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CASE REPORT

Endovascular treatment of intracranial blood blister-like aneurysms with the Willis covered stent: a case series

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Abstract

Background and purpose To evaluate the safety, feasibility, and effectiveness of the Willis covered stent (WCS) in treating blood blister-like aneurysms (BBAs).

Materials and methods Twenty-one consecutive patients with BBAs treated with the WCS were identified between July 2017 and July 2022. The demographic, clinical, and angiographic data and procedural-related complications were collected from the medical records and the operative reports.

Results The present study included six men and fifteen women, with a mean age of 51.6 years (31–70 years). The immediate postoperative angiography demonstrated that the complete occlusion rate was 100%, with no endoleak. Ophthalmic artery (OA) occlusion occurred in five patients (23.8%). One patient developed delayed stent thrombosis on the third postoperative day. The mean angiographic follow-up time was 9.2 months (range 3–21 months). All twenty-one BBAs were occluded entirely, and the patency of the parent arteries was preserved. No aneurysm rupture or recurrence was found, and no retreatment was needed. Two patients developed mild to moderate asymptomatic in-stent stenosis. The clinical follow-up time was 20.0 months (range 15–33 months). Twenty patients had an mRS score of zero, and one had an mRS score of one.

Conclusions Our series indicates that treating BBAs with WCSs was relatively safe and efficacious. However, the incidence of stent delivery failure and complications should not be neglected.

Keywords Endovascular treatment, Blood blister-like aneurysm, Willis covered stent, Case series

Introduction

Blood blister-like aneurysms (BBAs) are a particular type of aneurysm, accounting for approximately 0.9–6.6% of ruptured aneurysms and resulting in high morbidity and mortality [1]. They commonly arise from nonbranching internal carotid artery (ICA) sites. Histologically, BBAs are pseudoaneurysms, and their walls are only covered by fibrous tissue and adventitia, lacking both the intima and media [2].

The unique histological characteristics of BBAs pose significant challenges to neurosurgeons and neurointerventionists. The current treatment strategies include surgical and endovascular treatments. The BBA surgical treatments include clipping, suturing, wrapping, and trapping with or without bypass [3–5]. In contrast, the endovascular treatments include stent-assisted coiling, multiple overlapping stents, flow diverters, endovascular trapping, and covered stent treatment [6–9]. However,

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the ideal methodology for the management of BBAs remains uncertain.

A Willis-covered stent (WCS, MicroPort, Shanghai, China) has been used to treat complex carotid artery lesions, including pseudoaneurysms, carotid-cavernous fistulas, and giant aneurysms [10–13]. Unlike other covered stents such as Jostent (Abbott Vascular, IL, USA, GER) [14], WCS is a balloon-expandable stent designed explicitly for intracranial vessels. The WCS consists of three parts: a bare stent, an expandable polytetrafluoroethylene membrane, and a balloon catheter. The WCS is available in diameters ranging from 3.5 to 4.5 mm and lengths ranging from 7 to 16 mm.

Reports of the safety and efficacy of WCS for BBAs are scarce but some encouraging results have been shown [15–17]. This study presents our experiences treating BBAs by WCS implantation in 21 patients. The objective was to evaluate the safety, feasibility, and effectiveness of WCSs.

Materials and methods

Patient population

In this study, our institutional review board approved a retrospective review of our database to identify patients between July 2017 and July 2022 (Ethics approval number: L2023-Q253-002). Twenty-one consecutive patients with BBAs treated with the WCS were identified. Written informed consent was obtained from each patient.

Diagnostic criteria of BBAs

The diagnostic criteria for BBAs was similar to previous studies [17]: (1) located at nonbranching supraclinoid ICA sites; (2) a wide neck and a typical blister-like shape; (3) initially small (maximum diameter < 10 mm); (4) diagnosed after rupture and presented with SAH; (5) rapid growth (< 2 weeks) based on repeated angiograms; and (6) irregular wall of the aneurysm or the ICA. An aneurysm was diagnosed as a BBA when criteria 1–4 were met and either standard 5 or 6 was matched.

Endovascular procedure

Under general anesthesia, an 8 F–6 F-guiding catheter (Envoy MPC, Codman, Raynham, MA, USA) was introduced into the C1 segment of the ICA. A 0.072-in. or 0.058-in. Navien catheter (Covidien, Irvine, California, USA) was used as the intermediate catheter to achieve access close to the aneurysm. The Navien catheter was usually deployed over the neck of the aneurysm to acquire more support. Systematic heparinization was individually administered after sheath placement to maintain an activated clotting time of 250–350 s. A 0.014-inch Transcend microguidewire (Boston Scientific, USA) was navigated into the distal segment of the middle cerebral artery. The WCS was delivered through the Transcend microguidewire and was used to bridge the aneurysm orifice. Both sides of the stent should be at least 2 mm above the neck of the aneurysm. The stent diameter should be 0.5 mm larger than the parent artery [18]. Multiangle angiographies were obtained to confirm an optimal placement of the stent and avoid coverage of important side branches. The stent was then deployed, and the balloon was slowly inflated with a pressure of 5 atmospheres. We documented the deployment procedures of the WCS to the vessel wall using fluoroscopy. After the above steps, immediate DSA was performed to confirm that there was blockage of the aneurysm and that there was preservation of the essential side branches. If immediate angiography revealed the aneurysmal orifice was not wholly covered and rapid filling of the aneurysmal cavity, re-expansion of the stent was performed, or another WCS was deployed. However, no further treatment was performed if only slow and slight filling of the aneurysmal cavity was observed [19]. After surgery, unenhanced head CT and neurological examinations were performed to promptly exclude intracranial hemorrhage and ischemic events. Postoperative sedation and analgesia were continued, and blood pressure was strictly controlled at approximately 110/70 mmHg. Nimodipine is routinely used perioperatively to prevent vasospasm. However, if intraoperative vasospasm persists, the WCS is unsuitable. After the operation, the lumbar puncture was considered for patients with hydrocephalus and intraventricular hemorrhage.

Antiplatelet regimen

Before the procedure, no patients received antiplatelet therapy. In addition to full heparinization during the endovascular procedure, tirofiban was infused after the placement of the WCSs. Dual antiplatelet therapy was administered during the postoperative period, with 300 mg of aspirin and clopidogrel on the first day and then 100 mg aspirin and 75 mg clopidogrel daily for six months [20]. Then, drug adjustments were made according to the follow-up results. We measured the patients for an adequate platelet response by adenosine diphosphate (ADP) and arachnoid acid (AA) aggregation assays on postoperative day 7. According to the institutional standards, the clopidogrel and aspirin responses were considered adequate if the ADP-induced aggregation was < 70% (i.e., inhibition was > 30%) and the AA-induced aggregation was < 50% (i.e., inhibition was > 50%) [21]. The patients were given an additional medication dose if the platelet response was inadequate. Clopidogrel was replaced with ticagrelor 180 mg/day if there was consistent failure to achieve an adequate platelet response. The patients were instructed to take clopidogrel 75 mg/day (or ticagrelor 180 mg/day) for six months and aspirin 100 mg/day for one year to prevent thrombosis and stent stenosis [22]. No antiplatelet therapy is usually recommended after one year.

Baseline results and procedural results

Demographic, clinical, and angiographic data were collected from the medical records and the operative reports. The morphological characteristics of the aneurysms were determined by reviewing the digital subtraction angiography (DSA), including the shape, location, the largest diameter, and incorporated branch vessels. MRI and CT scans were performed 24 h postintervention. DSA was recommended at the 6-month follow-up. The patients who refused DSA underwent MR angiography (MRA) or CT angiography (CTA). The degree of aneurysm occlusion was assessed according to the 3-class Raymond scale (complete occlusion, neck remnant, and residual aneurysm). The functional outcome was recorded using the modified Rankin Scale (mRS) score. We also collected procedural-related complications, including arterial puncture complications, thromboembolic events, and hemorrhage complications. The initial clinical status of the patients was assessed by the Hunt and Hess grading system, and the clinical state at follow-up was evaluated by the mRS score.

Statistical analysis

Means with standard deviations were used to describe continuous variables, and frequency counts with proportions were used to describe categorical variables. All analyses were performed using SPSS version 23 (IBM, Armonk, New York).

Results

Baseline results

Twenty-one patients with BBAs treated with the WCS at our institute were enrolled between July 2017 and July 2022. The study included six men and fifteen women, with a mean age of 51.6 years (range 31–70 years). Of the twenty-one patients, the Hunt and Hess grades were 2 in fifteen patients, 3 in two patients, and 4 in four patients. The demographics, procedural characteristics, and follow-up data of the patients are summarized in Table 1.

Primary procedural results

Among the twenty-one patients, eighteen underwent single WCSs, and three underwent double WCSs. The implantation procedures were technically successful in all patients. The immediate postoperative angiography demonstrated that the complete occlusion rate was 100%, with no endoleak. Ophthalmic artery (OA) occlusion

Table 1 Demographic characteristics of 21 patients with blood blister-like aneurysm treated with Willis covered stent

Case no.	Sex / age (years)	Hunt and Hess grades	Location	Size (mm)	Stent size (mm)	Immediate angiographic result	Complication	angiographicFollow-uptime (months)	Final angiographic result	Clinical follow-up time (months)	mRS
1	F/68	4	RICA	3.7×3.1	3.5×10	Complete	No	21	Mild in-stent stenosis	33	0
2	M/57	2	LICA	3.2×3.5	3.5×13	Complete	No	4	Complete	16	0
3	F/57	2	LICA	3.3×4.2	3.5×10/4×10	Complete	OA occlusion	7	Complete	19	0
4	M/66	4	RICA	4.9×2.3	3.5×10	Complete	No	8	Complete	20	0
5	F/55	2	RICA	4.4×3.5	3.5×10	Complete	No	21	Mild in-stent stenosis	33	0
6	F/49	2	LICA	9.8×3.1	4×13	Complete	OA occlusion	3	Complete	16	0
7	M/41	2	RICA	4.5×2.6	4×7	Complete	No	6	Complete	20	0
8	F/51	2	LICA	2.8×2.6	3.5×7	Complete	No	9	Complete	22	0
9	F/33	2	RICA	3.3×2	3.5×10	Complete	No	12	Complete	24	0
10	F/52	2	RICA	9.6×5.6	3.5×10	Complete	No	16	Complete	16	0
11	F/52	3	RICA	3.9×3.9	3.5×10	Complete	No	12	Complete	21	0
12	F/45	2	LICA	4.5×2.7	3.5×10	Complete	No	6	Complete	17	0
13	M/42	3	LICA	6.0×3.2	4×10	Complete	OA occlusion	6	Complete	19	0
14	M/61	4	RICA	5.9×5.5	4×10	Complete	No	6	Complete	15	0
15	F/70	2	RICA	4.5×5.1	3.5×13	Complete	No	4	Complete	18	0
16	F/44	2	RICA	3.3×4.2	3.5×10/3.5×7	Complete	OA occlusion	12	Complete	24	0
17	M/49	2	RICA	5.5×4.7	4×10	Complete	No	10	Complete	20	0
18	F/31	2	LICA	5.6×4.4	4×10	Complete	No	6	Complete	19	0
19	F/58	2	LICA	3.3×3.2	4×7/4×10	Complete	Stent occlusion	15	Complete	15	1
20	F/59	2	RICA	4.0×3.1	4.5×10	Complete	No	4	Complete	18	0
21	F/44	2	RICA	3.5×2.0	4×10	Complete	OA occlusion	6	Complete	16	0

mRS, modified Rankin scale; LICA, left internal carotid artery; RICA, right internal carotid artery; OA, ophthalmic artery occurred in five patients (23.8%). The anterior choroidal artery (AChA) was well preserved in all patients. The WCS covered the posterior communicating artery in six patients, but none were fetal-type posterior cerebral arteries (PCAs).

Procedural complications

No procedural-related complications, such as aneurysm rupture, vasospasm, stent migration, and acute thrombosis, occurred during the operations. Although OA occlusion occurred in five patients, none of the patients had postoperative visual impairments due to adequate external carotid artery compensation. One patient developed delayed stent thrombosis on the third postoperative day. An emergency operation was performed to recanalize the occluded parent artery by combined interventional techniques, such as local thrombolysis via microcatheter and percutaneous transluminal angioplasty.

Follow-up results

The mean follow-up time was 9.2 months (range 3–21 months). All twenty-one BBAs were occluded entirely, and the patency of the parent arteries was preserved. No aneurysm rupture, retreatment, or recurrence was found. The mRS score of the patient who developed delayed stent thrombosis was two on discharge and one at the three-month follow-up. Two patients were seen with mild to moderate asymptomatic in-stent stenosis during the angiographic follow-up. It was recommended that they continue dual-antiplatelet therapy and regular follow-up. The clinical follow-up time was 20.0 months (range 15–33 months). Of the twenty-one patients, twenty had an mRS score of zero, and one had an mRS score of one. None of the five patients with OA occlusion had any visual impairments. Typical cases are shown in Figs. 1 and 2, and 3.

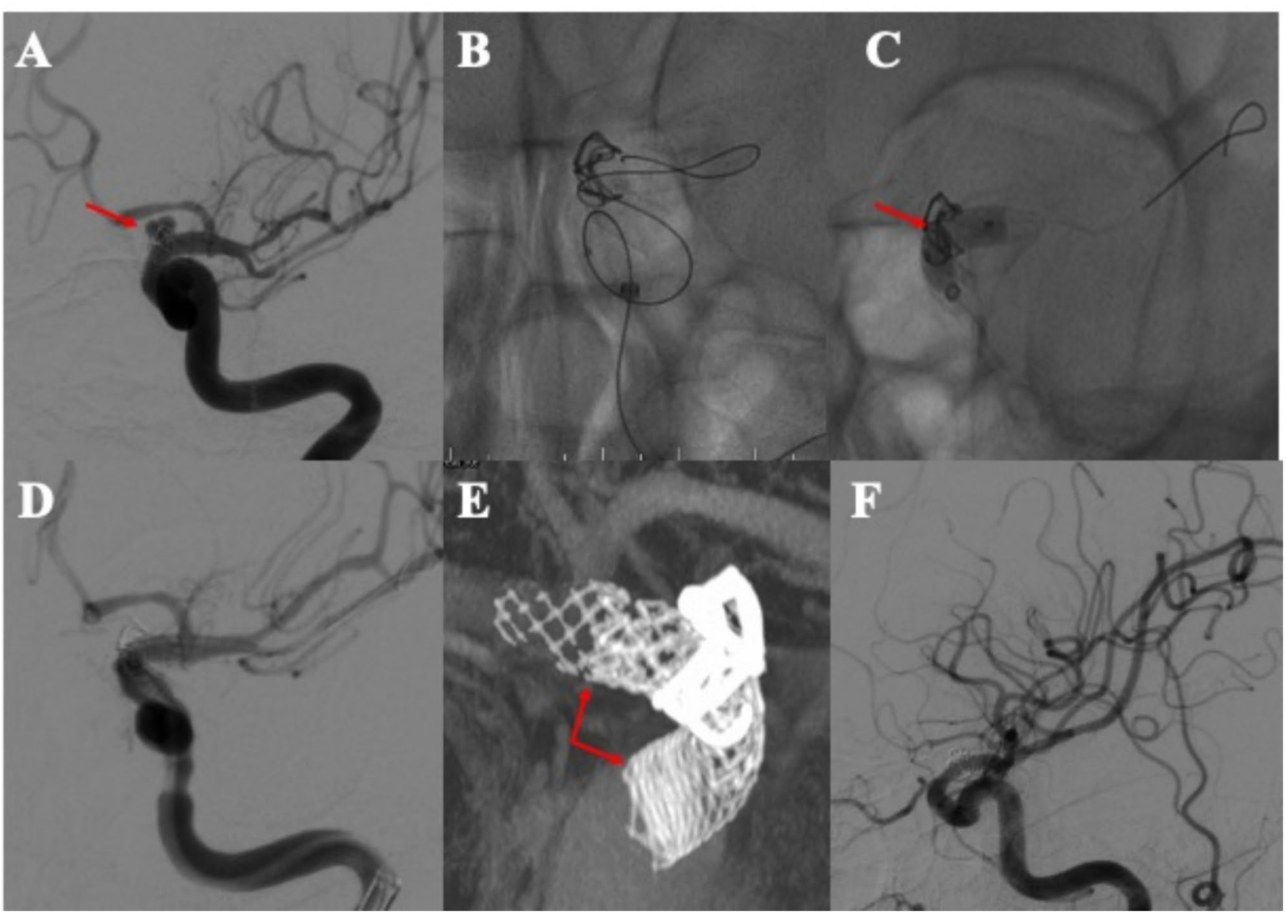

Fig. 1 An illustrative case of a 57-year-old man (patient no 2). (**A**) Preoperative angiography showed the location of the BBA. The red arrow indicates the aneurysm. (**B**) The aneurysm was embolized by the Enterprise stent-assisted coils during the first operation. (**C**) A Willis-covered stent (3.5 × 13 mm) was implanted at the target position guided by a microwire. (**D**) Immediate postprocedural angiography showed the complete occlusion of the BBA and the reconstruction of the ICA. (**E**) Xper-CT showed the reconstruction of the stent. Red arrows indicate the proximal and distal ends of the stent. (**F**) The 4-month follow-up digital subtraction angiography showed complete obliteration of the aneurysm with parent artery patency

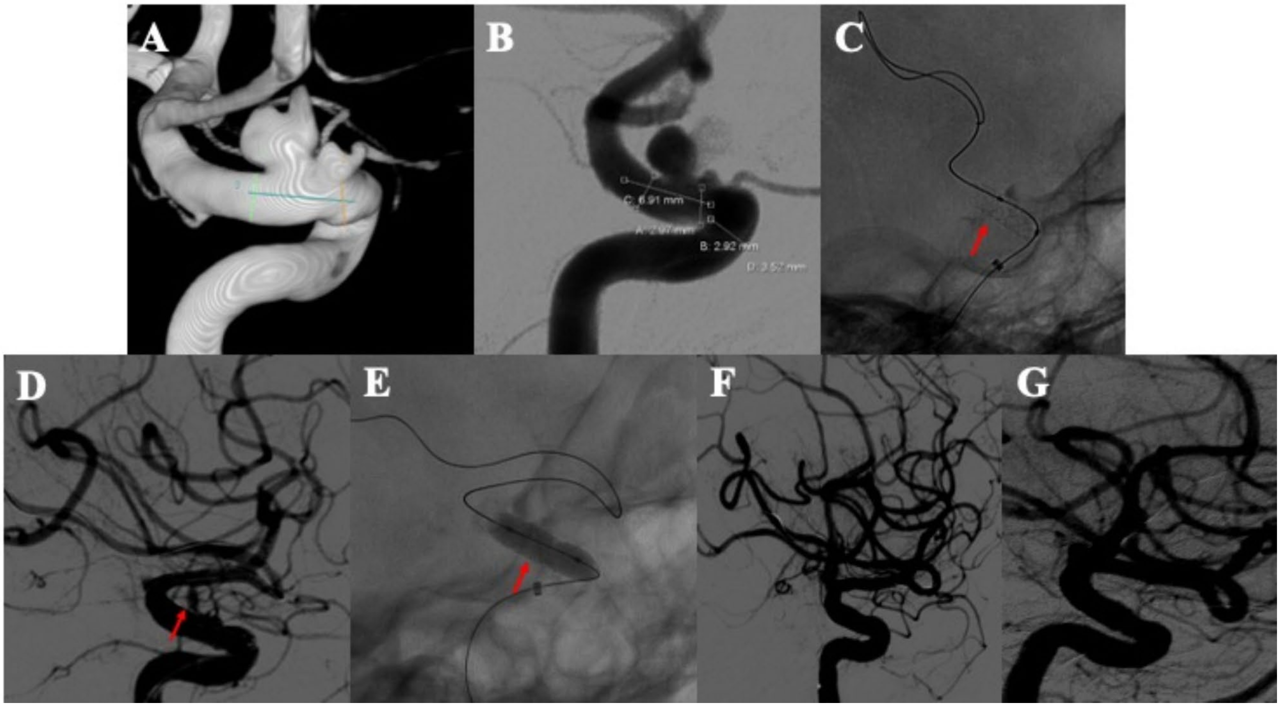

Fig. 2 An illustrative case of a 57-year-old woman (patient no 3). (**A**, **B**) Preprocedural digital subtraction angiography showed a blister aneurysm located at the dorsal wall of C6 segment of ICA. (**C**, **D**) After a WCS (3.5 × 10 mm) was deployed successfully, the instant angiographic revealed a persistent high-flow endoleak. The red arrow indicates the endoleak. (**E**) A second Willis-covered stent (4 × 10 mm) was implanted at the target position. (**F**) Immediate postprocedural angiography showed the complete occlusion of the BBA and the reconstruction of the ICA. (**G**) The 7-month follow-up digital subtraction angiography showed complete obliteration of the aneurysm with parent artery patency

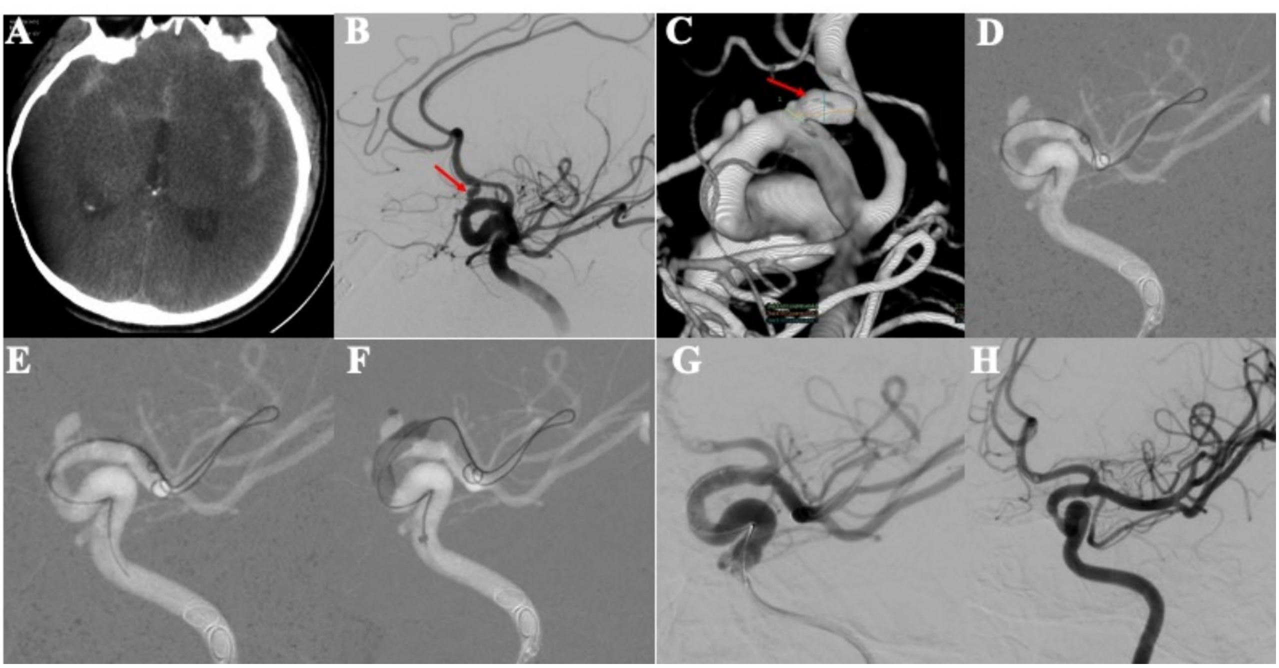

Fig. 3 An illustrative case of a 42-year-old man (patient no 13). (**A**) Brain CT showed SAH with Hunt and Hess grade III. (**B**, **C**) Preprocedural digital subtraction angiography showed a blister aneurysm located at the dorsal wall of the C6 segment of ICA. The red arrow indicates the aneurysm. (**D**) Under the roadmap, a support catheter was positioned in the M1 segment of the middle cerebral artery. (**E**, **F**) A Willis-covered stent (4 × 10 mm) was implanted at the target position guided by a microwire. (**G**) Immediate postprocedural angiography showed the complete occlusion of the BBA and the reconstruction of the ICA. (**H**) The 6-month follow-up digital subtraction angiography showed complete obliteration of the aneurysm with parent artery patency

Discussion

This study reported our experience with BBAs treated with WCSs. We obtained a high complete occlusion rate and favorable clinical outcomes, with a low incidence of complications. This study showed that the WCS effectively eliminates the lesion and repairs the parent artery perfectly, with satisfactory safety and efficacy. Some previous articles have demonstrated the safety and efficacy in treating BBAs with the WCS, and the results were similar to those of our case series.

Although numerous therapeutic strategies for managing BBAs have been suggested, there is still no optimal treatment. According to our experience, the advantages of the WCS include (1) a simple operation that is time-saving, and minimally invasive; (2) the immediate exclusion of lesions and reconstruction of the vascular wall; and (3) no embolization materials deployed into the aneurysm sac, which reduces rebleeding caused by aneurysm rupture during the operation [23]. Despite these advantages, WCSs still have limitations, such as a poor target arrival rate when passing them through tortuous intracranial vessels, a high endoleak incidence, and the possibility of side-branch occlusion, in-stent stenosis, and in-stent thrombosis.

The delivery process is an essential issue for the WCS graft procedure. Due to the unique design of the WCS, it is stiffer than the other bare-metal stents. Therefore, we still face some problems applying WCSs to the tortuous ICAs. They can damage the parent artery, causing severe vasospasm and even dissection. Chang et al. reported two cases of mild vasospasms and four instances of aggressive vasospasms during the WCS graft procedure [15]. Two patients with aggressive vasospasms were not relieved, which may lead to postoperative rebleeding. It may also lead to poor attachment of the stent, resulting in endoleak after the procedure [12]. A long sheath was selected to establish a stable pathway to get as close to the lesion as possible. We also used an intermediate catheter to navigate the WCS through tortuous ICAs. The support catheter was typically deployed over the neck of the aneurysm, and the microguidewire was placed in the distal part of the middle cerebral artery. For tortuous ICAs, we shaped the head segment of the intermediate catheter or used a thrombectomy stent to help the intermediate catheter pass over the neck of the aneurysm. Another treatment strategy may be needed if all attempts fail, and these strategies include multiple stent-assisted coil embolization and flow-diverter stents [6]. Therefore, one needs to consider the patient's vascular conditions before using the WCS.

Although the WCS had a high immediate complete occlusion rate, endoleak should not be ignored. The presence of an endoleak indicated a failure to exclude the aneurysm from the parent artery, which resulted in postoperative rebleeding and a high recurrence rate. The possible causes of endoleak include the tortuous vessels, stent migration, an inappropriate stent size, transient vasospasm, and rupture of the stent membrane [24, 25]. If an endoleak occurred, balloon dilation was suggested, especially at both ends of the WCS. After balloon dilation, a second covered stent was needed to eliminate a persistent high-flow endoleak. Patients with minimal endoleak were advised to use the follow-up observation strategy, which offers a chance for spontaneous occlusion [19]. However, this strategy may lead to a high risk of postoperative rebleeding until the endoleak is completely occluded. In our study, three patients underwent double WCSs, and no minimal endoleak persisted.

When using the WCS to treat BBAs, a side branch occlusion should not be neglected. BBAs will mainly be located at the clinoid-supraclinoid segment of the ICA, from which the OA, the fetal-type PCA, and the AChA originated. The OA occlusion occurred in five patients in the present study as the OA was localized extremely close to the BBAs. Fortunately, none of the patients developed postoperative visual impairments due to the adequate external carotid artery compensation [26, 27]. Some reports show that the posterior communicating artery can be sacrificed if the vessel is not the fetal-type PCA. However, it is necessary to protect the AChA as it feeds many vital structures, such as the cerebral peduncle, internal capsules, hypothalamus, and optic tract [28]. Its occlusion can cause hemiplegia, hemidysesthesia, and hemianopsia. To avoid coverage of the side branches, one should select the appropriate WCS, evaluate the relationship between the side branches and the parent artery from multiple angles, and deploy the WCS accurately. Other treatment strategies must be considered if the AChA and the fetal-type PCA cannot avoid WCS coverage.

In-stent stenosis is another concern for WCS implantation. Two patients showed mild to moderate asymptomatic in-stent stenosis during the angiographic follow-up, similar to that reported by Gu et al. and Fang et al. [18, 29]. The reported mechanisms of in-stent stenosis include inadequate stent dilation, mechanical injury of the parent artery during the stent deployment, in-stent thrombosis, and neointimal hyperplasia [30, 31]. Dual antiplatelet therapy is essential in reducing in-stent stenosis by inhibiting platelet aggregation and activation. In our cohort, one patient developed delayed stent thrombosis on the third postoperative day. We immediately recanalized the vessel by combined interventional techniques, such as local thrombolysis via microcatheter and percutaneous transluminal angioplasty. In addition to incomplete stent apposition, the clopidogrel resistance may be another reason, and then clopidogrel was replaced with 180 mg/day ticagrelor [21].

Further studies are needed to determine the variables related to in-stent thrombosis during WCS deployment. One study limitation is that the patients did not undergo long-term angiographic follow-up. Tan et al. reported that 10% of their patients had asymptomatic in-stent stenosis at 17.5 months [32]. Zhu et al. showed that the mean rates of in-stent stenosis at the 2-year, and 6-year follow-ups were 18% and 29%, respectively [19].

The WCS was first used at our center in 2009 to treat traumatic carotid cavernous fistula. It is reported that the stent was successfully deployed in 12 patients without complications [22]. Tong et al. reported that precise selection and evaluation of stent size and vessel condition were significant factors for cerebrovascular diseases treated by the WCS [33]. Professor Guan Sheng and Professor Guo Xinbin have applied WCS to more than 50 patients prior and have extensive experience in stent selection and placement, which is also the reason for the good treatment results in this study.

The application of Pipeline Embolization Devices (PEDs) in treating BBAs has been widely recommended. Mokin et al. reported a total of 45 BBAs of 43 patients from 14 institutions in the United States [34]. A total of 87.5% of the BBAs had complete occlusion that was observed on follow-up angiography, and 68% of these patients achieved a good clinical outcome. However, complications such as intraprocedural and delayed rebleeding of BBAs should still be taken seriously. Besides, patients still have a risk of recurrence in using PEDs. We firstly reported a case of short-term recurrence of BBA treated with PED combined with coil embolization and successfully retreated with a WCS in the second stage [35].

Our study has some limitations that should be highlighted. First, the study was a retrospective and observational study design. Second, a comparative control group of patients who received other treatments, such as multiple overlapping stents and flow diverters, was lacking. Third, not all the patients in our study undergo long-term angiographic follow-up.

Conclusion

Our series indicates that treating BBAs with WCS was relatively safe and efficacious. However, the incidence of stent delivery failure and complications, including endoleak, side branch occlusion, and in-stent stenosis, should not be neglected. Hence, the optimal treatment strategy for BBAs warrants further studies with larger samples and a more extended angiographic follow-up period.

Abbreviations

BBA Blood blister like aneurysm
WCS Willis covered stent
OA Ophthalmic artery
AChA Anterior choroidal artery
ICA Internal carotid artery
PCA Posterior cerebral artery
ADP Adenosine diphosphate
AA Arachnoid acid
mRS Modified rankin scale
LICA Left internal carotid artery
RICA Right internal carotid artery
PED Pipeline embolization device

Supplementary Information

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Supplementary Material 1

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Author contributions

Conceptualization: Sheng Guan; Writing original draft preparation: Yazhou Jin; Methodology: Xinbin Guo; Formal analysis and investigation: Zhen Chen; Supervision: Sheng Guan; Writing, review, and editing: Sheng Guan; All authors reviewed the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study was approved by the ethics review board of Zhengzhou University First Affiliated Hospital in accordance with the Declaration of Helsinki. Written informed consent was obtained from all individual patients included in the study. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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