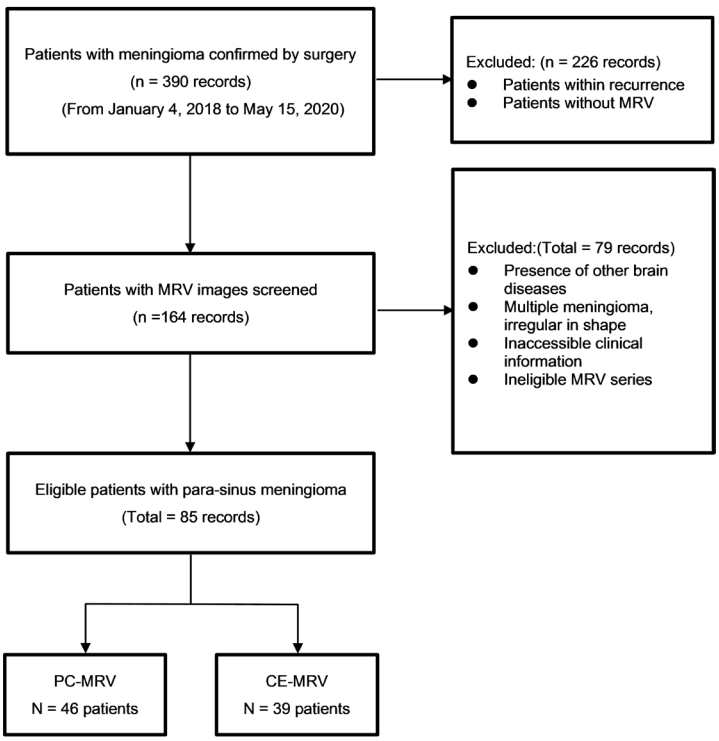
Supplementary

Appendix 1 Flow diagram for our research.



Appendix 2 Routine scanning parameters of the MR examination process

	T1WI	T2WI	T2-FLAIR	T1WI (+)	PC MRV	CE MRV
TR (ms)	2,000	4,000	4,000	2,000	14	25
TE (ms)	18	94	94	18	3.98	3.4
Matrix	358×512	358×512	358×512	358×512	–	–
Excitation	1	2	2	1	–	1
FOV (mm)	240×240	240×240	240×240	240×240	240×240	220×192
Bandwidth (Hz)	122	122	122	122	62.5	31.25
ST (mm)	3	3	3	3	1.6	1.4
FA (°)	–	–	–	–	8	20
Acquisition (s)	36	43	90	36	252	196

TR repetition time, TE echo time, FOV field of view, T1WI T1-weighted imaging, T2WI T2-weighted imaging, T1WI (+) enhanced T1-weighted imaging, ST Slice Thickness, FA Flip Angle, PC-MRV Phase Contrast Magnetic Resonance Venography, CE-MRV Contrast-Enhanced Magnetic Resonance Venography. A single injection of gadobutrolum (0.1 mmol/kg, Magnevist, Bayer-Schering, Berlin, Germany) was used for CE-MRV intravenous administration.

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Appendix 3 Consistency results of vessel characteristics from the first and the second measurements

Table S1 The intra/inter-observer consistency on vessel count from PC-MRV and CE-MRV

The inter-observer consistency	PC-MRV	CE-MRV
Reader A* *vs*. Reader B*	0.763	0.886
Reader A** *vs*. Reader B**	0.777	0.757
Reader A* *vs*. Reader A**	0.888	0.889
Reader B* *vs*. Reader B**	0.898	0.861
Reader A* *vs*. Reader B**	0.758	0.757
Reader B* *vs*. Reader A**	0.76	0.839
Mean* *vs*. Mean**	0.933	0.916

Table S2 Consistency results of vascular features from PC-MRV by the paired Mann-Whitney-U test

P value of PC-MRV	Sum	Mean	Max	Min
Reader 1* *vs*. Reader 2*	0.133	0.407	0.114	0.369
Reader 1** *vs*. Reader 2**	0.516	0.946	0.336	0.586
Reader 1* *vs*. Reader 1**	0.187	0.699	0.597	0.324
Reader 2* *vs*. Reader 2**	0.767	0.909	0.987	0.743
Reader 1* *vs*. Reader 2**	0.088	0.756	0.26	0.331
Reader 2* *vs*. Reader 1**	0.448	0.974	0.192	0.763
Mean* *vs*. Mean**	0.586	0.572	0.853	0.426

Table S3 Consistency results of vascular features from CE-MRV by the paired Mann-Whitney-U test

P value of CE-MRV	Sum	Mean	Max	Min
Reader 1* *vs*. Reader 2*	0.967	0.174	0.455	0.954
Reader 1** *vs*. Reader 2**	0.125	0.625	0.415	0.777
Reader 1* *vs*. Reader 1**	0.617	0.748	0.736	0.976
Reader 2* *vs*. Reader 2**	0.067	0.124	0.106	0.141
Reader 1* *vs*. Reader 2**	0.202	0.717	0.879	0.63
Reader 2* *vs*. Reader 1**	0.426	0.153	0.654	0.608
Mean* *vs*. Mean**	0.283	0.21	0.453	0.303

A two-way random ICC (Intraclass/Interclass correlation coefficient, > 0.75 regarded as good) and the paired Mann-Whitney-U tests (significant criterion of $p<0.05$) were conducted to check consistency results of vessel count and 4 diameter-associated features from the first and the second measurements. '*' represented the first measurements, while '**' represented the second measurements. (reader A: Prof. Lu; reader B: Prof. Yin; reader 1: Dr. Li; reader 2: Dr. Wang). The "mean*" value was referred to (reader A + reader B)/2 in the first measurements and the "mean**" value was referred to (reader A + reader B)/2 in the second measurements.

The measurements of vascular diameter parameters were based on 3D Slicer software (version 4.1.2; https://www.slicer.org), which is an open extensible platform in wide use for medical images.

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Appendix 4 Retrospective image analyses on sinus invasion based on MRV and the comparison with the gold-standard

	Based on PC MRV (n=46)		Based on CE MRV (n=39)	
	Invasion	Non-invasion	Invasion	Non-invasion
Rater 1	Rater 2		Rater 2	
Invasion	26	4	23	2
Non-invasion	1	15	2	12
Consensus	Gold-standard		Gold-standard	
Invasion	18	10	19	6
Non-invasion	7	11	4	10
Kappa test (value; 95% CI)				
Reader 1 & reader 2	0.77 (0.582–0.958)		0.783 (0.583–0.983)	
Consensus & final diagnosis	0.247 (–0.033 to 0.527)		0.46 (0.176–0.744)	

By means of 2 senior neuroradiologists' retrospective interpretations, the four-cell table of the diagnostic test was performed to record the sinus statuses (patency or sinus invasion). After the reader 1 (Prof. Lu) and reader 2 (Prof. Yin) finished each patient profile interpretation, they reviewed together thus to reach the final consensus. The consensus, compared with the pathological results, was then utilized the kappa scoring method to measure their consistency, by the following criteria: kappa≤0.4, poor; 0.4<kappa<0.75, moderate; kappa≥0.75, good. Meanwhile, the surgical result (sinus non-invasion & sinus invasion) was taken as a gold-standard reference (CI, Confidence Interval).

Appendix 5 Respective comparison analyses between the sinus compression group (group A) and the non-invasion on MR images (group B), and between the sinus compression (group A) and sinus invasion group (group C)

	Vessel count	Vessel sum diameter (mm)	Vessel mean diameter (mm)	Vessel max diameter (mm)	Vessel min diameter (mm)
PC MRV/P value					
Group A *vs*. group B	0.468	0.387	0.654	0.863	0.863
Group A *vs*. group C	0.014	0.012	0.356	0.064	0.175
CE MRV/P value					
group A *vs*. group B	0.492	0.635	0.958	0.792	0.713
group A *vs*. group C	0.009	0.007	0.092	0.017	0.366

In order to verify whether the vessel characteristics could identify those cases difficult to judge sinus status, three groups of group A, group B and group C were further for comparison (for PC MRV, group A: group B: group C=10: 11: 18; for CE MRV, group A: group B: group C=6: 10: 19) The vessel count and the 4 peritumoral vascular variables of the sum vessel diameter, mean vessel diameter, maximum vessel diameter, and minimum vessel diameter were tested by independent Mann-Whitney-U with the significant P setting at <0.05.

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Appendix 6 The correlation matrix between peritumoral vessel characteristics between those different WHO grades, or between different pathological types

Table S1 Baseline pathological details of the 85 para-sinus meningioma patients

Pathological type (%)	Overall	Invasion	Non-invasion	P
Fibrous (WHO I)	49 (57.6)	28 (58.3)	21 (56.8)	0.123*
Meningothelial (WHO I)	21 (24.7)	14 (29.2)	7 (18.9)	
Angiomatous (WHO I)	5 (5.9)	2 (4.2)	3 (8.1)	
Transitional (WHO I)	4 (4.7)	3 (6.2)	1 (2.7)	
Microcystic (WHO I)	1 (1.2)	0 (0.0)	1 (2.7)	
Psammomatous (WHO II)	1 (1.2)	1 (2.1)	0 (0.0)	
Atypical (WHO II)	4 (4.7)	0 (0.0)	4 (10.8)	

The classified patients by pathological types were expressed as numbers and percentages, and tested by Fisher Exact tests (signaled as "*") with the significant criteria of P<0.05.

Table S2 The correlation matrix between vessel characteristics and different pathological types, or different WHO grades for PC-MRV.

	Term	Vessel count	Sum diameter	Mean diameter	Max diameter	Min diameter
PC-MRV						
Pathological type	coef	–0.288	–0.248	0.211	0.053	0.063
	P	0.052	0.096	0.16	0.725	0.68
WHO grade	coef	–0.171	–0.14	0.124	–0.095	0.208
	P	0.255	0.352	0.413	0.528	0.166

The correlation matrix for PC-MRV, calculated correlations and relevantly P values by two-tailed Spearman correlation test with the significant P setting at <0.05.

Table S3 The correlation matrix between vessel characteristics and different pathological types, or different WHO grades for CE-MRV

	Term	Vessel count	Sum diameter	Mean diameter	Max diameter	Min diameter
CE-MRV						
Pathological type	coef	0.163	0.122	–0.095	0.327	–0.078
	P	0.321	0.458	0.566	0.042	0.637
WHO grade	coef	0.015	0	–0.053	0.218	–0.098
	P	0.926	1	0.751	0.183	0.554

The correlation matrix for CE-MRV, calculated correlations and relevantly P values by two-tailed Spearman correlation test with the significant P setting at <0.05.

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Appendix 7 Subgroup comparison analyses in 3 different SSS locations of the anterior (group A), middle (group B) and posterior (group C)

P	Anterior *vs*. middle *vs*. posterior SSS	
	PC-MRV	CE-MEV
Vessel count	0.992	0.717
vessel sum diameter	0.981	0.769
vessel mean diameter	0.749	0.352
vessel max diameter	0.73	0.884
vessel min diameter	0.997	0.241

In order to explore the differences vessel characteristics of meningiomas in 3 different SSS locations, three groups of the anterior, middle and posterior were further for comparison (for PC MRV, anterior: middle: posterior =6: 16: 5; for CE MRV, anterior: middle: posterior =8: 15: 3) The vessel count and the 4 peritumoral vascular variables were tested by Kruskal-Wallis's rank sum tests with the significant P setting at <0.05. Further, the Mann-Whitney U tests of each one and another group for both PC MRV and CE MRV were conducted while no significance was found.

Appendix 8 Prediction results based on peritumoral vessel count by MRV and the comparison with the gold standard

Based on PC MRV (n=46)			Based on CE MRV (n=39)		
Prediction: gold-standard	Gold-standard		Prediction: gold-standard	Gold-standard	
Prediction	Invasion	Non-invasion	Prediction	Invasion	Non-invasion
Invasion	15	4	Invasion	20	3
Non-invasion	10	17	Non-invasion	3	13

Under the vessel count of less than or equal to 3 and greater than 3 for PC-MRV (n=46), as well as less than or equal to 5.5 and greater than 5.5 for CE-MRV (n=39), a total of 85 samples were respectively divided into two categories to predict the non-invasion group and the invasion group, The results were also visualized in *Figure 5*.

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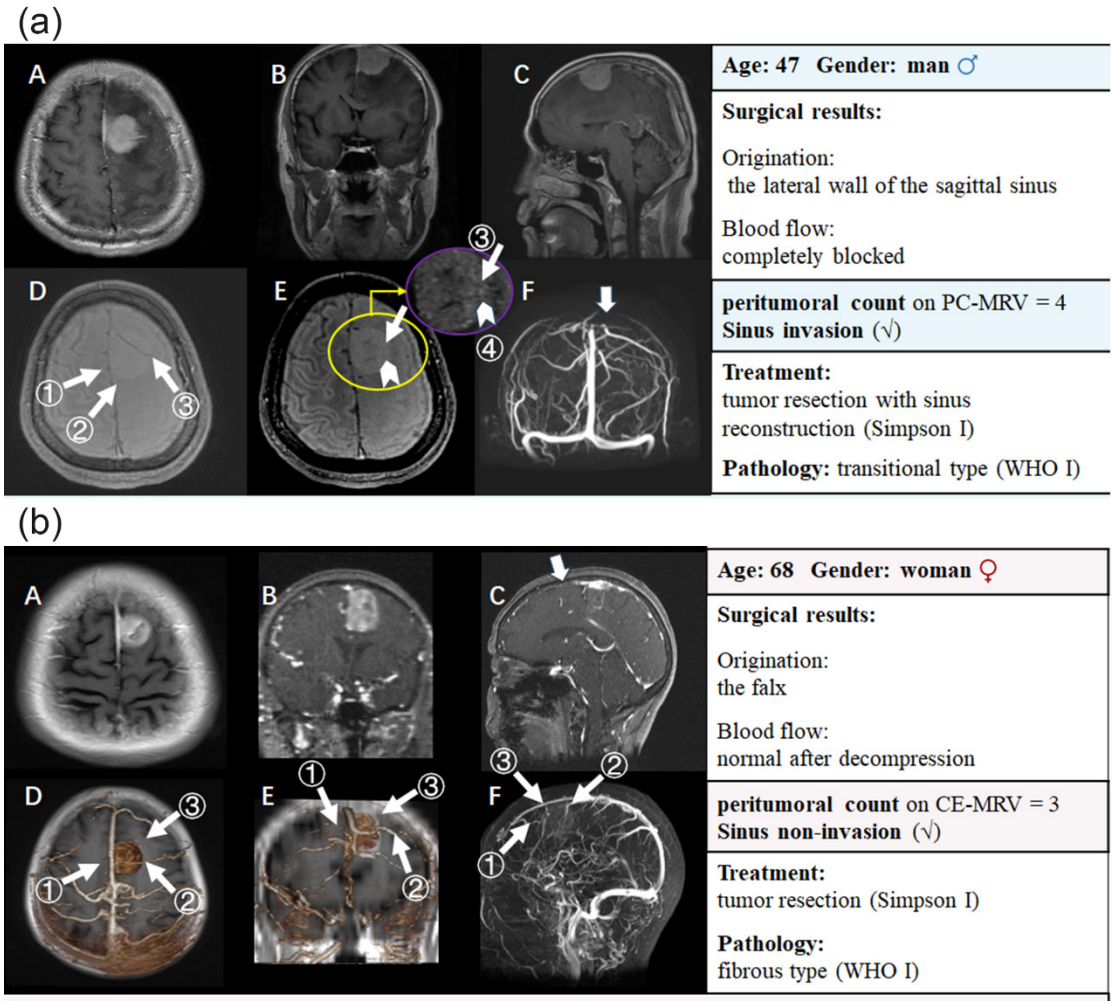
Appendix 9 Two typical cases of sinus invasion or non-invasion according to the threshold of vessel count on PC-MRV



The circled serial number identifies our counting process. In Figure a, the axial, coronal and sagittal T1 enhanced images (A-C) show the obvious lesion enhancement, with skull destruction. The soft issue image of D and E show a total of 4 peritumoral vessels closely adjacent to the neoplasm, which respectively represented the maximum section and another upper cross section. As the bold arrow points, the coronal Minimum Intensity Projection (MIP) reconstruction image (F) shows SSS stenosis due to focal invasion. Three thin arrows in image (D) represents peritumoral vessels, and the new tubular black signal marked by the bold arrow in image (E) points another peritumoral vessel in image with the reference of one thin arrow. The purple box is the enlarged part of image (E).

In Figure b (A-C), the axial, coronal and sagittal t1 enhanced images show the obvious lesion enhancement. As the bold arrow presents, a fine line of high signal in the sinus on the maximum cross section image (C) shows the slow passage of contrast agent above the tumor. The reconstructed axial, coronal and sagittal MIP image (D-F), shows a close relationship between meningioma and SSS, and 3 peritumoral vessels (thin arrow) are counted at three planes, which are represented by each circled serial number. PC-MRV, Phase Contrast MRV; MIP, Minimum Intensity Projection; SSS, superior sagittal sinus.

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