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ORIGINAL ARTICLE

Safety and Efficacy of LVIS Jr Stent-assisted Coiling of Intracranial Aneurysms in Small-diameter Parent Arteries

A Single-center Experience

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Abstract

Objective To investigate the safety and efficacy of LVIS Jr stent-assisted coiling (SAC) of intracranial aneurysms (IAs) in small-diameter parent arteries and determine the factors influencing incomplete aneurysm occlusion.

Material and Methods Clinical and imaging data of 130 patients with IAs in small-diameter parent arteries that were treated with LVIS Jr SAC were retrospectively analyzed. Stent apposition was evaluated by high-resolution flat detector CT, and aneurysm embolization density was evaluated using 2D-DSA. Perioperative complications were recorded. Multivariate logistic regression analyses were performed to determine possible factors for incomplete aneurysm occlusion.

Results In this study, 130 patients (60 and 70 patients with ruptured and unruptured aneurysms, respectively) were successfully treated with LVIS Jr SAC. Immediate digital subtraction angiography (DSA) showed that the aneurysm occlusion was Raymond-Roy class I, II, IIIa, and IIIb in 93 (71.5%), 24 (18.5%), 8 (6.2%), and 5 (3.8%) cases, respectively. There were three cases of acute in-stent thrombosis and two cases of severe vasospasm observed during the perioperative period. The 6-month follow-up angiograms indicated that complete aneurysm occlusion in 122 patients was 79.5% (97/122). Multivariate logistic regression analyses showed that an aneurysm size >10.0 mm, parent artery mean diameter <2.0 mm, and incomplete stent apposition at the aneurysm neck were possible risk factors for incomplete aneurysm occlusion.

Conclusion The LVIS Jr SAC is effective for managing IAs in small-diameter parent arteries. An aneurysm size >10.0 mm, parent artery mean diameter <2.0 mm, and incomplete stent apposition at the aneurysm neck are possible risk factors for incomplete aneurysm occlusion.

Keywords LVIS Jr stent · Aneurysm occlusion · Stent-assisted coiling · Complications · Stent apposition

Abbreviations

FD	Flow diverter
HR-FDCT	High-resolution flat detector computed tomography
IA	Intracranial aneurysm
LVIS Jr	Low-profile visualized intraluminal support junior
SAC	Stent-assisted coiling

Introduction

The widespread application of flow diverters (FDs) in interventions for managing intracranial aneurysms poses a seri-

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ous challenge to traditional stent-assisted coiling (SAC) [1]; however, the emergence of FDs does not signify the end of SAC. The advantages afforded by the use of FDs in the management of acutely ruptured aneurysms and vascular bifurcation aneurysms have not been fully confirmed and stent plus coil remains the first-line choice for clinical application [2, 3]. Unlike that in FDs, the metal trabeculae of conventional intracranial aneurysm stents (such as the Neuroform EZ [Styker, Kalmazoo, MI, USA] and Enterprise [Johnson and Johnson, New Brunswick, NJ, USA] stents) cannot be easily observed under digital subtraction angiography (DSA) fluoroscopy. In some small-diameter parent arteries, the limited vessel diameter and the strut thickness of stents make it difficult to detect incomplete stent apposition, which is the main cause of acute in-stent thrombosis, long-term in-stent restenosis, and other adverse events [4, 5].

The low-profile visible intraluminal support device junior (LVIS Jr, MicroVention Terumo, Tustin, CA, USA) represents a new generation of self-expanding nickel-titanium braided closed-cell stents. It is available with diameters of 2.5 and 3.5 mm in the native state and can be released through a 0.017-inch microcatheter (Headway-17, MicroVention Terumo, Tustin, CA, USA). Owing to its excellent flexibility, full-length visualization design, and high metal coverage (15–18%), it has been widely used in the SAC of intracranial aneurysms (IAs) [6, 7].

However, there are few clinical studies on the efficacy and complications of LVIS Jr SAC of IAs in small-diameter parent arteries, and the factors influencing incomplete aneurysm occlusion have not been sufficiently explored [8]. In this study, we investigated the efficacy and safety of LVIS Jr SAC of IAs in small-diameter parent arteries and analyzed the factors influencing incomplete aneurysm occlusion, with the aim of providing scientific guidance on the SAC of IAs in small-diameter parent arteries.

Material and Methods

Participants

Clinical and imaging data of patients with IAs who were treated with LVIS Jr SAC at our center from January 2022 to February 2023 were retrospectively analyzed. The inclusion criteria were as follows: IAs (both ruptured and unruptured) diagnosed by DSA and treated with LVIS Jr SAC. The exclusion criteria were as follows: 1) simultaneous use of FDs or multiple overlapping stents, 2) combined use of embolic materials other than coils, such as liquid embolic agents (e.g., Onyx®) and 3) combined use of surgical closure.

Clinical and imaging data of enrolled patients were collected, including basic information (e.g., sex, age, preoperative comorbidities, and preoperative mRS score), parent artery characteristics (e.g., mean diameter and diameter ratio), and aneurysm characteristics (e.g., location, size, and dome-to-neck ratio). The mean diameter of the parent artery was defined as the average value of three vessels in the aneurysm neck and beyond 5 mm at both ends. The diameter ratio of the parent artery was defined as the ratio of the diameter of the larger vessel to that of the narrower vessel.

Interventional Procedures

Stent implantation was completed using an angiography system (Artis Zeego, Siemens, Munich, Germany) capable of high-resolution flat detector CT (HR-FDCT), and image postprocessing was performed using the associated workstations (Syngo Workplace and InStudio 3D, Siemens, Munich, Germany). The perioperative medication, aneurysm embolization, and LVIS Jr stent implantation have been described previously [7, 9, 10]. The immediate aneurysm occlusion density and the angles of stenting were evaluated based on 2D-DSA at the working position. The aneurysm occlusion density was evaluated using the modified Raymond-Roy classification as follows [11]: class I complete obliteration; class II residual neck; class IIIa residual aneurysm with contrast within coil interstices and class IIIb residual aneurysm with contrast along the aneurysm wall. The angles of stenting were defined as the angles formed by the extension lines at the two ends of the stent by selecting an appropriate angle to fully deploy the stent.

The HR-FDCT scanning of the stent placement area was performed to observe whether the stent was completely deployed and detect any local deformities or distortions. After stent implantation, HR-FDCT was performed with low-concentration contrast agents and the stent apposition was assessed according to reconstructed images. The parameters and specific procedures for scanning using low-concentration contrast agents were described previously [12]. For patients who did not undergo scanning with low-concentration contrast agents, the HR-FDCT scanning information and 5s-DSA 3D imaging were imported into the postprocessing workstation. Dual-volume imaging technique was used to obtain dual volume reconstructed images of the stent, blood vessel, and vessel wall to assess stent apposition. The parameters and specific procedures for dual volume reconstruction scanning have been described previously [13].

Stent apposition was evaluated by two experienced neurointerventionalists and one imaging physician. The three professionals resolved any discrepancies in opinion by consulting with each other. With reference to the criteria of Li et al. [14] and Kato et al. [15], stent apposition was catego-

rized into complete apposition and incomplete apposition. Incomplete stent apposition was further classified into three types: type I proximal or distal incomplete stent apposition; type II local "crescent" incomplete stent apposition; type III incomplete deployment in long stent segments.

Complications and Follow-up

The perioperative complications were observed and recorded. Serious complications were defined as acute in-stent thrombosis, embolism dislodgement resulting in distal vascular embolization, parenchymal hemorrhage, or aneurysm rerupture hemorrhage. Postoperative outpatient follow-up or follow-up over the telephone was performed regularly, and the patients' neurological function after aneurysm embolization was evaluated using the mRS. The stent patency rate was observed at the 6-month postoperative DSA follow-up, and the complete occlusion rate of aneurysms was evaluated using modified Raymond-Roy classification.

Factors Influencing Incomplete Aneurysm Occlusion

The patients who underwent HR-FDCT were divided into a complete occlusion group (RR I) and an incomplete occlusion group (RR II, IIIa, and IIIb) according to the results of the 6-month DSA follow-up. The differences in general data between the two groups were analyzed and compared. For patients with incomplete aneurysm occlusion, with reference to the relevant literature [16–18] and based on clinical experience, univariate analysis was performed for the risk factors that might affect aneurysm occlusion, such as the parent artery diameter ratio, parent artery mean diameter, aneurysm size, the angles of stenting, stent apposition, and subarachnoid hemorrhage. Factors with a P-value <0.05 in the univariate analysis were included in the multivariate logistic regression analysis to determine the possible factors influencing incomplete aneurysm occlusion.

Statistical Analysis

Statistical analysis was performed using SPSS 26.0 (IBM, Armonk, NY, USA) software. Quantitative variables are expressed as mean ± standard deviation and were compared between groups using the Student's t-test. Categoric variables are presented as numbers with percentages and were compared between groups by using the χ^2-test or Fisher's exact test. Univariate analysis was used to determine the predictors of incomplete aneurysm occlusion, and factors with a P-value of <0.05 were included in the multivariate logistic regression analysis for further analysis. A P-value of <0.05 was considered statistically significant.

Table 1 Basic information and interventional treatment of the patients ($n = 130$)

Variable	Value
Sex (n [%])	
Male	48 (36.9)
Female	82 (63.1)
Age (years, [$\overline{x} \pm s$])	58.95 ± 9.69
Preoperative comorbidities (n, %)	
Hypertension	76 (58.5)
Diabetes	23 (17.7)
Hyperlipidemia	25 (19.2)
Smoking	31 (23.8)
Preoperative mRS score (n, %)	
0–2	103 (79.2)
3–5	27 (20.8)
Subarachnoid hemorrhage (n, %)	60 (46.2)
Hunt-Hess[a] clinical grade (n, %)	
I	25 (41.7)
II	22 (36.7)
III	13 (21.7)
Aneurysm size	
Aneurysm dome (mm, [$\overline{x} \pm s$])	5.78 ± 2.27
Aneurysm neck (mm, [$\overline{x} \pm s$])	4.32 ± 1.63
Dome-to-neck ratio ($\overline{x} \pm s$)	1.41 ± 0.47
Ascus (n, %)	41 (31.5)
Aneurysm location (n, %)	
AcomA	44 (33.8)
M1 bifurcation	30 (23.1)
ICA C7	20 (15.4)
A2	17 (13.1)
V3-V4	12 (9.2)
Basilar tip/P1	7 (5.4)
Immediate aneurysm occlusion (n, %)	
RR I	93 (71.5)
RR II	24 (18.5)
RR IIIa	8 (6.2)
RR IIIb	5 (3.8)
Parent artery mean diameter (mm, $\overline{x} \pm s$)	2.34 ± 0.46
Parent artery diameter ratio (ratio, $\overline{x} \pm s$)	1.13 ± 0.08
Parent artery stenosis (n, %)	19 (14.6)
Stent size (n, %)	
2.5 mm * 23 mm	89 (68.5)
3.5 mm * 23 mm	41 (31.5)
Mean coils ($\overline{x} \pm s$)	5.93 ± 3.41
Angle of stenting (°, [$\overline{x} \pm s$])	57.34 ± 10.72

mRS modified Rankin Scale, *AcomA* anterior communicating artery, *ICA* internal carotid artery, *RR* modified Raymond-Roy classification
[a]Hunt-Hess clinical grade of the aneurysm

Results

Patients and Aneurysms

Overall, 130 patients (60 ruptured and 70 unruptured aneurysms) met the enrolment criteria and were included in this study. Of the patients 20 were excluded including 15 who were treated with concomitant surgical closure or other brands of stents for multiple aneurysms and 5 who were considered to have dissecting aneurysms treated with overlapping double stent implantation or FD implantation. Of the 130 patients 48 (36.9%) were male and 82 (63.1%) were female. The mean age was 58.95 ± 9.69 years. The details are described in Table 1.

Interventional Therapy Outcomes

A total of 130 patients underwent successful LVIS Jr SAC of IAs (technical success rate: 100%) and LVIS Jr stents 23 mm in length and with a diameter of 2.5 mm (89 cases) or 3.5 mm (41 cases) were selected. The mean diameter of the parent artery was 2.34 ± 0.46 mm (Fig. 1). The modified Raymond-Roy classification of aneurysm occlusion as shown by immediate postoperative DSA was as follows: RR I, 93 cases (71.5%); RR II, 24 cases (18.5%); RR IIIa, 8 cases (6.2%); and RR IIIb, 5 cases (3.8%). The details are described in Table 1.

Complications and Follow-up Outcomes

During the perioperative period, acute in-stent thrombosis was noted in three patients in whom the thrombus disappeared after direct intra-arterial thrombolysis (urine plasminogen activator and tirofiban), after which the blood flow was restored. The patients were discharged without residual neurological symptoms. Two patients with a ruptured aneurysm developed severe vasospasm of the parent arteries during the operation, which was relieved after slow per-

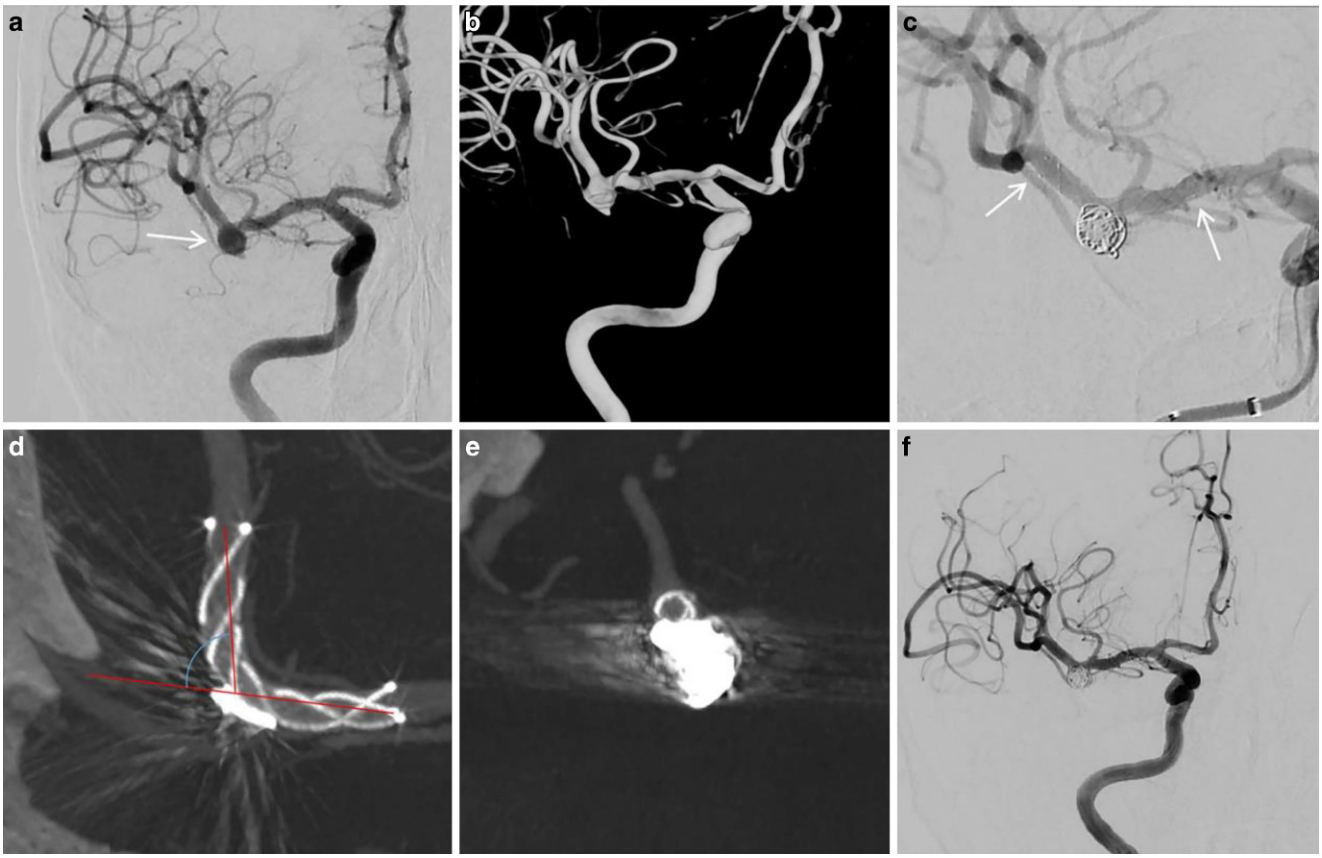

Fig. 1 LVIS Jr stent for the treatment of a ruptured aneurysm in the M1 segment of the right middle cerebral artery **a** 2D-DSA and **b** 3D-DSA suggest an aneurysm in the M1 segment of the right middle cerebral artery, measuring 3.5 × 3.8 mm, with a neck of 2.7 mm, dome-to-neck ratio of 1.41, and distal and proximal parent artery diameters of 2.4 and 2.3 mm, respectively (*white arrow* shows the aneurysm). **c** The aneurysm was treated with SAC by using a 2.5 × 23 mm LVIS Jr stent. The postoperative imaging showed that the aneurysm occlusion was Raymond-Roy class I (*white arrows* show the head and tail end of the stent). **d** HR-FDCT showed that the stent was fully deployed and complete apposition; the angle of stenting was 78.92°. **e** HR-FDCT imaging at the aneurysm neck showed complete apposition of the LVIS Jr stent and satisfactory protection of the coils. **f** Postoperative 6-month imaging showed that the aneurysm was satisfactorily embolized without recurrence, while the in-stent blood flow was smooth without significant stenosis

Table 2 Perioperative complications and follow-up outcomes($n = 122$)

Variable	Value
Perioperative complications (n, %)	
Acute in-stent thrombosis	3 (2.5)
Severe vasospasm	2 (1.6)
Mean follow-up duration (months, $\overline{x} \pm s$)	9.04 ± 2.18
mRS score at the last follow-up (n, %)	
0–2	119 (97.5)
3–5	3 (2.5)
Follow-up aneurysm occlusion (n, %)	
RR I	97 (79.5)
RR II	16 (13.1)
RR IIIa	6 (4.9)
RR IIIb	3 (2.5)

mRS modified Rankin Scale, *RR* modified Raymond-Roy classification

fusion of nimodipine and papaverine; the operations were successfully completed. No other complications such as aneurysm rupture hemorrhage, thromboembolism, or stent and coil migration occurred in the remaining patients.

Of the patients 122 received clinical follow-up; the average follow-up duration was 9.04 ± 2.18 months. Regarding the remaining 8 patients, 6-month DSA follow-up data were unavailable for these patients or they were lost to follow-up. The follow-up showed that 119 patients (97.5%) had a good prognosis and 3 had residual neurological deficits (mRS score of 3). DSA follow-up for approximately 6 months showed the modified Raymond-Roy classification of aneurysm occlusion as follows: RR I, 97 cases (79.5%); RR II, 16 cases (13.1%); RR IIIa, 6 cases (4.9%); and RR IIIb, 3 cases (2.5%). The complete occlusion rate was 79.5% (97/122) for the aneurysms in these patients. One patient with an anterior communicating artery aneurysm showed recurrence due to compression

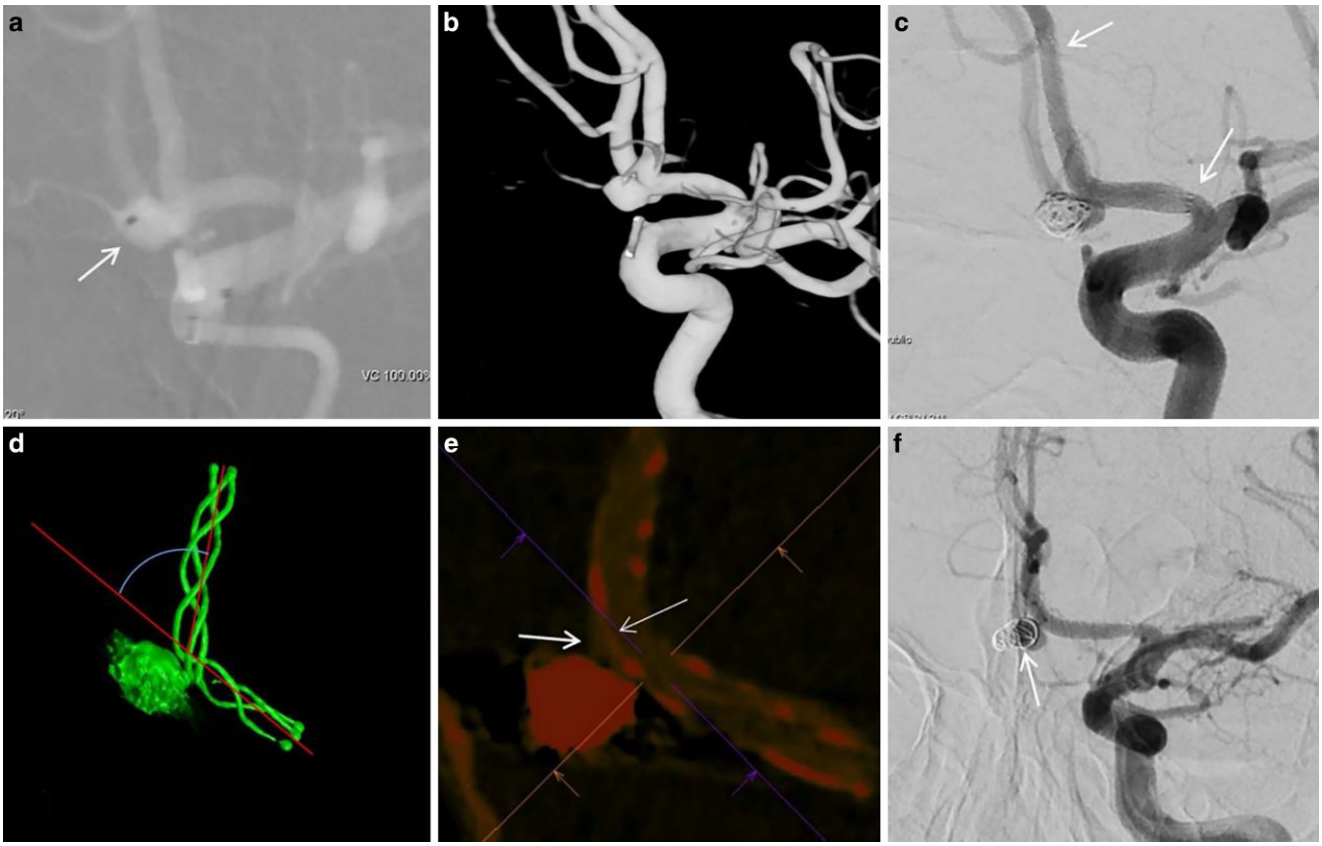

Fig. 2 LVIS Jr stent for the treatment of an unruptured aneurysm in the anterior communicating artery **a** 2D-DSA and **b** 3D-DSA suggest an anterior communicating artery saccular aneurysm, measuring 3.8 × 3.2 mm, with a neck of 2.1 mm, dome-to-neck ratio of 1.81, and distal and proximal parent artery diameters of 2.3 and 2.5 mm, respectively (*white arrow* shows the aneurysm). **c** The aneurysm was treated with SAC by using a 2.5 × 23 mm LVIS Jr stent, and postoperative imaging showed that the aneurysm occlusion was Raymond-Roy class I (*white arrows* show the head and tail end of the stent). **d** HR-FDCT showed that the stent was fully deployed and complete apposition, and the angle of stenting was 61.63°. **e** Volumetric roaming technique (VRT) reconstruction of an HR-FDCT scan showed a type II "crescent" incomplete stent apposition in the greater curvature of the aneurysm neck (*thin white arrows* show the braided filaments of the stent and *thick white arrows* show the incomplete apposition in the endovascular lumen). **f** Postoperative 6-month imaging showed compression of the intra-aneurysmal coils and recurrence of the aneurysm (*white arrow*)

Table 3 Univariate analysis for incomplete aneurysm occlusion with LVIS Jr SAC ($n = 66$)

Variable	Complete occlusion group ($n = 53$)	Incomplete occlusion group ($n = 13$)	*P*-value
Sex (n [%])			
Male	18 (34.0)	5 (38.5)	0.756[c]
Female	35 (66.0)	8 (61.5)	
Age (years, [$\overline{x} \pm s$])	60.62 ± 8.54	56.46 ± 10.48	0.137[a]
Preoperative comorbidities (n, %)			
Hypertension	32 (60.4)	9 (69.2)	0.752[c]
Diabetes	9 (17.0)	1 (7.7)	0.672[c]
Hyperlipidemia	7 (13.2)	1 (7.7)	1.000[c]
Smoking	11 (20.8)	3 (23.1)	1.000[c]
Preoperative mRS score (n, %)			
0–2	43 (81.2)	10 (77.0)	0.891[c]
3–5	10 (18.9)	3 (23.1)	
Subarachnoid hemorrhage (n, %)	24 (45.3)	10 (76.9)	0.041[b]
Hunt-Hess clinical grade (n, %)			
I	10 (41.7)	4 (40.0)	0.277[c]
II	10 (41.7)	2 (20.0)	
III	4 (16.7)	4 (40.0)	
Parent artery stenosis (n, %)	5 (9.4)	5 (38.5)	0.020[c]
Parent artery diameter ratio ($\overline{x} \pm s$)	1.13 ± 0.07	1.18 ± 0.10	0.083[a]
Parent artery mean diameter (n, %)			
> 2.0 mm	40 (75.5)	5 (38.5)	0.018[c]
< 2.0 mm	13 (24.5)	8 (61.5)	
Aneurysm dome (n, %)			
> 10.0 mm	3 (5.7)	5 (38.5)	0.006[c]
< 10.0 mm	50 (94.3)	8 (61.5)	
Aneurysm neck (n, %)			
> 4.0 mm	20 (37.7)	7 (53.8)	0.290[b]
< 4.0 mm	33 (62.3)	6 (46.2)	
Dome-to-neck ratio (n, %)			
> 2	6 (11.3)	4 (30.8)	0.098[c]
< 2	47 (88.7)	9 (69.2)	
Ascus (n, %)	13 (24.5)	7 (53.8)	0.050[c]
Aneurysm location (n, %)			
AcomA	15 (28.3)	6 (46.2)	0.251[c]
M1 bifurcation	12 (22.6)	3 (23.1)	
ICA C7	10 (18.9)	0 (0)	
A2	8 (15.1)	1 (7.7)	
V3-V4	6 (11.3)	1 (7.7)	
Basilar tip/P1	2 (3.8)	2 (15.4)	
Immediate aneurysm occlusion (n, %)			
Complete occlusion (RR I)	41 (77.4)	5 (38.5)	0.015[c]
Incomplete occlusion (RR II, IIIa, IIIb)	12 (22.6)	8 (61.5)	
Angle of stenting (°, [$\overline{x} \pm s$])	52.47 ± 12.13	58.74 ± 9.61	0.088[a]
Stent apposition (n, %)			
Complete stent apposition	49 (92.5)	8 (61.5)	0.011[c]
Incomplete stent apposition (I, II, III)	4 (7.5)	5 (38.5)	

mRS modified Rankin Scale, *AcomA* anterior communicating artery, *ICA* internal carotid artery, *RR* modified Raymond-Roy classification
[a]Student's t test
[b]χ^2-test
[c]Fisher's exact test

Table 4 Multivariable logistic analysis for incomplete aneurysm occlusion with LVIS Jr SAC

Variable	Odds ratio	95% Wald CI	*P*-value
Subarachnoid hemorrhage	4.100	0.567–29.659	0.162
Parent artery stenosis	6.351	0.537–75.071	0.142
Parent artery mean diameter of < 2.0 mm	8.997	1.259–64.275	0.029
Aneurysm dome of > 10.0 mm	18.301	2.014–166.337	0.010
Ascus	1.318	0.196–8.875	0.777
Immediate aneurysm occlusion	0.296	0.045–1.957	0.206
Stent apposition	9.401	1.267–69.747	0.028

of the coils in the aneurysm lumen, and follow-up observation was performed for this patient because the family refused further treatment (Fig. 2). In addition, three patients had mild in-stent stenosis but no stent occlusion and did not receive any intervention. The details are described in Table 2.

Factors Influencing Incomplete Aneurysm Occlusion

According to whether aneurysm occlusion was complete during the 6-month follow-up, 66 patients who underwent HR-FDCT were divided into a complete occlusion group ($n = 53$) and an incomplete occlusion group ($n = 13$). There were no significant differences in clinical data between the two groups, in terms of parameters such as patient sex, age, preoperative comorbidities, preoperative mRS score, and aneurysm location (all *P*-values > 0.05) (Table 3). Univariate analysis showed that subarachnoid hemorrhage, parent artery stenosis, parent artery mean diameter, aneurysm size, ascus, immediate aneurysm occlusion, and stent apposition at the aneurysm neck were predictor factors influencing incomplete aneurysm occlusion (all *P*-values < 0.05) (Table 3). Multivariate logistic regression analysis of these factors revealed that an aneurysm size > 10.0 mm, parent artery mean diameter < 2.0 mm, and incomplete stent apposition at the aneurysm neck were possible risk factors for incomplete aneurysm occlusion (Table 4).

Discussion

The results of this study indicated that LVIS Jr stent deployment and apposition were satisfactory in parent arteries with a diameter of < 2 mm. Furthermore, the stent protected the coils at the aneurysm neck and demonstrated an excellent performance. Furthermore, the immediate aneurysm occlusion rate was 71.5% (93/130), which was generally consistent with the results of previous studies [8, 10, 11]. The LVIS Jr stent has high metal coverage (15–18%) and small cell size (< 1.5 mm) and is thus protective for the aneurysm neck and improves the rate of complete occlusion. Regarding the occlusion of small aneurysms, in particular, the LVIS Jr stent effectively prevents the escape of smaller coils during the procedure. The aneurysm neck metal coverage can be increased to 35% by the lantern and push-pull techniques, which play an almost blood flow-diverting role, thereby producing more pronounced hemodynamic effects and improving the healing rate of aneurysms [19–21]. Several studies have shown that the LVIS Evo stent can also accurately and safely reach the distal tortuous intracranial artery and has better visibility. Nevertheless, the metal coverage rate of up to 28% also makes it difficult to re-cross the stent, which may increase the incidence of ischemic complications [22, 23]. Further studies are needed to confirm the differences in efficacy and performance between the LVIS Jr and LVIS Evo stents.

In the present study, the perioperative complication rate associated with the LVIS Jr stent was 4.1%, which was similar to that in clinical studies of general LVIS SAC of IAs [22, 24]. Despite the majority of LVIS Jr stents being implanted into parent arteries with a diameter of < 2 mm in this study, the rate of ischemic complications was not significantly high. This may be related to better stent deployment and apposition in parent arteries with a diameter of < 2 mm, which was confirmed by HR-FDCT findings. In addition, all patients underwent preoperative antiplatelet pharmacogenetic testing and an individualized antiplatelet regimen was used, which was another reason for the low incidence of ischemic complications. There were three cases of intraoperative acute in-stent thrombosis, which occurred in patients with atherosclerotic stenosis of the parent artery. These may be attributable to the presence of atherosclerotic stenosis making complete stent apposition difficult, and the formation of eddy currents between the stent and the vessel wall, resulting in the microthrombus.

The 6-month DSA follow-up showed that the long-term complete occlusion rate of aneurysms in our patients reached 79.5%, which was significantly higher than that in previous studies, such as those by Wang et al. [11] and Lauzier et al. [25] who reported complete occlusion rates of aneurysms of 65.0% and 64.8%, respectively. It is hypothesized that on the one hand, it might be associated with lower blood pressure in parent arteries with a diameter of < 2 mm and the lumen of coil-filled aneurysms being more

prone to thrombus formation. On the other hand, it might be related to the blood flow-directing effect of the denser cells and the higher metal coverage of the LVIS Jr stent. In 66 patients who underwent HR-FDCT, the possible factors affecting incomplete aneurysm occlusion were further analyzed by multivariate logistic regression analysis, which showed that an aneurysm size of >10.0 mm, parent artery mean diameter <2.0 mm, and incomplete stent apposition at the aneurysm neck were possible factors influencing incomplete aneurysm occlusion; however, the sample size for multivariate analysis was small, and only 13 aneurysms were incompletely occluded, which could not fully meet the principle of 10 events per variable. Therefore, the results may not be robust enough for multivariate analysis and need to be further verified using larger samples; however, we believe the results still have some guiding significance.

There were 5 cases (38.5%) in which the aneurysm size was >10.0 mm in patients with incomplete aneurysm occlusion. The reason may be the fact that the metal coverage of LVIS Jr stent, although 15–18%, is still insufficient to change the hemodynamics of larger aneurysms. Secondly, larger aneurysms are mostly wide-neck aneurysms, and the coils in the aneurysm lumen are prone to compression due to the impact of the blood flow. Furthermore, the occurrence of inflammatory reactions leads to further expansion of the residual aneurysm lumen owing to thrombolysis, thus leading to long-term incomplete aneurysm occlusion. Therefore, for larger aneurysms, the metal coverage of the aneurysm neck should be increased as much as possible by using the push-pull or lantern techniques to minimize the impact of blood flow. Parent artery mean diameter of <2.0 mm is a possible risk factor for incomplete aneurysm occlusion. The reason may be the fact that the LVIS Jr stent is mostly recommended in vessels with a diameter of 2–3 mm. Because of its braiding properties, the stent is extruded and stretched during its release in vessels with a diameter of <2.0 mm, resulting in decreased metal coverage, increased cell size, and weakened blood flow-diverting effect. These factors have a low impact on intra-aneurysmal hemodynamics, thus causing long-term incomplete aneurysm occlusion. Furthermore, several clinical studies have confirmed that stent apposition is closely related to the stent endothelialization process. Muhl-Benninghaus et al. [26] reported that in rabbit models of saccular aneurysms at the aortic arch that were treated with FDs, stent apposition was observed on intraprocedural 2D-DSA and histopathological testing. The results indicated that whether the stent apposition was complete or not was closely correlated with aneurysm occlusion. Although the LVIS Jr stent with its braided design had significantly improved stent apposition compared with the laser-cut stents, in this study, we found that a larger parent artery diameter ratio and the angles of stenting still resulted in a certain degree of incomplete stent apposition, thereby affecting the stent endothelialization process at the aneurysm neck and incomplete occlusion of aneurysms. These findings suggest that we should still pay great attention to LVIS Jr stent apposition in aneurysms with larger angles or diameter ratios of the parent arteries, and if necessary, push-pull or microguidewire massage should be employed to enhance stent apposition.

Our study has several limitations. First, this study is a single-center retrospective study and there is a selection bias for stents and coils. A multicenter prospective randomized controlled study is required to further confirm their safety and efficacy. Second, the sample size of this study is small and does not fully satisfy the requirements of events per variable. Therefore, the results may not be sufficiently robust and their reliability needs to be corroborated in further studies. Third, it was not possible to standardize and systematically evaluate the activated prothrombin time in each enrolled patient, which may have an impact on the study results. Fourth, the follow-up period was short, and long-term DSA results after SAC were not observed.

Conclusion

The LVIS Jr SAC is effective for the management of IAs in small diameter parent arteries. An aneurysm size >10.0 mm, parent artery mean diameter <2.0 mm, and incomplete stent apposition at the aneurysm neck are possible risk factors influencing incomplete aneurysm occlusion.

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Declarations

Conflict of interest S. Shi, S. Long, F. Hui, Q. Tian, Z. Wei, J. Ma, J. Yang, Y. Wang, X. Han and T. Li certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical standards This retrospective observational study was approved by the ethics committee of our institution and complied with the 1964 Declaration of Helsinki and its later amendments or comparable ethical

standards. Informed consent was obtained from all individual participants included in the study.

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