Application of parallel stent placement in the treatment of unruptured vertebrobasilar fusiform aneurysms

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OBJECTIVE Large vertebrobasilar fusiform aneurysms (VFAs) represent a small subset of intracranial aneurysms and are often among the most difficult to treat. Current surgical and endovascular techniques fail to achieve a complete or acceptable result because of complications, including late-onset basilar artery thrombosis and perforator infarction. The parallel-stent placement technique was established in the authors' department, and this study reports the application of this technique in the treatment of unruptured VFAs.

METHODS Eight patients with 8 unruptured VFAs who underwent parallel stent placement between April 2011 and August 2012 were included. The diameters of the VFAs ranged from 7.9 to 14.0 mm, and the lengths from 27.5 to 54.4 mm. Of the 8 patients with unruptured VFAs, 3 received double or triple parallel stents and 5 patients received a series-connected stent with another 1 or 2 stents deployed parallel to them. Outcomes for these patients were tabulated, based on the modified Rankin Scale (mRS) score and angiographic results.

RESULTS All of the 25 stents were successfully placed without any treatment-related complications. During follow-up, 5 patients had decreased mRS scores, 2 were unchanged, and 1 was increased for subarachnoid hemorrhage. Immediate and follow-up clinical outcome was completely or partially recovered in most patients. Follow-up angiograms revealed 2 aneurysms were reduced in size and 6 were unchanged after stent placement. No in-stent stenosis, occlusion of the posterior inferior cerebellar artery, or perforators jailed by the stent occurred in any of the aneurysms.

CONCLUSIONS These results provide encouraging support for the parallel-stent placement technique, which can be envisaged as an alternative strategy against unruptured VFAs. However, testing in more patients is needed.

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KEY WORDS unruptured vertebrobasilar fusiform aneurysm; endovascular treatment; self-expandable stent; parallel stent placement; vascular disorders

VERTEROBASILAR fusiform aneurysms (VFAs), also known as vertebrobasilar dolichoectasia, are a vasculopathy characterized by pathologically enlarged, elongated, and abnormally tortuous vertebral and basilar arteries. The disorder has an estimated incidence of 0.06%–5.8%. Fusiform aneurysms can be categorized as segmental ectasia, which have a stretched and fragmented internal elastic lamina, or dissecting aneurysms, which are characterized by widespread disruption of the elastic lamina, thickened intima, and extensive intraluminal thrombus.²⁰ VFAs present as frequently in the posterior circulation as in the anterior circulation, and they have an aggressive natural history.¹⁹ Fusiform aneurysms, which

generally do not occur at arterial bifurcations, have a high probability for producing perforating branches.⁴ These aneurysms have several etiologies, and atherosclerotic degeneration, congenital defects, and segmental dysplasia of the arterial wall are believed to be predominating contributors.⁴ Patients with VFAs commonly manifest symptoms related to mass effects, including headaches, cranial nerve compression, ataxia, ischemic stroke secondary to dissection involving perforating branches or thromboembolic events, and subarachnoid hemorrhage (SAH). The natural history of these aneurysms leads to mortality rates at 5 years between 23% and 35%, and these aggressive lesions cause an elevated risk of death within several days.^{3,17}

ABBREVIATIONS BA = basilar artery; DSA = digital subtraction angiography; mRS = modified Rankin Scale; PCA = posterior cerebral artery; SAH = subarachnoid hemorrhage; VA = vertebral artery; VFA = vertebrobasilar fusiform aneurysm.

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The management of unruptured fusiform aneurysms at the vertebrobasilar trunk remains controversial and challenging due to their complex morphology, and none of the available approaches have been shown to be comprehensively effective or low risk.^{18,19} In this study, multiple self-expandable stents were placed in parallel (side by side) in vascular lesions with unruptured large VFAs. The purpose of this study was to evaluate the technical feasibility and efficacy of the parallel-stent placement technique in treating unruptured VFAs.

Methods

Patient Population

Institutional review board approval was obtained for the study from our hospital. Endovascular treatment was performed when it was considered the most appropriate treatment option after individualized evaluation by the vascular neurosurgeon and interventional neuroradiologist, taking into account collateral blood supply, aneurysm location and surgical accessibility, and patient preferences. All consecutive patients treated at our institution between April 2011 and August 2012 for unruptured fusiform aneurysms of the VBA trunk were included in this study. Eight posterior circulation aneurysms at the VBA trunk in 8 patients were managed using stent-only techniques. The 8 patients were all men with an average age of 55.50 years (range 42–71 years; Table 1). Ruptured cases with VBAs had been excluded from this study. For treating large fusiform aneurysms of the VBA trunk, commercially available intracranial stents, generally with a diameter less than 6 mm, always exhibit unfavorable effects. We therefore designed this study to learn more about the possibility of treating large fusiform aneurysms by using multiple parallel stents, which have a better fit with the vascular wall and can prevent the size of the aneurysm from increasing. Eight patients with 8 aneurysms were managed by using parallel stent placement. Informed consent was obtained from all enrolled patients.

Procedure Management

Dual antiplatelet therapy (100 mg/day of aspirin as well as 75 mg/day of clopidogrel) was routinely given to the

patients with unruptured VFAs beginning 1 week before stent placement. In patients receiving parallel stent placement or series parallel stent placement, dual antiplatelet therapy was maintained for 12 months and then changed to aspirin monotherapy (100 mg/day). Activated coagulation time monitoring was performed from the beginning of the stenting procedure. A target activated coagulation time between 200 and 250 seconds was maintained, and a dose of 3000 units of heparin was injected intravenously just prior to stent deployment, followed by 1000 units of heparin per hour.

Device and Deployment Technique

To make the introduced stents fit better within the affected vascular segment with a large fusion aneurysm, multiple parallel stents (side by side) were deployed. With the guidance and assistance of a microcatheter, a self-expanding stent was advanced over the prepositioned exchangeable guidewire and was deployed to cover the entire lesion segment. Eight patients with 8 aneurysms at the VBA trunk were treated; 3 of these patients received double or triple parallel stents and 5 received a series-connected stent with another 1 or 2 stents deployed parallel to them (Table 2). The 2 series-connected stents must overlap by more than 5 mm to ensure the stability of the connection between them. The number and arrangement of the stents was determined according to the location, size (diameter and length), and shape of the aneurysms. The self-expanding stents used included Neuroform 2 stent (Boston Scientific) and Solitaire (ev3). Technical success was defined by correct placement of the stents.

Clinical Assessment and Angiographic Follow-Up

The initial neuroimaging evaluation included a nonenhanced CT scan or MRI sequence. For visualization of the aneurysm, all patients underwent CT angiography in addition to digital subtraction angiography (DSA); 3D DSA reconstruction was available for some patients.

Preoperative status and follow-up clinical outcomes were clinically assessed according to the modified Rankin Scale (mRS) score. Clinical outcomes were classified as improvement, unchanged, and aggravated, according to the mRS score change. Each patient's clinical status at the

TABLE 1. Characteristics of 8 patients with fusiform aneurysms in the vertebrobasilar arterial trunk

Case No.	Age (yrs)*	Aneurysm Diameter × Length (mm)	Aneurysm Location	Previous Medical Conditions	Mode of Presentation	Clinical Indications
1	47	8.7 × 31.8	Lt VA	Smoking	Headache, dizziness, tinnitus	—
2	64	14.0 × 39.0	Lt VA, BA	Hypertension	Headache, dizziness	—
3	71	9.1 × 41.1	BA	Hypertension, smoking	Headache, dizziness	—
4	67	8.2 × 50.7	Rt VA, BA	Smoking	Headache, slurred speech	Oculomotor paralysis, hemifacial spasm, dysarthria
5	49	9.6 × 37.6	BA	Stroke, hypertension	Headache, slurred speech, dizziness	Dysarthria
6	53	7.9 × 52.7	Lt VA, BA	Coronary artery disease	Headache, dizziness	—
7	42	11.9 × 27.5	Lt VA, BA	Hypertension, smoking	Headache, dizziness	—
8	51	9.5 × 54.4	Bilat VA, BA	Hypertension, diabetes	Headache, slurred speech, myasthenia of limbs, dizziness	Dysphagia, dysarthria

* All patients were male.

TABLE 2. Summary of stents characteristics and follow-up data

Case No.	Stent Type/Size (mm) & Deployment	Immediate Symptoms	Follow-Up Symptoms	Follow-Up DSA/Mos	mRS score	
					Preop	Last Follow-Up (mos)
1	NF 4.5/30 parallel w/ SOL 6/30	Mild tinnitus	No	Unchanged/14	1	0 (18)
2	SOL 6/30 parallel w/ NF 4.5/30 parallel w/ SOL 6/30	Mild headache	No	Improvement/21	2	1 (21)
3	(NF 4.5/30 series w/ NF 4.5/30) parallel w/ SOL 6/20 parallel w/ SOL 6/30	Mild headache	No	Unchanged/23	2	1 (23)
4	(NF 4.5/30 series w/ NF 4.5/30) parallel w/ SOL 6/30	Relieved dysarthria & headache	Dysarthria, incidental headache	Unchanged/19	2	2 (22)
5	NF 4.5/30 parallel w/ SOL6/30 parallel w/ SOL6/20	Relieved dysarthria	Relieved dysarthria	Unchanged/23	2	2 (28)
6	(SOL 6/30 series w/ SOL 6/30) parallel w/ NF 4.5/30	Mild headache	Incidental headache	Unchanged/18	3	2 (24)
7	(NF 4.5/30 series w/ NF 4.5/30) parallel w/ SOL6/30	No	No	Improvement/21	1	0 (24)
8	(NF 4.5/30 series w/ NF 4.5/30) parallel w/ NF 4.5/30 parallel w/ SOL 6/30	Improved myasthenia of limbs, dysarthria	Myasthenia, dysarthria, sudden SAH	Unchanged/4	4	6 (5)

NF = Neuroform; SOL = Solitaire.

last clinical follow-up evaluation was defined as the final outcome. At least 1 angiographic follow-up was available in 8 patients at 14 to 23 months (mean 18 months) after treatment. The size of the aneurysmal sac was assessed by an interventional neuroradiologist (Y.P.L.), who was blinded to the treatment.

Results

Descriptive Data

Between April 2011 and August 2012, 8 patients (mean age 55.50 ± 10.47 years) with 8 unruptured VFAs were successively admitted to our institution and treated with parallel stent placement according to the individualized evaluation by the vascular neurosurgeon and interventional neuroradiologist. Clinical characteristics are summarized in Table 1. The 8 aneurysms presented at a mean diameter of 9.86 ± 2.07 mm (range 7.9–14.0 mm) and length of 41.85 ± 9.91 mm (range 27.5–54.4 mm). The majority of the aneurysms were located in the left vertebral artery (VA) that extended to the basilar artery (BA). Five of the patients had a history of hypertension, 1 patient had coronary artery disease, and 1 patient had experienced ischemic stroke. Most of the patients experienced headaches and dizziness, with other brainstem compression symptoms such as dysarthria, dysphagia, and tinnitus. No aneurysms presented with SAH. The patients were referred to our department because of their presentation for approximately 5 days to 1 year.

Of the 8 giant VFAs, 3 were treated by parallel stenting only, and 5 by series stenting combined with parallel stenting. A total of 25 stents were deployed and an average of 3.13 stents (range 2–4 stents) were used to treat each aneurysm. All stents were successfully delivered to the target vessel. Angiography immediately after placement revealed that the deployed stents were well established and

no overlapping stents became separated. No operation-related complications occurred.

Clinical Outcomes

Clinical and angiographic follow-up results of the patients are summarized in Table 2. Stent placement was successfully accomplished without any treatment-related complications in all 8 patients. The mean angiographic follow-up duration was 17.88 ± 6.33 months (range 4–23 months). During the periprocedural periods, no deaths, distal embolism, or ischemic stroke occurred. One patient presented with transient ischemic attack. In the delayed follow-up, 1 patient died due to hemorrhage at 5 months postoperatively. The mean mRS score decreased from 2.13 ± 0.99 to 1.75 ± 1.91 , and the clinical outcomes of 5 patients improved, 2 were unchanged, and 1 patient became worse and died of SAH. The follow-up angiographic results revealed that 2 aneurysms decreased in size and 6 were unchanged. None of the aneurysms in this study showed in-stent stenosis, occlusion of the posterior inferior cerebellar artery, or perforators jailed by the stent.

Illustrative Cases

Case 2

A 64-year-old man presented to our department with headache and dizziness. On MRI, a large VFA with brainstem compression was apparent (Fig. 1A). A left VA angiogram and 3D reconstruction confirmed a giant VFA (maximum diameter 14.0 mm, length 39.0 mm) that extended from the V₄ segment of the left VA up to the proximal segment of the BA (Fig. 1B–D). The aneurysm was treated with 3 telescopically implanted parallel intracranial stents. Under general anesthesia, an 8-Fr guiding catheter (Guidar MPA, Cordis) was positioned at the left VA. A microcatheter (Prowler14 Select Plus; Codman Neurovascular)

FIG. 1. Case 2. A 64-year-old man with VFA presented with headache, dizziness, and tinnitus. MRI showed a large VFA with brainstem compression (A). Anteroposterior (B) and lateral (C) views of a preoperative left VA angiogram revealed a giant fusiform aneurysm in the vertebrobasilar arterial trunk. A preoperative anteroposterior 3D CT angiogram showed a VFA with a maximum diameter of 14.0 mm (D). An unsubtracted DSA (E) showed the 3 stents (Solitaire 6 × 30 mm, Neuroform 4.5 × 30 mm, Solitaire 6 × 30 mm) deployed in parallel by the guidewire and positioned in the left PCA. Immediate preoperative angiograms (F and G), an unsubtracted digital subtraction angiogram (H) of the aneurysm, and anteroposterior and axial angiograms (I and J) acquired after deployment of the stents are shown. An illustration shows the definitive parallel placement of stents after deployment (K). Figure is available in color online only.

was navigated through a 0.014-inch microguidewire (Essence, Codman) and placed into the left posterior cerebral artery (PCA). An X-celerator microguidewire (0.014-inch diameter, 300-cm length; X-celerator300, ev3) was placed into the P₁ segment of the left PCA through this microcatheter. A Rebar-27 catheter (ev3) was navigated through the 0.014-inch microguidewire (Essence, Codman) and placed into the distal BA (Fig. 1E). A Solitaire stent (6.0 × 30 mm) was advanced through the Rebar-27 catheter and completely deployed into the aneurysmal sac distally. The

second stent (Neuroform 4.5 × 30 mm, Boston Scientific) was navigated through the X-celerator microguidewire (0.014 inch/300 cm, X-celerator300, ev3) and placed 10 mm proximal to the head end of the first stent, and incompletely (one-third) deployed. A Rebar-27 catheter (ev3) was navigated through the 0.014-inch microguidewire (Essence, Codman) and placed next to this incompletely deployed stent. The third stent (Solitaire 6.0 × 30 mm, ev3) was advanced through the Rebar-27 catheter and deployed completely (Fig. 1I and J). The placement of the 3 stents

is illustrated in Fig. 1K. The immediate postprocedure angiograms revealed that 3 stents were successfully deployed, and the flow of the giant VFA was attenuated (Fig. 1F–H). After the operation, the patient experienced mild headache, which greatly improved during follow-up (Table 2). Follow-up angiography at 6 months revealed progressive thrombosis, while no remarkable change in size or configuration of the aneurysm occurred (Fig. 2A and B). Nineteen months after the procedure, DSA revealed that the aneurysmal sac had decreased in size, especially in the proximal segment of the BA (Fig. 2C and D). The maximum diameter of the aneurysm based on DSA and 3D reconstruction had been reduced by 32.1% (14.0 mm preoperatively vs 9.5 mm postoperatively; Fig. 2E). Clinically, the patient was asymptomatic.

Case 4

A 67-year-old man presented with headaches, oculomotor paralysis, dysarthria, hypesthesia of the left side of the face, and sensory deficits in the right upper and lower extremity. He had undergone internal carotid artery stent placement 10 months previously. The DSA revealed a large VFA (maximum diameter 8.2 mm, length 50.7 mm; Fig. 3A). The aneurysm was treated by 2 telescopically inserted overlapping Neuroform 4.5 × 30 mm stents side by side with a Solitaire 6.0 × 30 mm stent. The postprocedure angiograms showed that bilateral posterior circula-

tion was well preserved (Fig. 3B). Cranial nerve palsies were partially recovered immediately after the operation. A follow-up angiogram at 9 months showed that the aneurysm was unchanged in size, and no detachment or shift of the deployed stents occurred, as shown in the CT scan (Fig. 3C–F). During follow-up, the patient continued to experience dysarthria and incidental headache with an unchanged mRS score.

Discussion

Large or giant VFAs, a well-known cause of acute SAH or ischemic stroke of the posterior circulation, constitute a relatively small, uncommon subgroup of aneurysms. Our study reported a new stent-only therapeutic endovascular approach for posterior circulation aneurysms. Multiple self-expandable stents were deployed in parallel in the treatment of 8 aneurysms, and follow-up outcomes showed that most of the patients had improved and had stable symptoms as reflected by the reduced mRS scores, decreased aneurysm size, and few delayed complications. VFAs remain one of the most formidable lesions due to their size, location, and morphology, and no firmly accepted management paradigm is currently available. Traditional surgical clipping techniques are gradually falling out of favor due to unsatisfactory results and high surgical risk, and a variety of endovascular treatment strategies

FIG. 2. Case 2. Follow-up angiograms of the VFA treated with parallel stent placement. Anteroposterior (A) and lateral (B) views of angiograms acquired 6 months after deployment of the stents. Anteroposterior and lateral views of angiograms acquired 19 months after deployment of the stents (C–D). Anteroposterior 3D CT angiogram acquired 19 months after deployment of stents (Solitaire 6 × 30 mm, parallel with Neuroform 4.5 × 30 mm, parallel with Solitaire 6 × 30 mm) revealed that the fusiform aneurysm was reduced in size, with a maximum diameter of 9.5 mm (E). Figure is available in color online only.

FIG. 3. Case 4. A 67-year-old man with VFAs and occlusion of the right carotid artery presented with headaches, dysarthria, and sensory deficits. **A and B:** An anteroposterior view of a right VA angiogram before (A) and after (B) stenting of the fusiform aneurysm. **C–F:** Follow-up angiogram (C) and DSA 3D reconstruction (D), as well as axial and coronal 3D CT images (E and F) at 9 months.

are being used as the first-choice treatment of VBAs.^{5,16} To date, flow diverters, stent-assisted coil embolization, and stent-only therapy with single or multiple stents comprise the main techniques in treating VFAs.^{4,12,20,23} Flow-diverting stents, including the Pipeline embolization device and Silk stent, are characterized by much higher metal coverage and lower porosity.⁶ Flow-diverting stents have received US FDA approval for large anterior circulation intracranial aneurysms and gained momentum as a curative approach for complex aneurysms.^{10,13,14} Moreover, Phillips et al. showed the Pipeline embolization device is effective in the treatment of posterior circulation aneurysms and exhibits safety comparable to that of stent-assisted coiling techniques. However a higher clinical perforator infarction rate and late-onset BA thrombosis (after 2 years) has also been documented concerning the application of the Pipeline embolization device or Silk stent.^{1,13} Stent-assisted coil embolization is an endovascular reconstructive technique and takes advantage of the parent vessel preservation, which obviates the need to consider whether collateral blood flow is sufficient to allow parent vessel sacrifice without neurological deficit.^{8,9,22} Stent-assisted coil embolization in the perforator-rich vertebrobasilar system also contributes to thrombotic occlusion of perforating vessels

and subsequent ischemic complications, and ultimately to perforator stroke.^{9,15} Therefore, these devices should be chosen judiciously.^{12,19}

In more recent years, a stent-only approach has been used and has achieved excellent results. Park et al. reported that stent-only therapy (balloon-expandable or self-expanding stents) was safe and effective in the treatment of vertebrobasilar dissecting aneurysms, and use of a single stent for aneurysms in the posterior circulation complex was shown to be a safe and effective technique.^{11,23} To treat large VFAs, double or triple self-expandable stents deployed in series (placed end to end) were documented in several reports.²¹ Ansari et al. used overlapping Neuroform stents to treat fusiform intracranial aneurysms and revealed that they can induce spontaneous thrombosis of intracranial aneurysms and facilitate parent artery reconstruction through flow remodeling and stent endothelialization.²

However, because of their size and irregular morphology, large VFAs are difficult to treat by single stenting or series stenting. These stents cannot completely obliterate the dissecting aneurysm sac, and the inflow is dispersed into the aneurysm sac. A single stent or stents in a series cannot stabilize the vessel wall to the best effect. Ultimately, the large VFAs treated with single stenting or series stenting might enlarge and be exacerbated. Therefore, in our clinical practice, the stents were placed in parallel for the first time in 8 patients with large VFAs because the self-expandable stents have better adaptability to the tortuous vessels, have low radial force, and are less traumatic. The results showed that no worsening occurred in the 8 patients after the operation, indicating that parallel stent placement successfully prevented the enlargement of large VFAs. In addition, the outcomes of 2 patients were found to be improved at follow-up angiography, indicating that the parallel-stenting technique reversed the development of the giant VFAs.

Parallel stenting still has several limitations. This treatment is not suitable for ruptured VFAs because the self-expandable stents are too porous to support intraluminal thrombosis and prevent bleeding.⁷ Moreover, there is a high risk of delayed stent thrombosis. The possibility of the perforators covered by the stent becoming occluded is another major concern in stent therapy, especially for the perforator-rich vertebrobasilar system. In addition, a small number of patients and a relatively short follow-up duration also prevent definitive conclusions from our study. Further investigation and clinical trials are required.

Conclusions

Parallel stent placement may be a feasible and alternative technique in the treatment of unruptured VFAs. However, a larger series of patients is required to support our evidence.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: B Li, Wang. Acquisition of data: B Li, Wang, Liu, S Li, Cao, Liang, Feng. Analysis and interpretation of data: B Li, Wang, Liu, S Li, Cao, Ge. Drafting the article: Wang. Critically revising the article: Wang, Liu, S Li. Reviewed submitted version of manuscript: B Li, Wang. Approved the final version of the manuscript on behalf of all authors: B Li. Statistical analysis: Liu, S Li, Cao, Liang, Ge, Feng. Administrative/technical/material support: B Li. Study supervision: B Li.

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