ORIGINAL RESEARCH

Low-and intermediate-grade lateral sinus dural arterio venous fistulas: Factors affecting the outcome of endo vascular treatment over 18-year experience in a high-volume neurovascular center

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ABSTRACT

BACKGROUND AND PURPOSE: Lateral sinus dural arteriovenous fistulas (LS-DAVFs) carry a higher rate of recurrence after endovascular treatment (EVT). Our objective was to investigate the independent predictors of recurrence and unfavorable functional outcome of low-and intermediate-grade LS-DAVFs after EVT.

MATERIALS AND METHODS: Retrospectively reviewed our database of prospectively collected information for all patients with low- and intermediate-grade LS-DAVFs that underwent EVT from May 2004 to December 2021. Patient demographic, angiographic, treatment, and outcome were analyzed to identify independent predictors of recurrence and unfavorable outcome.

RESULTS: One hundred and seventeen patients with 117 low-and intermediate-grade LS-DAVFs underwent EVT were included in this study. The mean age of the patients was 53.0±17.5 years. Immediately complete obliteration was achieved in 103/117 (88%) patients after EVT. Clinical follow-up were available for all of 117 patients, with an unfavorable outcome rate of 5.1%. Angiographic follow-up was available in 91 patients (78%). Recurrence occurred in 16 (18%) patients and 8 (6.8%) received retreatment. Contralateral sinus severe stenosis or occlusion was an independent high-risk factor for the unfavorable outcome (OR=11.7; 95% CI: 1.9-70.9, P<0.01) and recurrence (OR=63.8; 95% CI: 10.3-396.5, P<0.01) for low-and intermediate-grade LS-DAVFs at follow-up.

CONCLUSIONS: Contralateral sinus severe stenosis or occlusion represents a stronger independent risk factor associated with recurrence and unfavorable outcome in patients with low-and intermediate-grade LS-DAVFs when the involved ipsilateral sinus was occluded after EVT. For patients with LS-DAVFs, the patency of the contralateral sinus should be considered when therapeutic decision-making.

ABBREVIATIONS: LS-DAVFs = Lateral sinus dural arteriovenous fistulas; EVT = endovascular treatment; TAE = Transarterial Embolization; TVE = Transvenous Embolization; CN = cranial nerve; CVD = cortical venous drainage.

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SUMMARY SECTION

PREVIOUS LITERATURE: The probability of recurrence and unfavorable outcomes after endovascular treatment are relatively high of low- and intermediate-grade Lateral sinus dural arteriovenous fistulas (LS-DAVFs). However, there was a paucity of robust cohort studies that had conducted a detailed analysis of the risk factors associated with recurrence and the clinical prognostic indicators.

KEY FINDINGS: Contralateral sinus severe stenosis or occlusion represents a stronger independent risk factor associated with recurrence and unfavorable outcome in patients with low-and intermediate-grade LS-DAVFs when the involved ipsilateral sinus was occluded after EVT.

KNOWLEDGE ADVANCEMENT: The study emphasized the importance of considering contralateral sinus patency in endovascular treatment strategies for low- and intermediate-grade LS-DAVFs, potentially improving treatment outcomes.

INTRODUCTION

The lateral sinus dural arteriovenous fistulas (LS-DAVFs) refers to the abnormal arteriovenous shunt located in the transverse sinus, sigmoid sinus area, or its affiliated structures. It is the most common type of dural arteriovenous fistula, accounting for 13-32% of intracranial dural arteriovenous fistula.[1-3]

The most common symptoms of low- and intermediate-grade LS-DAVFs (Cognard I-IIa+b) are pulsatile tinnitus, headache, and intracranial hemorrhage.[3-5] Treatment is indicated in low- and intermediate-grade LS-DAVFs patients for risk reduction, symptom management, and preventing adverse effects.[6] Current dura AVF treatment options include endovascular treatment (EVT), microsurgery, and stereotactic radiosurgery, of which EVT is the first-line treatment for most LS-DAVFs.[7, 8] Some previous studies have reported that the probability of recurrence in medium- and long-term imaging follow-up after EVT of low- and intermediate-grade LS-DAVFs were 2%-14%, and it faces a relatively high risk of complications.[9-11] However, the sample size of these studies is small, and the risk of recurrence and clinical prognostic factors have not been analyzed in detail.

Therefore, we conducted this retrospective analysis based on a large cohort of patients with low- and intermediate-grade LS-DAVFs in a high-volume center to clarify the risk factors of recurrence and unfavorable outcome after EVT, so as to provide a basis for individualized treatment of low- and intermediate-grade LS-DAVFs.

MATERIALS AND METHODS

Patients and Guidelines

After approved by the Medical Ethics Committee of Changhai Hospital and informed consent was obtained from all of the patients, we retrospectively reviewed our DAVFs database of prospectively recorded information for all patients with low- and intermediate-grade LS-DAVFs that underwent EVT from May 2004 to December 2021. The patients' demographic characteristics, presenting symptoms, angioarchitecture features, treatment strategies, the angiographic results at immediate post-embolization and follow-up evaluations, procedure-related complications, and clinical outcome, using mRS at admission and subsequent follow-up visits were recorded for analysis. In line with the guidelines of the RECORD statement, the methodology and all subsequent analyses were meticulously documented. A comprehensive account of these findings is detailed in the supplementary material provided.

The patient inclusion criteria were as follows: 1) DAVFs located at the lateral sinus, 2) Cognard Types I-IIa+b and 3) treated with EVT. Patients with any of the following conditions were excluded: 1) Cognard Types III-V, 2) bilateral untreated LS-DAVFs, as well as 3) those treated with stereotactic radiosurgery or microsurgery after EVT. Figure 1 shows a flow diagram of the study enrollment of the patients at our institute during the study period.

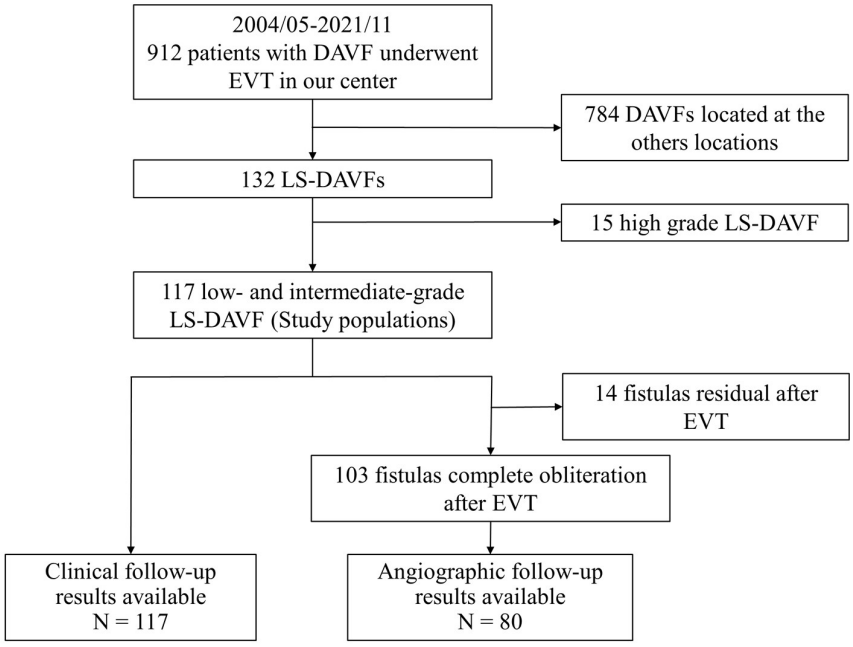

FIG 1. Flow diagram of the study enrollment of the patients.

Endovascular Procedures

The decision regarding the most appropriate method of treatment in every case was made by our multidisciplinary neurovascular teams made up of expert interventional neuroradiologists and neurosurgeons. All endovascular procedure was performed by experienced interventional neuroradiologists under general anesthesia with a biplane neuroangiography suite (Artis zee Biplane; Siemens, Munich, Germany; Allura Xper FD20/20, Philips, Best, the Netherlands). Rotational angiography followed by 3D/4D and Dyna CT/Xper CT reconstruction were performed to understand the angiographic features.

The treatment approaches were defined according to the vessel in which the microcatheter was navigated with embolic agent injection, including transarterial, transvenous, or combined approach. A 6Fr guiding catheter (Envoy, USA) was used to perform angiography and transarterial embolization through the femoral artery approach. An 8 Fr guiding catheter (Cook, USA) or a long sheath (Neuron Max 088, Penumbra, USA) was used to perform transvenous embolization or sinus protection through the femoral vein approach or internal jugular vein approach. We used Histoacryl (B. Braun, GER), Glubran (GEM, Italy), Onyx (ev3, USA), coils (different sizes, lengths, and manufacturers) in different combinations to emblaze the fistulas. And a large remodeling balloon (Copernic, Balt Extrusion, France; Hyperform, Hyperglide, Micro Therapeutics, CA) was used to protect the involved sinus. The remodeling balloon, liquid embolic agent, and coils were deployed according to standard procedure, as recommended by the manufacturer.

At the end of the procedure, the puncture point of the femoral vein was sealed through manual compression and the femoral artery puncture site was sealed using an arterial closure device, Exoseal (Cordis Europe, Waterloo, Belgium).

Follow-up Protocol and Complications

All of the patients underwent a cerebral CT/MR scan before and after the procedure. Immediate post-embolization angiograms were obtained at the end of the endovascular procedures to evaluate embolization results. The standard angiographic follow-up was typically scheduled at 3 months with cerebral CT/MR scan, and 6 months with DSA to assess the fistulas and sinus status. The angiographic follow-up results were classified into 4 categories (Cured, improved, stable, and recurrence) when compared with the immediate embolization degree. The assessment of the degree of sinus patency was measured by three experienced interventional neuroradiologists, based on DSA image during procedures according to the study of Hu et al.[12] Severe stenosis was defined as within a segment of conduit estimated as less than 25% of the cross-sectional diameter of the lumen of the adjacent fully patent sinus..

The peri-procedure complications included cranial nerve (CN) palsy, symptomatic ischemic stroke, intracranial hemorrhage, and epilepsy within 30 days after EVT. Ischemic stroke with symptoms was defined as a clinically evident ischemic stroke with evidence of infarction on diffusion-weighted imaging, post-procedural intracranial hemorrhage including SAH, subdural hemorrhage or intraparenchymal hemorrhage which was diagnosed according to a new clinically neurological defect and confirmed on CT/MR imaging.

Clinical outcome was assessed when the patients were admitted to perform the angiographic follow-up or during an outpatient visit. The clinical outcome were assessed using the mRS score, with scores of 0-2 indicating favorable functional outcome and 3-5 denoting unfavorable functional outcome.

Statistical Analysis

Data normality was assessed using the Shapiro-Wilk test, and variables were expressed as absolute frequencies and percentages, mean±standard deviation (SD), or median and interquartile range (IQR) values as appropriate. Continuous variables were compared using the independent samples t-test for data that were normally distributed, and the Mann-Whitney U test for those that were not. Categorical variables were analyzed using the Chi-square test or Fisher's exact test. To identify variables for inclusion in the multivariable logistic regression analysis, we conducted univariable analysis using t-tests, nonparametric tests, Chi-square tests, or Fisher exact tests, based on the distribution of the variables. A P-value of less than 0.05 (two-tailed) was set as the threshold for statistical significance. The multivariable logistic regression analysis was conducted using the stepwise backward maximum likelihood ratio method, which is a backward elimination process based on the probability of the likelihood-ratio statistic. This method allows for the identification of the most significant variables associated with complications and angiographic recurrence while controlling for potential confounders. Receiver Operating Characteristic (ROC) curve analysis was conducted to assess the discriminative ability of contralateral sinus patency in predicting favorable functional outcome. The area under the ROC curve (AUC) was calculated to quantify the test's accuracy, with a higher AUC indicating superior discrimination. All statistical analyses were conducted using SPSS version 19.0 for Windows (SPSS Inc., Chicago, IL, USA).

RESULTS

Patient and fistula characteristics

A total of 912 patients with DAVFs received EVT from May 2004 to November 2021 in our center. For these patients, 132 DAVFs involving the lateral sinus, and 117 of which were low- and intermediate-grade (Cognard type I-IIa+b) and were included in our study for analysis. The details are presented in Figure 1. The mean age of the patients was 53.0±17.5 years, with 64% male. Common presentations included hemorrhage (16%), headache (40%), pulsatile tinnitus (46%), and non-hemorrhagic neurological deficit (20%). The baseline mRS score was 0-2 in 96 patients (82%).

The majority of the LS-DAVFs were single orifice fistulas (55%), 64% were Borden grade II; 59% were Cognard type IIa+b and 59% were Lalwani grade III. Twenty-five patients were accompanied by contralateral sinovenous stenosis or occlusion. Detailed baseline characteristics were summarized in Online Supplemental Data.

Treatment strategies, results, and procedure-related complications

Of all 117 patients, 56 (48%) received embolization with a transarterial approach alone, 19 (16%) received embolization with a transvenous approach alone, and combined transarterial with transvenous approach were used in 42 (36%) patients. Of 117 LS-DAVFs, 29 received sinus-preserving strategies and 88 received sinus-occluding strategies. Particularly, 40 patients were treated with the intravenous balloon protection technique. Complete obliteration was achieved in 103/117 (88%) patients after embolization treatments. Fourteen patients (12%) showed few fistula remnants, among them 12 (10%) had CVD discontinuation, and 2 (1.7%) venous filling decreased. Ipsilateral sinus occlusion after endovascular treatment existed in 88 patients (75%), of which 72 were accompany with contralateral sinus patency and 16 were accompany with contralateral sinus stenosis or occlusion. Peri-procedure complications occurred in 21 patients, including ten patients with epilepsy (8.5%), six symptomatic ischemic strokes (5.1%), two intracranial hemorrhages (1.7%), and three cranial nerve palsy (2.6%) after EVT. There were no deaths attributed to procedural complications. Detailed procedural information were summarized in Table 1 and supplemental table 1.

Table 1: Treatment strategy and outcome of patients with low- and intermediate-grade LS-DAVFs underwent EVT (n=117).

Characteristics	N (%)
Treatment approach	
TAE	56 (48)
TVE	19 (16)
TAE+TVE	42 (36)
Balloon protection in sinus	40 (34)
Ipsilateral sinus condition post-embolization	
Patency	29 (25)
Contralateral sinus patency	20 (17)
Contralateral sinus stenosis or occlusion	9 (7.7)
Stenosis or occlusion	88 (75)
Contralateral sinus patency	72 (62)
Contralateral sinus stenosis or occlusion	16 (14)
Embolization result	
Complete obliteration	103 (88)
CVD discontinuation	12 (10)
Decreased venous filling	2 (1.7)
Persistent venous drainage	0 (0.0)
Peri-procedure complications	21 (18)
CN palsy	3 (2.6)
Ischemic stroke	6 (5.1)
Intracranial hemorrhage	2 (1.7)
Epilepsy	10 (8.5)
Total complications	17 (15)

*Median±IQR. TAE, Transarterial Embolization; TVE, Transvenous Embolization; CN, cranial nerve; CVD, cortical venous drainage

Clinical and angiographic follow-up outcome

Clinical follow-up were available for whole 117 patients. The median clinical follow-up time was 24 months (interquartile range 8.5-54.5). The unfavorable functional outcome was evident at follow-up in 6 (5.1%) patients. The rate of favorable functional outcome at follow-up was significantly higher than those at pre-embolization (95% vs. 82%, P<0.01). The graphic distribution of mRS at pre-embolization and follow-up in all study populations were summarized in Table 2 and graphically in Supplementary Figure 1.

Angiographic follow-up was available in 91 patients (78%). The median angiographic follow-up time was 7 months (interquartile range 5.0-10.0). Among them, 66 (73%) patients were cured, 6 (6.6%) were improved and 3 (3.3%) were stable compared with immediate post-embolization results. Recurrence occurred in 16 (18%) patients. Among them, 6 cases were asymptomatic, 10 cases reappeared with pulsatile tinnitus, and 8 cases received retreatment. Detailed information was summarized in Table 2.

Table 2: Clinical and angiographic follow-up results.

Characteristics	N (%)
Clinical follow-up	117 (100)
Length of follow-up (months)*	24 ± 46
mRS at latest follow-up	
0-2	111 (95)
3-5	6 (5.1)
Angiographic follow-up	91/117 (78)
Length of image follow-up (months)*	7 ± 5
Angiographic follow-up results	
Cured	66 (73)
Improve	6 (6.6)
Stable	3 (3.3)
Recurrence	16 (18)

*Median±IQR.

Risk factor analysis of unfavorable functional outcome and recurrence

Univariate analysis indicated that patients with contralateral sinus patency had a significantly higher rate of favorable functional outcome (70/72, 97%) compared to those with contralateral sinus stenosis or occlusion (12/16, 75%) following ipsilateral sinus stenosis or occlusion

post-embolization (P<0.01) at long-term follow-up. Detailed information were summarized in Online Supplemental Data. The graphic distribution of mRS at follow-up in 2 cohorts were illustrated in Figure 2A. Contralateral sinus patency was significantly associated with more mRS downshift to grades 2 or lower (P<0.01). The analysis of mRS shift between patients with contralateral sinus patency and contralateral sinus stenosis or occlusion in the cohort of involved ipsilateral sinus stenosis or occlusion was graphically in Figure 2B and summarized in Online Supplemental Data. Within the involved ipsilateral sinus stenosis or occlusion subgroup, contralateral sinus stenosis or occlusion was a high-risk factor for the unfavorable outcome (OR=11.7; 95% confidence interval [CI]: 1.9-70.9, P<0.01).

One hundred and three patients with complete obliteration after EVT, 80 of whom obtained angiographic follow-up data and were used to analyze the risk factors for recurrence. Univariate analysis showed that Lalwani grade (P=0.05), and the involved ipsilateral sinus stenosis or occlusion post-embolization accompany the contralateral sinus stenosis or occlusion (P<0.01) were associated with recurrence for LS-DAVFs. Detailed information were summarized in Online Supplemental Data.

Multivariable logistic regression analysis revealed that in the cohort of ipsilateral sinus stenosis or occlusion after embolization, contralateral sinus stenosis or occlusion was independently associated with quite higher rates of recurrence for LS-DAVFs (OR=63.8; 95% CI: 10.3, 396.5, P<0.01) at follow-up. And the mean value of the area under the ROC curve of contralateral sinus stenosis or occlusion was larger than 0.85 (88%; 95% CI: 71.1%-95.2%, Supplementary Figure 2), indicating its high diagnostic value.

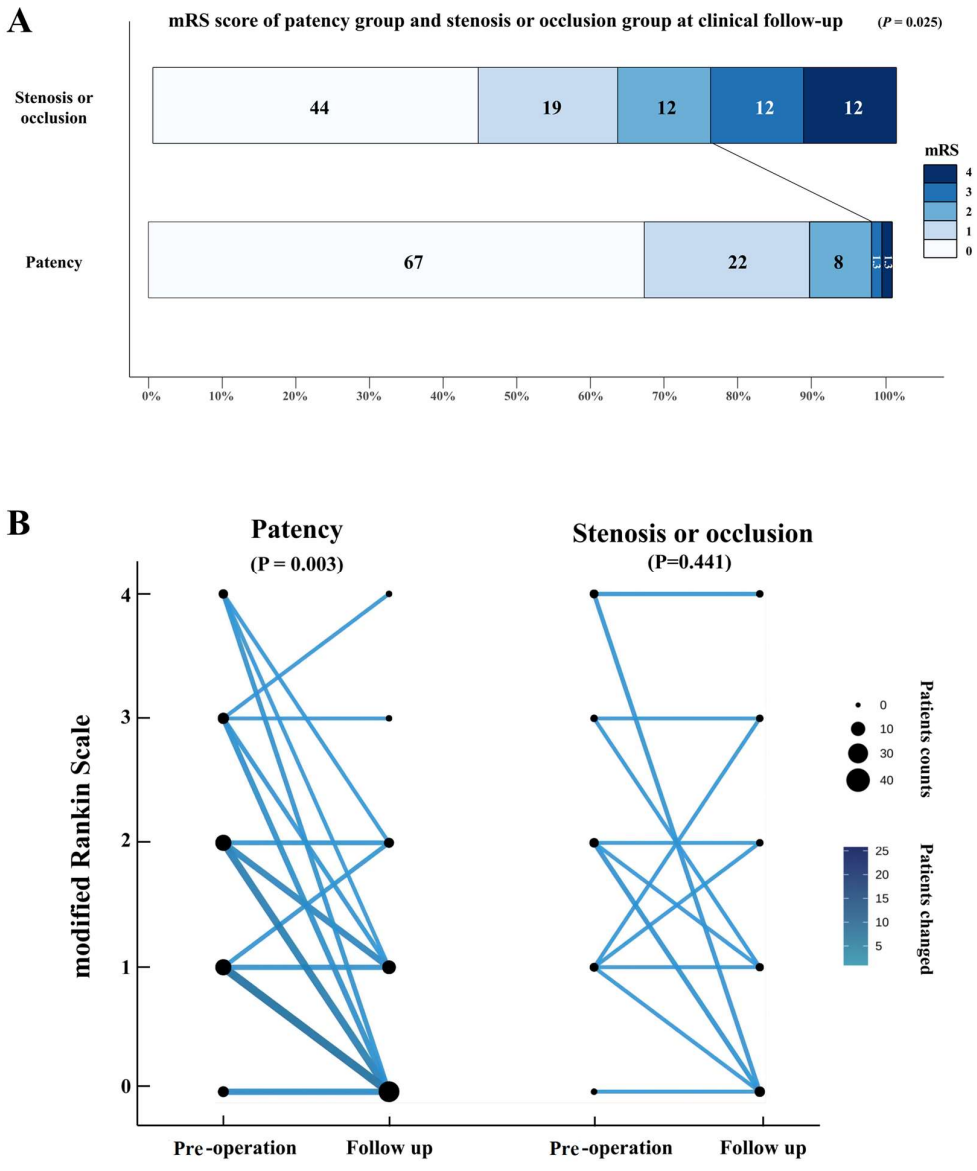

Figure 2. Distribution of mRS score between pre- or post-operation and clinical follow-up in patients with contralateral sinus patency subgroup and with contralateral sinus stenosis or occlusion subgroup. A) Tendency in mRS score post-operation and clinical follow-up in patients with contralateral sinus patency subgroup and with contralateral sinus stenosis or occlusion subgroup. Changes in mRS score greater than one point were considered to indicate worse or better. B) Analysis of mRS shift in patients with

ipsilateral sinus patency subgroup vs. stenosis or occlusion subgroup, showing that an ipsilateral sinus patency subgroup is significantly associated with more shift to mRS score 2 or lower (P<0.01). Raw distribution of scores is shown. The thickness of each line represents the change in the number of patients, as shown in the label on the right.

DISCUSSION

Our center is one of the largest neurovascular centers in China, and also one of the first batches of centers to carry out EVT for patients with dura AVF in China, forming the largest single-center retrospective cohort for EVT of low- and intermediate-grade LS-DAVFs in China. In this study, we confirmed for the first time that severe stenosis or occlusion of the contralateral sinus is an independent risk factor for recurrence and unfavorable functional outcome in patients with low- and intermediate-grade LS-DAVFs after EVT when the involved ipsilateral sinus is occluded after EVT. It is suggested that we should consider the patency of the contralateral sinus when formulating EVT strategies of low- and intermediate-grade LS-DAVFs. The research results have important guiding significance and application value for the treatment of LS-DAVF.

Previous studies on the risk factors of recurrence after dura AVF treatment showed that the residual after embolization and CVD were the main factors of recurrence.[9, 13] Therefore, the primary goal of dura AVF embolization was to occlude the fistula as fully and thoroughly as possible and eliminate venous reflux. However, some studies found that even if the fistula was occluded and the venous reflux disappeared, there was still a high risk of recurrence.[14] In order to find other important influencing factors, our study included only patients with immediate complete occlusion after EVT to analyze the risk factors of recurrence and excluded the influence of residual fistula on the results.

EVT strategies of low- and intermediate-grade LS-DAVFs can be divided into sinus-preserving strategy and sinus-occluding strategy. Direct occluded the involved ipsilateral sinus deliberately is a simple and definitive treatment method. The advantage is that the immediate occlusion rate is high after the embolization and can eliminate the cortical venous reflux. However, this method faces a certain risk of complications.[15] Therefore, some researchers consider that the sinus-occluding strategy should be restricted to cases in which the sinus-preserving strategy does not achieve a downgrading to no worse than Cognard Type IIa.[16] However, the number of cases in these studies is small. In addition, the drainage function of the contralateral sinus is not considered in these studies, and the research results have certain limitations.

In our center, our treatment concept considers the drainage function of the ipsilateral involved sinus and the patency of the contralateral sinus. For patients which ipsilateral involved sinus were dysfunctional, sinus-occluding strategy is an effective method for treating dura AVF if contralateral sinus were patency. For patients which ipsilateral involved sinus have potential drainage function and contralateral sinus was stenosi or dysplasia, sinus- preserving or even sinus- reconstructing should be regarded as the first choice.[17] However, most of the patients with LS-DAVFs were involved with severe stenosis or occlusion of the ipsilateral sinus before the operation due to congenital dysplasia, sinus thrombosis, or secondary pathological effects of fistulas.[18] These patients are difficult to carry out sinus-preserving strategies, and sinus reconstruction was feasible but may increase the risk of complications.[19] Therefore, sinus-occluding strategy are often selected for treatment. In addition, even if the venous sinus protection strategy is adopted, the affected side of the venous sinus may still be occluded after EVT.[16] The reasons include that the liquid embolic agent entered the sinus, the blood flow of the fistula shunt disappeared and the impact pressure of the blood flow on the wall of the sinus decreased resulting in thrombosis in the sinus after the embolization.[17]

Previous studies have found that sinovenous outflow restriction is a risk factor associated with hemorrhage and lower obliteration rate after gamma knife radiosurgery in patients with LS-DAVFs.[12, 20, 21] In this study, we found that among 117 patients with LS-DAVFs, 66 patients had severe stenosis or occlusion at the proximal end of the involved ipsilateral sinus before EVT. The venous drainage was mainly through retrograde flow, and the patients were complicated with venous hypertension and cortical venous reflux. In addition to the cases of direct sinus-occluding treatment, there are also patients who still occurred severe stenosis or occlusion of the involved ipsilateral sinus after the use of a sinus-preserving strategy. In our cohort, the angiography immediately after the EVT showed that 75% of patients accompany with severe stenosis or occlusion of the involved ipsilateral sinus. 13% of these patients with ipsilateral sinus stenosis or occlusion after EVT accompany by severe stenosis or occlusion of the contralateral lateral sinus. For these patients, the drainage of the intracranial venous flow was limited, and the intracranial venous pressure was higher, resulting in the clinical symptoms of patients after EVT were not significantly relieved. At the same time, long-term intracranial venous hypertension is also an inducing factor for the recurrence and new onset of dura AVF.[17, 22]

In this study, the clinical symptoms of LS-DAVFs patients have been improved and the functional outcome by and large is well after EVT. Angiography immediately after embolization showed that the immediate obliteration rate of LS-DAVFs after EVT was 88%, higher than that reported in the same type of study.[8, 11] However, among patients who completed angiographic follow-up, the recurrence rate was 18%, slightly higher than in other studies.[9, 23] Interestingly, subgroup analysis showed that when the involved ipsilateral sinus was stenosis or occlusion after EVT, contralateral sinus stenosis or occlusion was a high-risk factor for unfavorable functional outcome and recurrence. These suggests that the drainage function of the sinus is the real influence on the prognosis of LS-DAVFs after EVT, which is also the direct factor affecting the intracranial venous pressure after the fistula is obliterated.

When formulating the EVT strategies of low- and intermediate-grade LS-DAVFs, the operator should consider the sinus drainage pattern and the patency of the contralateral sinus. For patients involving the main drainage sinus, that is, the contralateral sinus is congenital dysplasia, stenosis or occluded due to sinus thrombosis or others reasons, we should seek to protect the patency of the sinus as much as possible while embolizing the low- and intermediate-grade LS-DAVFs, and reconstruct the involved sinus if feasible. In addition, even if the contralateral sinus patency before EVT, it is difficult to predict whether the contralateral sinus will be affected during the procedures,

once the involved ipsilateral sinus is sacrificed, the contralateral sinus is possible to occur stenosis or occlusion during follow-up, which may affect the patient's functional outcome.[15, 24, 25] If it is necessary to treat by occluding the involved ipsilateral sinus, or if the involved ipsilateral sinus is stenosis or occluded after EVT accompany with by the contralateral sinus stenosis or occlusion, the contralateral sinus reconstruction can be considered to restore the normal intracranial venous drainage.[26]

It should be acknowledged that the present study has some limitations. Firstly, the present study was a nonrandomized retrospective study conducted in a single-center. The results of this study reflected only the systematic and conventional endovascular approach of an experienced neurovascular center. Therefore, the results were influenced by selection bias and may not be generalizable to patients who are treated at institutions where different treatment strategies are used. In addition, 26 patients without angiographic follow-up were excluded and the short follow-up period of partial patients didn't fully reflect the recurrence after EVT. A multi-center, prospective cohort study based on more cases needs to be carried out to further clarify the factors affecting the functional outcome of LS-DAVFs.

CONCLUSIONS

Contralateral sinus stenosis or occlusion represents a stronger risk factor associated with recurrence and poor functional outcome in patients with low-and intermediate-grade LS-DAVFs when the involved ipsilateral sinus was occluded after EVT. For patients with LS-DAVFs, the patency of the contralateral sinus should be considered when therapeutic strategy determining. When the contralateral sinus is stenosis or occluded, the involved ipsilateral sinus should be protected or reconstructed to avoid the use of the sinus occlusion strategy.

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SUPPLEMENTAL FILES

Online Supplemental Data: Demographics and angioarchitecture of patients with low- and intermediate-grade LS-DAVFs underwent EVT (n=117).

Characteristics	N (%)
Age (yr)*	53.0±17.5
Sex (Male)	73 (62)
Clinical presentation	
Hemorrhage	19 (16)
Headache	47 (40)
Pulsatile tinnitus	54 (46)
Ocular Signs	12 (10)
Epilepsy	15 (13)
Progressive visual changes	7 (6.0)
Non-hemorrhagic neurological deficit	23 (20)
Mental status deterioration	9 (7.7)
mRS score at baseline	
0-2	96 (82)
3-5	21 (18)
Numbers of orificium fistulas	
Single	64 (55)
Multi	53 (45)
Cognard classification	
Type I	19 (16)
Type IIa	23 (20)
Type IIb	6 (5.1)
Type IIa+b	69 (59)
Borden grade	
I	42 (36)
II	75 (64)
Lalwani grade	
I	19 (16)
II	29 (25)
III	69 (59)
Contralateral sinus condition pre-embolization	
Patency	92 (79)
Stenosis or occlusion	25 (21)

*Median±IQR.

Online Supplemental Data: Univariate analyses for predictors of unfavorable functional outcome of patients with low- and intermediate-grade LS-DAVFs underwent EVT (n=117).

Characteristics	Favorable (mRS 0-2)	Unfavorable (mRS 3-6)	P-value
Age*	54.0±32.0	53.0±18.0	0.70
Sex (Male)	40 (36)	4 (67)	0.20
Numbers of orificium fistulas			0.69
Single	60 (54)	4 (67)	
Multi	51 (46)	2 (33)	
Cognard classification			0.57
Type I	19 (17)	0 (0.0)	
Type IIa	22 (19)	1 (17)	
Type IIb	6 (5.4)	0 (0.0)	
Type IIa+b	64 (58)	5 (83)	
Borden grade			0.42
I	41 (37)	1 (17)	
II	70 (63)	5 (83)	
Lalwani grade			0.40
I & II	47 (42)	1 (17)	
III	64 (58)	5 (83)	
Endovascular approach			0.41
TAE	53 (48)	3 (50)	
TVE	17 (15)	2 (33)	
TAE+TVE	41 (37)	1 (17)	
Balloon protection in sinovenous	73 (66)	4 (67)	>0.99
Embolization result			0.95
Complete obliteration	91 (82)	5 (83)	
CVD discontinuation	18 (16)	1 (17)	
Decreased venous filling	2 (1.8)	0 (0.0)	
Persistent venous drainage	0 (0.0)	0 (0.0)	
Ipsilateral sinovenous condition post-embolization			0.33
Patency	29 (26)	0 (0.0)	-

Contralateral sinus patency	20 (17)	0 (0.0)	
Contralateral sinus stenosis or occlusion	9 (7.7)	0 (0.0)	
Stenosis or occlusion	82 (74)	6 (100)	<0.01
Contralateral sinus patency	70 (85)	2 (34)	
Contralateral sinus stenosis or occlusion	12 (15)	4 (67)	

*Median±IQR. TAE, Transarterial Embolization; TVE, Transvenous Embolization; CN, cranial nerve; CVD, cortical venous drainage

Online Supplemental Data: Univariate analyses for predictors of recurrence with low- and intermediate-grade LS-DAVFs underwent EVT (n=80).

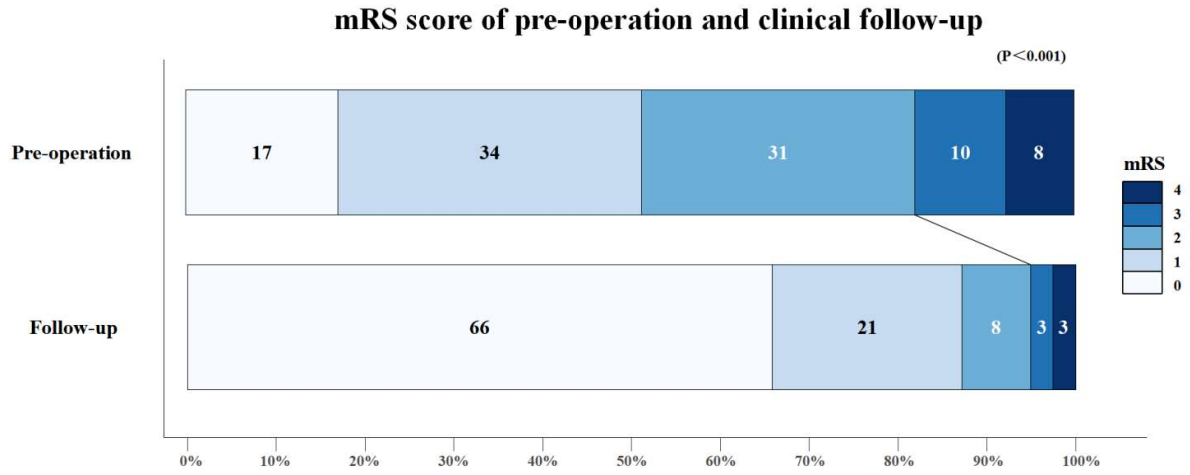
Characteristics	Recurrence	Non-recurrence	P-value
Age*	49.5±26.2	52.0±17.0	0.30
Sex (Male)	11 (85)	40 (60)	0.16
Numbers of orificium fistulas			0.36
Single	5 (39)	35 (52)	
Multi	8 (62)	32 (48)	
Cognard classification			0.19
Type I	0 (0.0)	10 (15)	
Type IIa	2 (15)	15 (22)	
Type IIb	0 (0.0)	5 (7.5)	
Type IIa+b	11 (85)	37 (55)	
Borden grade			0.23
I	2 (15)	25 (37)	
II	11 (85)	42 (63)	
Lalwani grade			0.05
I & II	2 (15)	30 (45)	
III	11 (85)	37 (55)	
Endovascular approach			0.62
TAE	7 (54)	32 (48)	
TVE	1 (7.7)	14 (21)	
TAE+TVE	5 (39)	21 (31)	
Balloon protection in sinovenous	6 (46)	21 (31)	0.48
Treatment strategies			
Sinus-preserving	1 (7.7)	12 (18)	
Sinus-occluding	12 (92)	55 (82)	
Ipsilateral sinovenous condition post-embolization			0.62
Patency	1 (7.7)	12 (18)	0.31
Contralateral sinus patency	0 (0.0)	9 (75)	
Contralateral sinus stenosis or occlusion	1 (100)	3 (25)	
Stenosis or occlusion	12 (92)	55 (82)	<0.01
Contralateral sinus patency	2 (17)	51 (93)	
Contralateral sinus stenosis or occlusion	10 (83)	4 (7.3)	

*Median±IQR. TAE, Transarterial Embolization; TVE, Transvenous Embolization

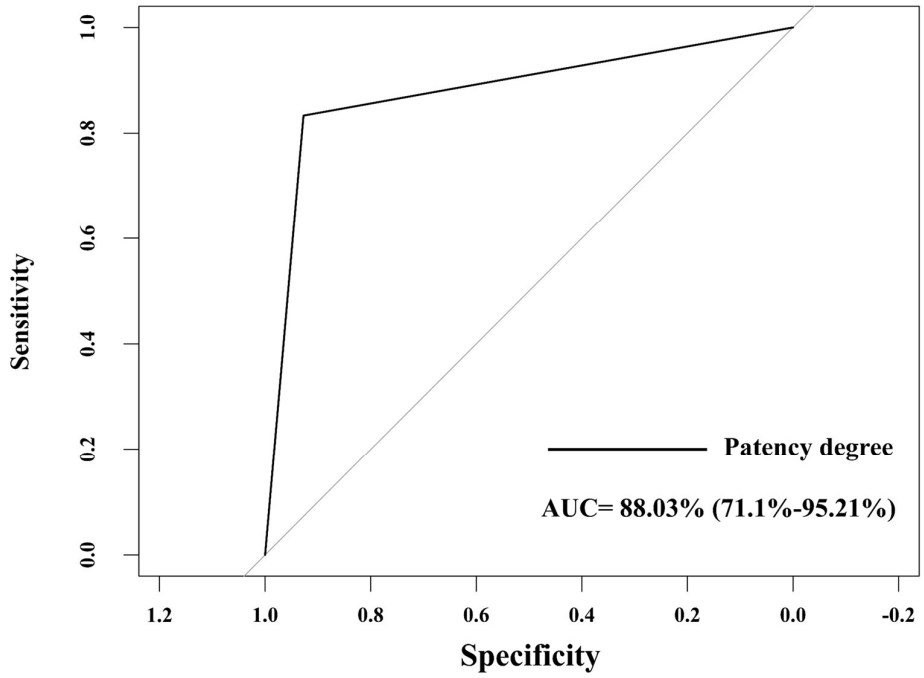
SUPPL. TAB 1. The patency of the sinus was assessed based on the Cognard classification and Borden grade.

	Pre-embolization (N = 117)				Post-embolization (N = 117)				Follow-up (N=91)			
Ipsilateral sinovenous	Patency (n=27)		Stenosis or occlusion (n=90)		Patency (n=29)		Stenosis or occlusion (n=88)		Patency (16)		Stenosis or occlusion (n=75)	
Contralateral sinovenous	Patency (n=23)	Stenosis or occlusion (n=24)	Patency (n=69)	Stenosis or occlusion (n=21)	Patency (n=20)	Stenosis or occlusion (n=9)	Patency (n=72)	Stenosis or occlusion (n=16)	Patency (n=10)	Stenosis or occlusion (n=6)	Patency (n=59)	Stenosis or occlusion (n=16)
Cognard												
I	7	1	9	2	7	2	9	1	3	2	7	1
IIa	9	0	12	2	6	0	15	2	3	0	15	2
IIb	2	0	4	0	2	0	4	0	1	0	4	0
IIa+b	5	3	44	17	5	7	44	13	3	4	33	13
Borden												
I	16	1	21	4	13	2	24	3	6	2	22	3

II	7	3	48	17	7	7	48	13	4	4	37	13



SUPPL. FIG 2. Tendency in mRS score of pre-operation and clinical follow-up in patients. Changes in mRS score greater than one point were considered to indicate worse or better.



SUPPL. FIG 2. ROC curve assessing contralateral sinus patency as a predictor of favorable functional outcome in the LS-DAVFs subgroup with ipsilateral sinus stenosis or occlusion.