15(1):E10. https://doi.org/10.3171/foc.2003.15.1.10
6. Eichberg DG, Casabella AM, Menaker SA, Shah AH, Komotar RJ (2020) Parasagittal and parafalcine meningiomas: integral strategy for optimizing safety and retrospective review of a single surgeon series. Br J Neurosurg 34(5):559–564. https://doi.org/10.1080/02688697.2019.1635988
7. Ferroli P, Acerbi F, Albanese E, Tringali G, Broggi M, Franzini A, Broggi G (2011) Application of intraoperative indocyanine green angiography for CNS tumors: results on the first 100 cases. Acta Neurochir Suppl 109:251–257. https://doi.org/10.1007/978-3-211-99651-5_40
8. Kuijf HJ, Bouvy WH, Zwanenburg JJ, Razoux Schultz TB, Viergever MA, Vincken KL, Biessels GJ (2016) Quantification of deep medullary veins at 7 T brain MRI. Eur Radiol 26(10):3412–3418. https://doi.org/10.1007/s00330-016-4220-y
9. Lee M, Kim MS (2012) Image findings in brain developmental venous anomalies. J Cerebrovasc Endovasc Neurosurg 14(1):37–43. https://doi.org/10.7461/jcen.2012.14.1.37
10. Letchuman V, Donohoe C (2022) Neuroanatomy, Superior Sagittal Sinus. 2022 Jan 26. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing
11. Low D, Lee CK, Dip LL, Ng WH, Ang BT, Ng I (2010) Augmented reality neurosurgical planning and navigation for surgical excision of parasagittal, falcine and convexity meningiomas. Br J Neurosurg 24(1):69–74. https://doi.org/10.3109/02688690903506093
12. Mathiesen T, Pettersson-Segerlind J, Kihlström L, Ulfarsson E (2014) Meningiomas engaging major venous sinuses. World Neurosurg 81(1):116–124. https://doi.org/10.1016/j.wneu.2013.01.095
13. Mathiesen T, Haslund-Vinding J, Skjøth-Rasmussen J, Poulsgaard L, Fugleholm K, Mirian C, Daniela Maier A, Santarius T, Rom Poulsen F, Andrée Larsen V, Winther Kristensen B, Scheie D, Law I, Ziebell M (2022) Letter to the Editor. Copenhagen grading of meningioma. J Neurosurg 1–3. https://doi.org/10.3171/2021.10.JNS204467
14. Mistry N, Dixon J, Tallantyre E, Tench C, Abdel-Fahim R, Jaspan T, Morgan PS, Morris P, Evangelou N (2013) Central veins in brain lesions visualized with high-field magnetic resonance imaging: a pathologically specific diagnostic biomarker for inflammatory demyelination in the brain. JAMA Neurol 70(5):623–628. https://doi.org/10.1001/jamaneurol.2013.1405
15. Munich SA, Eddelman D, Byrne RW (2019) Retrospective review of a venous sparing approach to resection of parasagittal meningiomas. J Clin Neurosci 64:194–200. https://doi.org/10.1016/j.jocn.2019.02.013
16. Nakase H, Shin Y, Nakagawa I, Kimura R, Sakaki T (2005) Clinical features of postoperative cerebral venous infarction. Acta Neurochir (Wien) 147(6):621–6; discussion 626. https://doi.org/10.1007/s00701-005-0501-y
17. Patel D, Machnowska M, Symons S, Yeung R, Fox AJ, Aviv RI, Jabehdar MP (2016) Diagnostic Performance of Routine Brain MRI Sequences for Dural Venous Sinus Thrombosis. AJNR Am J Neuroradiol 37(11):2026–2032. https://doi.org/10.3174/ajnr.A4843
18. Raza SM, Gallia GL, Brem H, Weingart JD, Long DM, Olivi A (2010) Perioperative and long-term outcomes from the management of parasagittal meningiomas invading the superior sagittal sinus. Neurosurgery 67(4):885–93; discussion 893. https://doi.org/10.1227/NEU.0b013e3181ef2a18
19. Rhoton AL, Congress of Neurological Surgeons (2003) Rhoton cranial anatomy and surgical approaches. Lippincott Williams & Wilkins, Philadelphia
20. Sahoo SK, Ahuja CK, Dhandapani S, Madan R, Tomar P, Kumar S, Kaur M (2021) MR venography in Gamma knife radiosurgery for parasagittal meningiomas: a technical note with the rationale of venous protection and a review of literature. Asian J Neurosurg 16(2):307–311. https://doi.org/10.4103/ajns.AJNS_436_20
21. Sindou M (2001) Meningiomas invading the sagittal or transverse sinuses, resection with venous reconstruction. J Clin Neurosci 8(Suppl 1):8–11. https://doi.org/10.1054/jocn.2001.0868
22. Sindou M, Auque J (2000) The intracranial venous system as a neurosurgeon's perspective. Adv Tech Stand Neurosurg 26:131–216. https://doi.org/10.1007/978-3-7091-6323-8_5
23. Sindou MP, Alvernia JE (2006) Results of attempted radical tumor removal and venous repair in 100 consecutive meningiomas involving the major dural sinuses. J Neurosurg 105(4):514–525
24. Vetrano IG, Ferroli P, Acerbi F (2018) Dynamic Intraoperative Assessment of Draining Veins in Parasagittal Meningiomas: Changing the Paradigm? World Neurosurg 118:399. https://doi.org/10.1016/j.wneu.2018.07.094
25. Wang D, Lu Y, Yin B, Chen M, Geng D, Liu L, Wen J, Zhong P, Li Y (2019) 3D fast spin-echo T1 black-blood imaging for the preoperative detection of venous sinus invasion by meningioma : comparison with contrast-enhanced MRV. Clin Neuroradiol 29(1):65–73. https://doi.org/10.1007/s00062-017-0637-1
26. Wang X, Wang MY, Qian K, Chen L, Zhang FC (2018) Classification and protection of peritumoral draining veins of parasagittal and falcine meningiomas. World Neurosurg 117:e362–e370. https://doi.org/10.1016/j.wneu.2018.06.037
27. Wang Q, He J, Ma X (2014) Preoperative evaluation of collateral venous anastomoses in meningioma involving cerebral venous sinus by susceptibility weighted imaging. Medicine (Baltimore) 93(27):e191. https://doi.org/10.1097/MD.0000000000000191