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Original Article

Effects of parasagittal meningiomas on intracranial venous circulation assessed by the virtual reality technology

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Abstract: Objective: This study is to investigate the compensatory intracranial venous pathways in parasagittal meningiomas (PSM) patients by virtual reality technology. Methods: A total of 48 PSM patients (tumor group) and 20 patients with trigeminal neuralgia and hemifacial spasm but without intracranial venous diseases (control group) were enrolled. All patients underwent 3D CE-MRV examination. The 3D reconstructed images by virtual reality technology were used for assessment of diameter and number of intracranial veins, tumor location, venous sinus invasion degree and collateral circulation formation. Results: Diameter of bridging veins in posterior 1/3 superior sagittal sinus (SSS) in tumor group was significantly smaller than that of the control group ($P < 0.05$). For tumors located in mid 1/3 SSS, diameter of bridging veins and vein of Labbé (VL) in posterior 1/3 SSS decreased significantly ($P < 0.05$). For tumors located in posterior 1/3 SSS, bridging vein number and transverse sinus (TS) diameter significantly decreased while superficial Sylvian vein (SSV) diameter increased significantly ($P < 0.05$). Compared with tumor in posterior 1/3 SSS subgroup, number of bridging veins in the tumor in mid 1/3 SSS subgroup increased significantly ($P < 0.05$). Compared with control group, only the bridging vein number in anterior 1/3 SSS segment in invasion Type 3-4 tumor subgroup decreased significantly ($P < 0.05$). Diameter of TS and bridging veins in posterior 1/3 SSS segment in sinus invasion Type 5-6 tumor subgroup decreased significantly ($P < 0.05$). Compared with control group, only the diameter of VL and TS of collateral circulation Grade 1 tumor subgroup decreased significantly ($P < 0.05$) while in Grade 3 tumor subgroup, TS diameter decreased and SSV diameter increased significantly ($P < 0.05$). Conclusions: The intracranial blood flow is mainly drained through SSV drainage after SSS occlusion by PSM.

Keywords: Parasagittal meningioma, collateral circulation, venous protection, virtual reality, magnetic resonance venography

Introduction

Parasagittal meningiomas (PSM) refer to a group of meningiomas with the substrate attached to the superior sagittal sinus (SSS) or even invaded into the SSS cavity. There is no brain tissue between the tumor and SSS. PSM accounts for about 17%-20% of meningiomas. PSM can invade SSS at different degrees, and it can even invade adjacent cortical veins, which will change the venous circulation and bring challenges to the operation. Systematic protection of the venous system especially SSS, bridging vein and collateral venous circulation channel, is the key to reduce the complications and mortality of operation [1]. If the venous outflow is destroyed or there is thrombosis in drainage vein (and/or venous sinus) after operation, cerebral infarction, cerebral edema, intracranial hemorrhage or death of neurons might occur [1-3]. Therefore, identification and protection of collateral venous pathway around the tumor is very important. However, over-protection of venous outflow might result in incomplete tumor resection, eventually leading to tumor recurrence [1, 2]. Therefore, accurate assessment of SSS, bridging veins and cortical veins before operation is of great importance for selecting operation approach and making surgical plans.

At present, there are many kinds of methods that can be used to evaluate intracranial veins [4, 5]. Digital subtraction angiography (DSA) is the gold standard to evaluate the intracranial venous system, however, DSA is an invasive method with high risk and high costs. Thus,

Table 1. General condition of 48 cases of PSM patients

		Number of cases
Location of tumor attaching or invasion to SSS	Anterior 1/3 SSS	7
	Mid 1/3 SSS	31
	Posterior 1/3 SSS	10
Invasion type of PSM to SSS	Type 1-2	24
	Type 3-4	12
	Type 5-6	12
Collateral circulation	Grade 0	23
	Grade 1	9
	Grade 2	0
	Grade 3	16

DSA is not suitable for routine evaluation. Magnetic resonance venography (MRV) can display peripheral venous anastomosis in approximately 87% of meningioma patients [6]. Brockmann [7] found that computed tomography venography (CTV) could effectively show the structure of intracranial cortical veins. Deng et al [8] reported that the imaging methods of DSA, MRV and CTV had similar ability in evaluating the bridging veins. Virtual reality (VR) technology can re-construct 3D image of the tumor and its surrounding structures.

In this study, VR technology was used for measuring the diameter and number of bridging veins connecting SSS. The diameter and number of superficial Sylvian vein (SSV), vein of Trolard (VT), vein of Labbé (VL), great cerebral vein (GCV), inferior sagittal sinus (ISS), straight sinus (StS), transverse sinus (TS), and sigmoid sinus (SS) was also measured. The establishment of intracranial venous compensatory pathways was further evaluated to improve the quality of operation planning for PSM.

Materials and methods

Patient's data

A total of 48 cases of patients diagnosed as PSM admitted to our hospital from October 2011 to March 2014 were included as tumor group. Among them, 20 were male and 28 were female. They were aged from 22-84 years old, with an average age of 54 years old. The inclusion criteria: patients with PSM attached to SSS confirmed by surgery. The exclusion criteria: PSM patients who were treated with radiotherapy or surgery before. Additionally, 10 cases of trigeminal neuralgia patients and 10 cases of hemifacial spasm patients without intracranial venous system diseases from our hospital were considered as the control group. In control group, 9 cases were male and 11 cases were female. They were aged between 21 and 75 years old, averaged 50 years old.

Prior written and informed consent were obtained from all patients and the study was approved by the ethics review board of the Fuzhou General Hospital, Fujian Medical University, China.

Three dimensional contrast-enhanced MRV (3D CE-MRV) image sequence scanning

3D CE-MRV image sequence scanning was performed with 3.0T magnetic resonance scanner (Tim Trio; Siemens Medical Solutions, Erlangen, Germany) at 1-3 days before operation. According to the sagittal view, 3D CE-MRV and T1 3D scanning was performed from the vertex to skull base. T1 3D parameters were as follows: TR, 1900 ms; TE, 2.52 ms; voxel, 1 mm × 1 mm × 1 mm; flip angle, 9 degrees; matrix, 256 × 256; vision, 250 mm × 250 mm; scan time, 258 s; layer thickness, 1.0 mm. Parameters of 3D CE-MRV were: TR, 2.6 ms; TE, 1.1 ms; voxel, 1.2 mm × 1.1 mm × 1.2 mm; flip angle, 20 degrees; matrix, 448 × 322; vision, 320 mm × 320 mm; scanning time, 30 s; layer thickness, 1.0 mm. Magnevist solution was intravenously injected at the rate of 2.0 ml/s as contrast agent with the dose of 0.3 ml/kg. All the sequential image data was saved in DICOM format.

VR image reconstruction

The imaging data was processed with Radio Dexter TM1.0 software system (Dextroscope, Volume Interaction, Singapore). The clear and smooth venous images with less artery interference from 3D CE-MRV were used for 3D venous sinus reconstruction. The enhanced and clear 3D CE-MRV sequential tumor images were used for tumor reconstruction. MRI-T1WI 3D sequences were used for brain tissue recon-

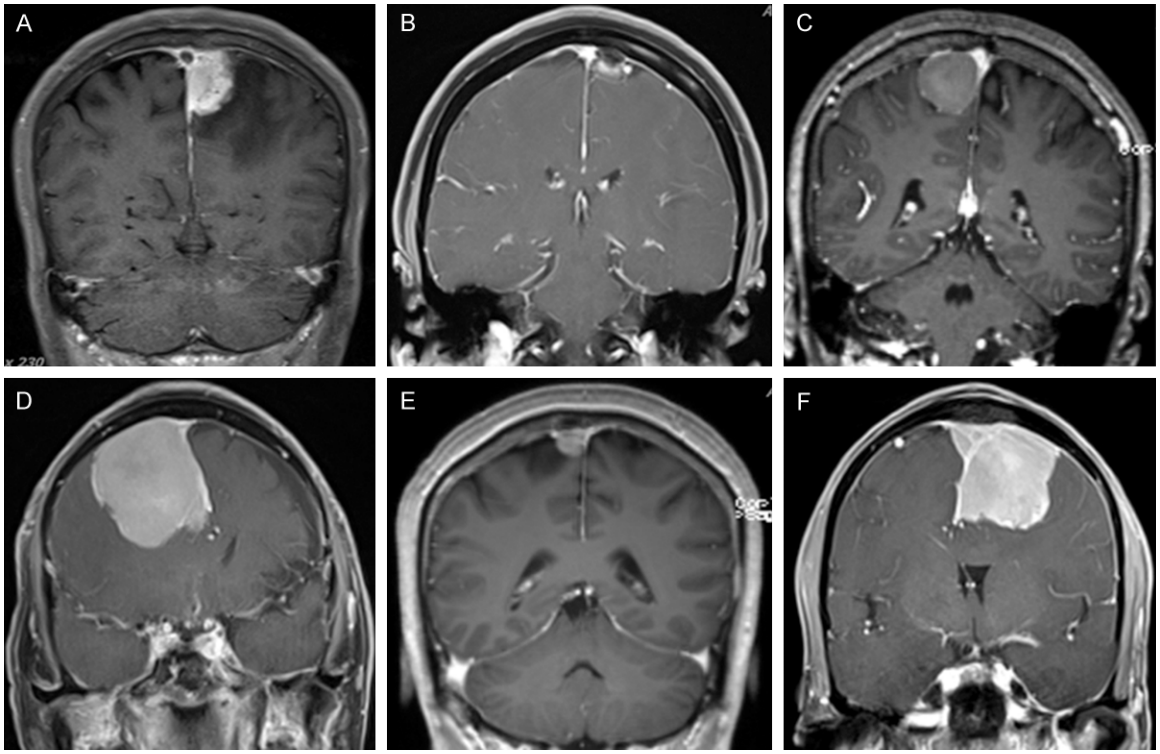

Figure 1. MRI images of PSM invasion to SSS. According to the invasion degree of PSM to SSS, the PSM were divided into 6 types (Type1-6). A. MRI image of a patient with Type 1 PSM: PSM attached to the lateral wall of SSS and falx cerebri without invasion to SSS. B. MRI image of a patient with Type 2 PSM: tumor invaded to lateral recess of SSS. C. MRI image of a patient with Type 3 PSM: the side wall of venous sinus was completely invaded. D. MRI image of a patient with Type 4 PSM: PSM invasion to ipsilateral sinus lateral wall and sinus top. E. MRI image of a patient with Type 5 PSM: venous sinus occlusion with the contralateral sinus wall unaffected. F. MRI image of a patient with Type 6 PSM: totally venous sinus occlusion with three sinus faces all invaded.

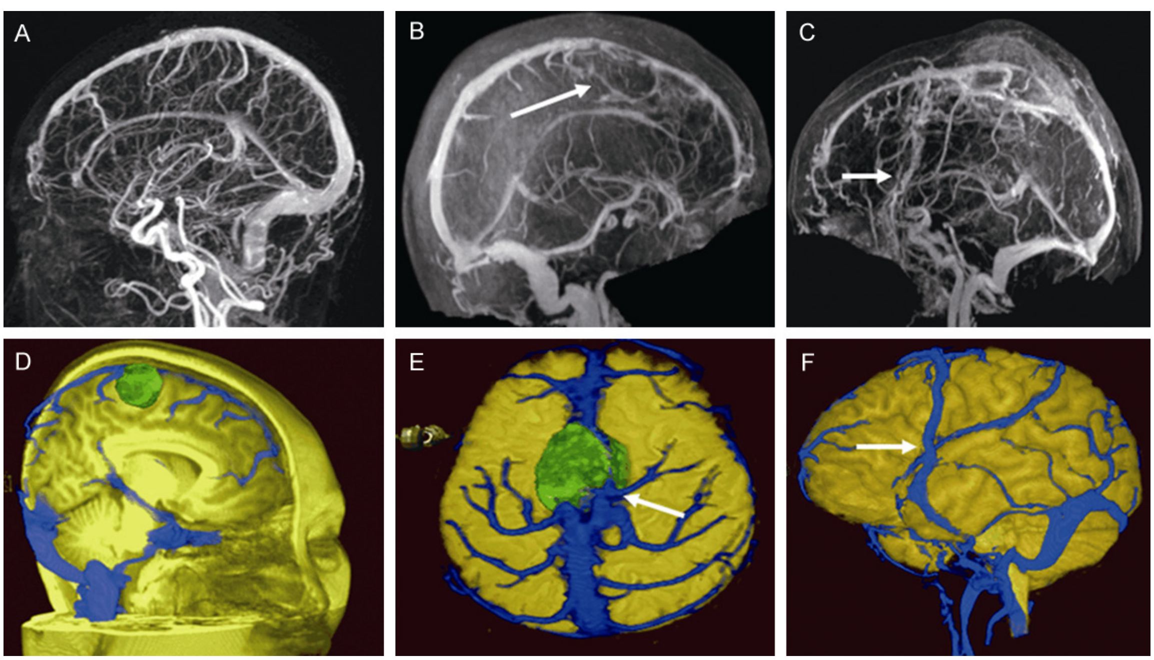

Figure 2. MRV and VR images of intracranial venous collateral circulation. Collateral venous circulation was classified into 4 grades (Grade 0-3). A. MRV image of a patient with Grade 0 collateral circulation. B. MRV image of a patient with Grade 1 collateral circulation. The arrow indicated the cortical veins formed a loop around the tumor. C.

MRV image of a patient with Grade 1 and Grade 3 collateral circulation. The arrow showed the cortical veins were rich and the compensatory drainage flowed to the cavernous sinus. D. VR image of a patient with Grade 0 collateral circulation. E. VR image of a patient with Grade 1 collateral circulation. The arrow indicated collateral circulation pathway. F. VR image of a patient with Grade 3 collateral circulation. The arrow showed the main compensatory cortical vein.

Table 2. Diameter of bridging vein in tumor and control groups

Groups	Diameter of bridging vein (mm)		
	Anterior 1/3 SSS	Mid 1/3 SSS	Posterior 1/3 SSS
Tumor group (n = 48)	2.26 ± 0.77	2.94 ± 0.87	2.07 ± 0.84*
Control group (n = 20)	2.68 ± 0.98	3.11 ± 0.73	2.64 ± 0.97

Note: Compared with the control group, *P < 0.05.

struction. Different anatomical structures were endowed with different colors for distinction. PSM related important anatomic structures were observed and measured in multi angle and multi orientation.

Index measurement, collateral circulation classification and tumor invasion grading

In VR reconstructed images, the diameter and number of bridging veins in SSS, SSV, VT, VL, GCV, ISS, StS, TS, and SS were measured and recorded. All the data were measured by 3 neurosurgery physicians who were familiar with VR workstation. According to the site of meningioma attaching or invasion to SSS, the tumors were classed into three groups of anterior 1/3 SSS, mid 1/3 SSS and posterior 1/3 SSS [9]. In accordance with the method of classification defined by Qureshi et al [10], venous collateral circulation was classified as follows. Grade 0, no establishment of collateral circulation; Grade 1, collaterals bypass occluded segment of dural venous sinus but connect to proximal segment within the same venous sinus; Grade 2, collateral circulation connect to a different venous sinus but still in the same circulation pathway; Grade 3, collaterals connect to a different circulation (through deep or cavernous sinus circulation).

According to the degree of PSM invasion into SSS, meningioma was classified into 6 types [11]. Type 1: meningioma attached to outer surface of the sinus wall; Type 2: one lateral recess invaded; Type 3: one lateral wall invaded; Type 4: one lateral wall and the roof of the sinus both invaded; Types 5 and 6: sinus totally occluded, one wall being free of tumor in type V.

Statistical analysis

All data were analyzed by SPSS17.0 software (SPSS Inc, Chicago, IL, USA). One-way ANOVA was used to analyze the differences among multiple groups. The t test was performed to analyze the difference between two samples. $P < 0.05$ was considered as statistically significant.

Results

General condition of 48 cases of PSM patients

As shown in **Table 1**, the number PSM patients with tumor attached to anterior 1/3 SSS segment, mid 1/3 SSS segment and posterior 1/3 SSS segment was 7 cases (14.58%), 31 cases (64.58%) and 10 cases (20.83%) respectively. The venous sinus invasion degree of 48 PSM patients was shown in **Figure 1**. Among the 48 cases, 24 cases had Type 1-2 PSM (50%), 12 cases had Type 3-4 PSM (25%) and 2 cases had Type 5-6 PSM (25%). The classification of venous collateral circulation was shown in **Figure 2**. There were 23 cases (47.92%) without collateral circulation formation (Grade 0), 9 cases (18.75%) with collateral circulation connect to proximal segment within the same venous sinus (Grade 1), and 16 cases (33.33%) with collateral circulation connect to a different circulation (Grade 3). There were no cases with Grade 2 collateral circulation.

Effects of PSM on diameter and number of intracranial veins

In order to find out the influence of tumor on the diameter and number of veins, the diameter and number of veins between the tumor group and control group was compared. In the tumor group, the average diameters of bridging veins in the anterior 1/3 SSS segment, mid 1/3 SSS segment and posterior 1/3 SSS segment were (2.26 ± 0.77) mm, (2.94 ± 0.87) mm and (2.07 ± 0.84) mm, respectively (**Table 2**). In the con-

Table 3. Diameter of bridging vein in patients with different locations of PSM

Groups		Diameter of bridging vein (mm)		
		Anterior 1/3 SSS	Mid 1/3 SSS	Posterior 1/3 SSS
Tumor group (n = 48)	Tumor in anterior 1/3 SSS subgroup (n = 7)	2.21 ± 1.14	2.67 ± 0.67	2.10 ± 1.00
	Tumor in mid 1/3 SSS subgroup (n = 31)	2.28 ± 0.75	3.00 ± 0.88	2.11 ± 0.79*
	Tumor in posterior 1/3 SSS subgroup (n = 10)	2.25 ± 0.60	2.96 ± 0.98	1.95 ± 0.92
Control group (n = 20)		2.68 ± 0.98	3.11 ± 0.73	2.64 ± 0.97

Note: Compared with the control group, $^*P < 0.05$.

Table 4. Number of bridging vein in patients with different locations of PSM

Groups		Number of bridging vein (branch)		
		Anterior 1/3 SSS	Mid 1/3 SSS	Back 1/3 SSS
Tumor group (n = 48)	Tumor in anterior 1/3 SSS subgroup (n = 7)	3.14 ± 1.86	4.86 ± 2.19	1.71 ± 0.95
	Tumor in mid 1/3 SSS subgroup (n = 31)	4.07 ± 1.66	4.89 ± 1.80	2.59 ± 1.30
	Tumor in posterior 1/3 SSS subgroup (n = 10)	3.60 ± 1.50	4.40 ± 0.84	1.60 ± 0.70*,Δ
Control group (n = 20)		2.68 ± 0.98	3.11 ± 0.73	2.64 ± 0.97

Note: Compared with the control group, $^*P < 0.05$. Compared with tumor in mid 1/3 SSS subgroup, $^{\Delta}P < 0.05$.

Table 5. Diameters of main intracranial deep and superficial veins in patients with different location of PSM

Groups		SSV diameter (mm)	VT diameter (mm)	VL diameter (mm)	GCV diameter (mm)
Tumor group (n = 48)	Tumor in anterior 1/3 SSS subgroup (n = 7)	2.51 ± 0.54	2.58 ± 0.69	2.23 ± 0.41	2.56 ± 0.86
	Tumor in mid 1/3 SSS subgroup (n = 31)	2.52 ± 0.58	2.48 ± 0.48	2.16 ± 0.35*	2.36 ± 0.65
	Tumor in posterior 1/3 SSS subgroup (n = 10)	2.90 ± 0.57*	2.53 ± 0.52	2.44 ± 0.45	2.44 ± 0.64
Control group (n = 20)		2.32 ± 0.45	2.41 ± 0.34	2.41 ± 0.35	2.68 ± 0.61

Note: Compared with the control group, $^*P < 0.05$. Superficial Sylvian vein (SSV), vein of Trolard (VT), vein of Labbé (VL), and great cerebral vein (GCV).

Table 6. Diameter of different segments of intracranial venous sinus in patients with different location of PSM

Groups		ISS diameter (mm)	StS diameter (mm)	TS diameter (mm)	SS diameter (mm)
Tumor group (n = 48)	Tumor in anterior 1/3 SSS subgroup (n = 7)	2.53 ± 0.42	3.73 ± 1.05	4.98 ± 1.13	6.72 ± 1.45
	Tumor in mid 1/3 SSS subgroup (n = 31)	2.32 ± 0.60	3.58 ± 0.89	5.00 ± 1.41	6.12 ± 1.31
	Tumor in posterior 1/3 SSS subgroup (n = 10)	2.51 ± 0.48	3.36 ± 1.13	4.54 ± 1.26*	6.48 ± 2.84
Control group (n = 20)		2.25 ± 0.80	3.98 ± 1.33	5.70 ± 0.90	6.04 ± 1.15

Note: Compared with the control group, $^*P < 0.05$. Inferior sagittal sinus (ISS), Straight sinus (StS), transverse sinus (TS), and sigmoid sinus (SS).

trol group, the average diameters of bridging veins in three SSS segments were (2.68 ± 0.98) mm, (3.11 ± 0.73) mm and (2.64 ± 0.97) mm. Compared with the control group, the average diameter of bridging vein in the posterior 1/3 SSS segment was significantly smaller ($P < 0.05$) (**Table 2**). There was no statistical difference in the number of bridging veins between each SSS segment. To sum up, these results argue that PSM can change the diameter and the number of the veins in the posterior 1/3 SSS segment.

Effects of different positions of PSM on intracranial veins

To master the effects of different positions of PSM on intracranial veins, the diameter and number of veins in different locations was measured and compared. According to the position of PSM in SSS, PSM patients in the tumor group were divided into three groups, including tumor in anterior 1/3 SSS subgroup (n = 7), tumor in mid 1/3 SSS subgroup (n = 31) and tumor in posterior 1/3 SSS subgroup (n = 10). As shown

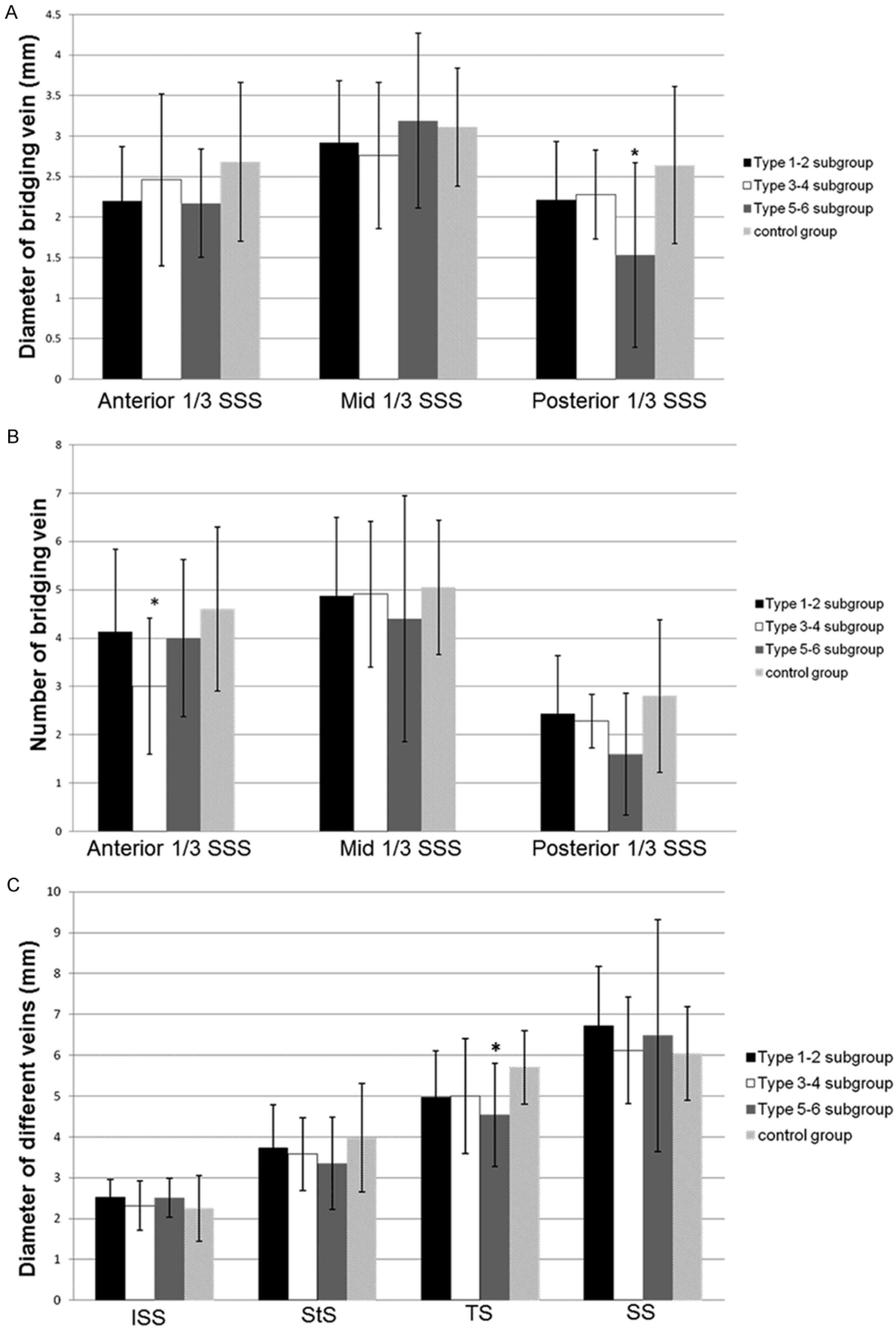
A
Diameter of bridging vein (mm)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Anterior 1/3 SSS
Mid 1/3 SSS
Posterior 1/3 SSS
*
Type 1-2 subgroup
Type 3-4 subgroup
Type 5-6 subgroup
control group
B
Number of bridging vein
0
1
2
3
4
5
6
7
8
*
Anterior 1/3 SSS
Mid 1/3 SSS
Posterior 1/3 SSS
Type 1-2 subgroup
Type 3-4 subgroup
Type 5-6 subgroup
control group
C
Diameter of different veins (mm)
0
1
2
3
4
5
6
7
8
9
10
*
ISS
StS
TS
SS
Type 1-2 subgroup
Type 3-4 subgroup
Type 5-6 subgroup
control group

Figure 3. Intracranial venous measurement of tumor group and control group. According to the invasion degree of PSM to SSS, the patients in tumor group were divided into Type 1-2 subgroup (n = 24), Type 3-4 subgroup (n = 12) and Type 5-6 subgroup (n = 12). A. Histogram showing the diameter of bridging vein in tumor subgroups and control group. B. Histogram showing the number of bridging vein in tumor subgroups and control group. C. Histogram showing the diameter of ISS, StS, TS and SS in tumor subgroups and control group. Compared with control group, *$P < 0.05$.

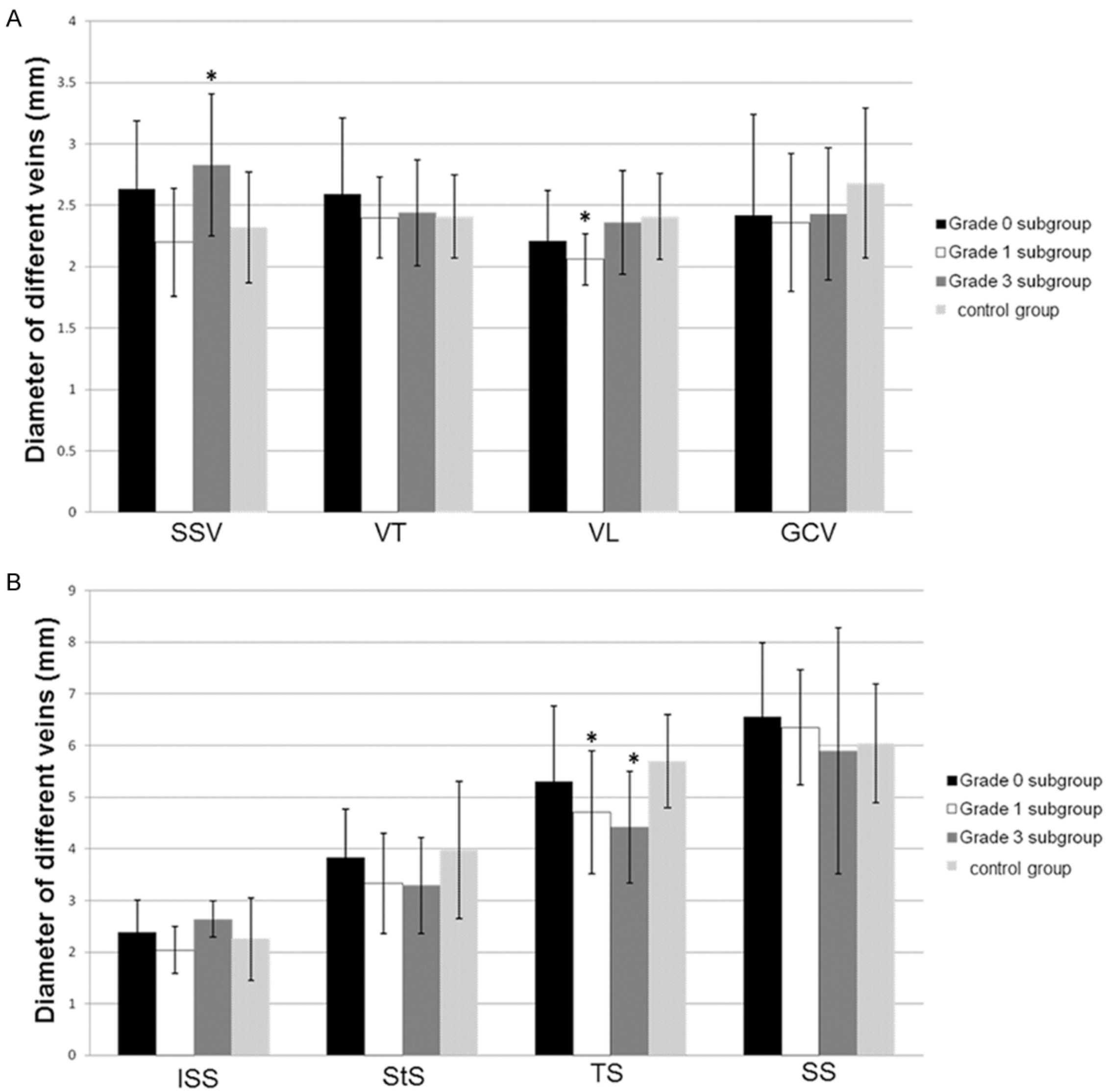

Figure 4. The diameter of intracranial veins of tumor group and control group. According to the classification of collateral venous circulation, the 48 cases of PSM patients were divided into Grade 0 subgroup (n = 23), Grade 1 subgroup (n = 9) and Grade 3 subgroup (n = 16). A. Histogram showing the diameter of SSV, VT, VL and GCV in tumor subgroups and control group. B. Histogram showing the diameter of ISS, StS, TS and SS in tumor subgroups and control group. Compared with control group, *$P < 0.05$.

in **Table 3**, the diameter of bridging vein in the posterior 1/3 SSS segment in the tumor in mid 1/3 SSS subgroup was (2.11 ± 0.79) mm, significantly different from that in the control group ($P < 0.05$). No significant difference ($P > 0.05$) was found in the diameter of bridging vein between other comparisons.

As shown in **Table 4**, compared with the control group, the number of bridging vein in the posterior 1/3 SSS segment in the tumor in posterior 1/3 SSS subgroup (1.60 ± 0.70) was significantly lower ($P < 0.05$). No statistically significant difference ($P > 0.05$) was found between other tumor subgroups and control group. Similarly, the number of bridging vein in the posterior 1/3 SSS segment in the tumor in posterior 1/3 SSS subgroup was also significantly lower than that in the tumor in mid 1/3 SSS subgroup ($P < 0.05$). There was no significant difference between other tumor subgroups ($P > 0.05$).

As shown in **Table 5**, in the tumor in mid 1/3 SSS subgroup, the diameter of VL was (2.16 ± 0.35) mm, significantly shorter than that in the control group (2.41 ± 0.35 mm) ($P < 0.05$). Compared with the control group (2.32 ± 0.45 mm), the diameter of SSV in the tumor in posterior 1/3 SSS subgroup (2.90 ± 0.57 mm) was significantly longer ($P < 0.05$). No statistically significant difference ($P > 0.05$) was found between other tumor subgroups and control group or between other tumor subgroups.

The diameters of intracranial venous sinus in each tumor subgroup were compared with those in the control group (**Table 6**). The diameter of TS in the tumor in the posterior 1/3 SSS subgroup was (4.54 ± 1.26) mm, and it was significantly shorter than that in the control group (5.70 ± 0.90) mm. No more difference was found ($P > 0.05$) in the rest of the venous sinus. There was no statistically significant difference ($P > 0.05$) between other tumor subgroups and control group or between other tumor subgroups. Taken together, these results suggest that PSM in different locations have different influence on the vein diameter and number, especially the bridging veins, SSV and VL.

Effects of invasion degree of PSM to SSS on intracranial veins

To understand the effect of invasion degree of PSM to SSS on intracranial veins, the diameter and number of brain veins was compared. According to the invasion degree of PSM to SSS, the patients in tumor group were divided into Type 1-2 subgroup (n = 24), Type 3-4 subgroup (n = 12) and Type 5-6 subgroup (n = 12). As shown in **Figure 3A**, compared with the control group (2.64 ± 0.97 mm), the diameter of the posterior 1/3 SSS in Type 5-6 subgroup (1.53 ± 1.14 mm) was significantly shorter ($P < 0.05$). No significant difference ($P > 0.05$) was found between other tumor subgroups and control group or between other tumor subgroups. Venous diameters of PSM, SSV, VT, VL and GCV in different tumor invasion subgroups were compared with the control group, and there was no statistical difference.

The number of bridging vein in the anterior 1/3 SSS in Type 3-4 subgroup was (3 ± 1.41). There was significant difference when compared with the control group (4.60 ± 1.70) ($P < 0.05$) (**Figure 3B**). No significant difference was found in other groups ($P > 0.05$).

Diameters of venous sinus of the three tumor invasion subgroups were compared to the control group, respectively. The diameter of TS in Type 5-6 subgroup was (4.16 ± 1.10) mm, significantly shorter than the control group (5.70 ± 0.90 mm) ($P < 0.05$). No significant difference was found in other groups ($P > 0.05$) (**Figure 3C**). As mentioned above, these results suggest that the higher the degree of tumor invasion to SSS, the deeper the influence on the diameter of intracranial veins, especially the bridging veins and TS.

Effects of collateral circulation on intracranial veins

To grasp the effects of collateral circulation on intracranial veins, the diameter and number of intracranial veins were measured and compared. According to the classification of collateral venous circulation, the 48 cases of PSM patients were divided into Grade 0 subgroup (n = 23), Grade 1 subgroup (n = 9) and Grade 3 subgroup (n = 16). No significant difference was found in the diameter and number of bridging vein between tumor subgroups with different degree of venous collateral circulation and the control group.

As shown in **Figure 4A**, the diameter of SSV of Grade 3 subgroup (2.83 ± 0.58 mm) was significantly larger than the control group (2.32 ± 0.45 mm) ($P < 0.05$). VL diameter of Grade 1 subgroup (2.06 ± 0.21 mm) was significantly shorter than the control group (2.41 ± 0.35 mm) ($P < 0.05$). No significant difference was found between other groups ($P > 0.05$).

As shown in **Figure 4B**, the diameters of TS in Grade 1 and Grade 3 subgroups were (4.71 ± 1.19) mm and (4.42 ± 1.08) mm, which were significantly smaller than that of the control group (5.70 ± 0.90) ($P < 0.05$). No significant difference ($P > 0.05$) was found between other groups ($P > 0.05$). In summary, these results suggest that the higher the level of collateral circulation, the deeper the influence on the diameter of intracranial veins, especially the SSV, VL and bridging veins.

Discussion

PSM can invade and obstruct SSS and change the velocity and direction of the blood flow of intracranial veins, leading to establishment of compensatory venous pathway and changes of vein diameter and number [12-14]. In this study, SSS was divided into the anterior 1/3 SSS segment, the mid 1/3 SSS segment and the posterior 1/3 SSS segment. The diameter and number of bridging vein in the posterior 1/3 SSS segment changed because of PSM invasion into venous sinus, especially when the tumor was located in the posterior 1/3 SSS segment. After invasion of PSM to SSS, the number and diameter of the bridging veins behind SSS obstruction site reduced while SSV diameter increased. Thus, these results indicate that PSM could induce changes in the diameter of bridging vein and in the velocity and direction of venous reflux. However, Khu et al [15] reported that PSM had no significant effect on the number and diameter of the cortical veins. This difference might be caused by different number of cases enrolled or different image contrast during image reconstruction.

When there is oppression, stenosis or occlusion in SSS, intracranial blood flow can be drained through other compensatory venous pathway. During selection of operation approach and flap size and treatment of intracranial veins during surgery, main compensatory venous pathway should be protected, damage to which may cause serious complications. Tigliev et al [16] found that in 52.1% of PSM patients with tumor in the anterior 1/3 SSS segment, cortical veins were involved in the compensatory venous circulation. And in 67% of PSM patients with tumor in the mid and posterior 1/3 SSS segments, ectopic reflux formed by cortical veins was observed. It is reported that collateral venous circulation established by the bridging vein beside SSS and SSV is the main collateral circulation of SSS, especially in patients with occlusions in the mid-posterior SSS segment [17]. In this study, the grading method of Qureshi [10] for collateral circulation was used and we found that PSM could cause SSS stenosis or occlusion, thus leading to reduce in VL, TS and SSS, and bridging vein drainage and changes in the direction of venous drainage. The intracranial blood flow was mainly drained through the SSV drainage.

Anastomosis between intracranial deep and superficial veins also exists in PSM patients. Under normal circumstances, anastomosis between intracranial deep and superficial veins is very small, therefore, blood flow through these anastomoses are quite small [18, 19]. Here in our study, taking into account of the establishment of compensatory pathways between cortical vein and cerebral deep vein, VR technology was used for measuring the diameter and number of intracranial cortical vein and deep vein. The results showed that the diameter of intracranial deep vein had no significant change. Hence, we considered that deep vein anastomoses only played auxiliary effects while compensatory pathways through superficial vein was the main drainage in the intracranial compensatory pathway.

In summary, in this study, VR technology was firstly used for overall assessment of compensatory pathway in PSM patients with SSS obstruction. Compensatory venous pathway was compared according to tumor location, invasion degree to SSS and collateral circulation classification.

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Disclosure of conflict of interest

None.

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