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Case report

Application of virtual deployment and hemodynamic simulation in treatment of a basal arterial dissecting aneurysm using flow diverter: A case report and literature review

Shijie Zhu [a], Rong Zou [b], Zhiwen Lu [a], Yazhou Yan [a,c], Yina Wu [a], Jianping Xiang [b,**], Qinghai Huang [a,*]

[a] *Department of Neurovascular Center, Changhai Hospital, Naval Medical University, Shanghai, China*
[b] *ArteryFlow Technology Co., Ltd, Hangzhou, China*
[c] *Department of Neurosurgery, 971 Hospital of People's Liberation Army (PLA), Qingdao, China*

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ABSTRACT

The application of flow diverters (FDs) to treat basilar artery (BA) aneurysms has been proven to be one of the most effective ways. The hemodynamic changes caused by FD have been proven to be a principal factor affecting the healing of aneurysms. Virtual deployment based on simulation technology can intuitively reflect the hemodynamic changes caused by FD, providing more information for the surgeon. A 6-year-old child presented with a week of persistent, severe headaches due to a large dissecting aneurysm in the upper-middle BA. To select the appropriate size of the stent and observe the changes in blood flow, the virtual deployment of the FD was completed in AneuPlan. The simulated results were in good agreement with postoperative digital subtraction angiography (DSA). Moreover, hemodynamic analysis indicated the overall thrombosis and healing of the aneurysm and the incomplete occlusion risk close to the left superior cerebellar artery, which was confirmed by the subsequent assessment following the FD deployment. Encouragingly, the DSA images at 28 weeks showed that the residual sac of the basilar artery aneurysm had been basically healed. This case report initially reflects the guiding role of AneuPlan in the endovascular treatment protocol for complex cerebrovascular diseases.

1. Introduction

Intracranial dissecting aneurysm can occur in various age groups, but it is more common in young and middle-aged people and is one of the important causes of stroke. With the continuous advancement of interventional materials, intravascular therapy has gradually become the main treatment method for dissecting aneurysms. However, there is still controversy in clinical practice regarding the indications for endovascular treatment, the selection of specific treatment methods, and the safety and effectiveness of endovascular treatment. Flow diverter (FD) is increasingly used as a new treatment method for intracranial aneurysms (IAs) [1]. The size of the FD dramatically influences its efficacy and safety [2,3]. Furthermore, the hemodynamic changes caused by FD have been

* Corresponding author. Department of Neurovascular Center, Changhai Hospital, Naval Medical University, No. 168 Changhai Road, Shanghai, 200433, China.
** Corresponding author. ArteryFlow Technology Co., Ltd, No. 459 Qianmo Road, Hangzhou, Zhejiang, 310051, China.
E-mail addresses: jianping.xiang@arteryflow.com (J. Xiang), ocinhqh@163.com (Q. Huang).

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proven to be a principal factor affecting the healing of aneurysms [4]. However, in preoperative planning, selection of the most appropriate size of the stent and simulation of changes in blood flow rapidly and accurately remain enormous challenges. Virtual deployment based on simulation technology can intuitively reflect the hemodynamic changes caused by FD, providing more information for the surgeon. Here we report a rare pediatric patient with a basilar artery dissection aneurysm treated by FD deployment after virtual surgical planning. During the follow-up, we found local residues in the aneurysm, which were highly consistent with the

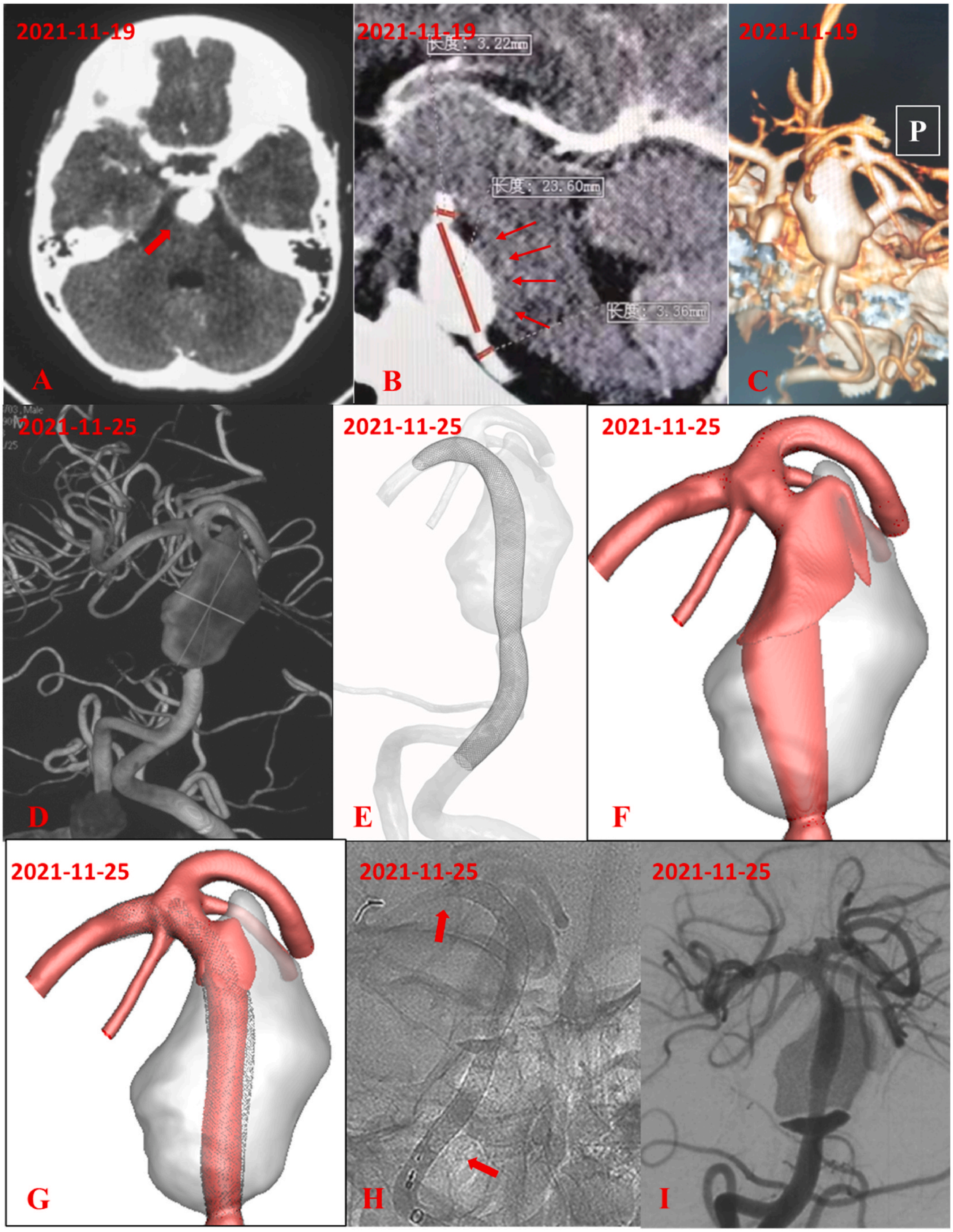

Fig. 1. (A–C) The Computed Tomography Angiography (CTA) showed significant mass effect from a basilar artery aneurysm, with compression of the brainstem (arrowhead). (D) Preoperative coronal digital subtraction angiography (DSA) demonstrated a giant basilar dissecting aneurysm. (E) A virtual flow diverter (Pipeline 4.0*35 mm) was deployed by AneuPlan software. (F–G) The high flow area (velocity >0.05m/s) indicating that a jet flow existed before flow diverter (FD) deployment and constrained blood flow was constrained after FD deployment. (H) The non-subtractive image illuminated the position and morphology of the stent (arrowhead). (I) Postoperative DSA showed no occlusion with the parent artery patent.

location indicated by hemodynamic analysis.

2. Case presentation

A previously healthy, 6-year-old child presented with a one-week history of severe, persistent headaches. The medical history did not disclose other illnesses, and the physical examination was normal. The neurological examination did not reveal focal neurological signs or cranial nerve deficits. Additionally, there was no history of cerebral aneurysms in his family among multiple first- and second-degree family members.

Enhanced CTA images suggested a large basilar artery (BA) aneurysm with mass effect (Fig. 1A and B & 1C). MRI showed that the

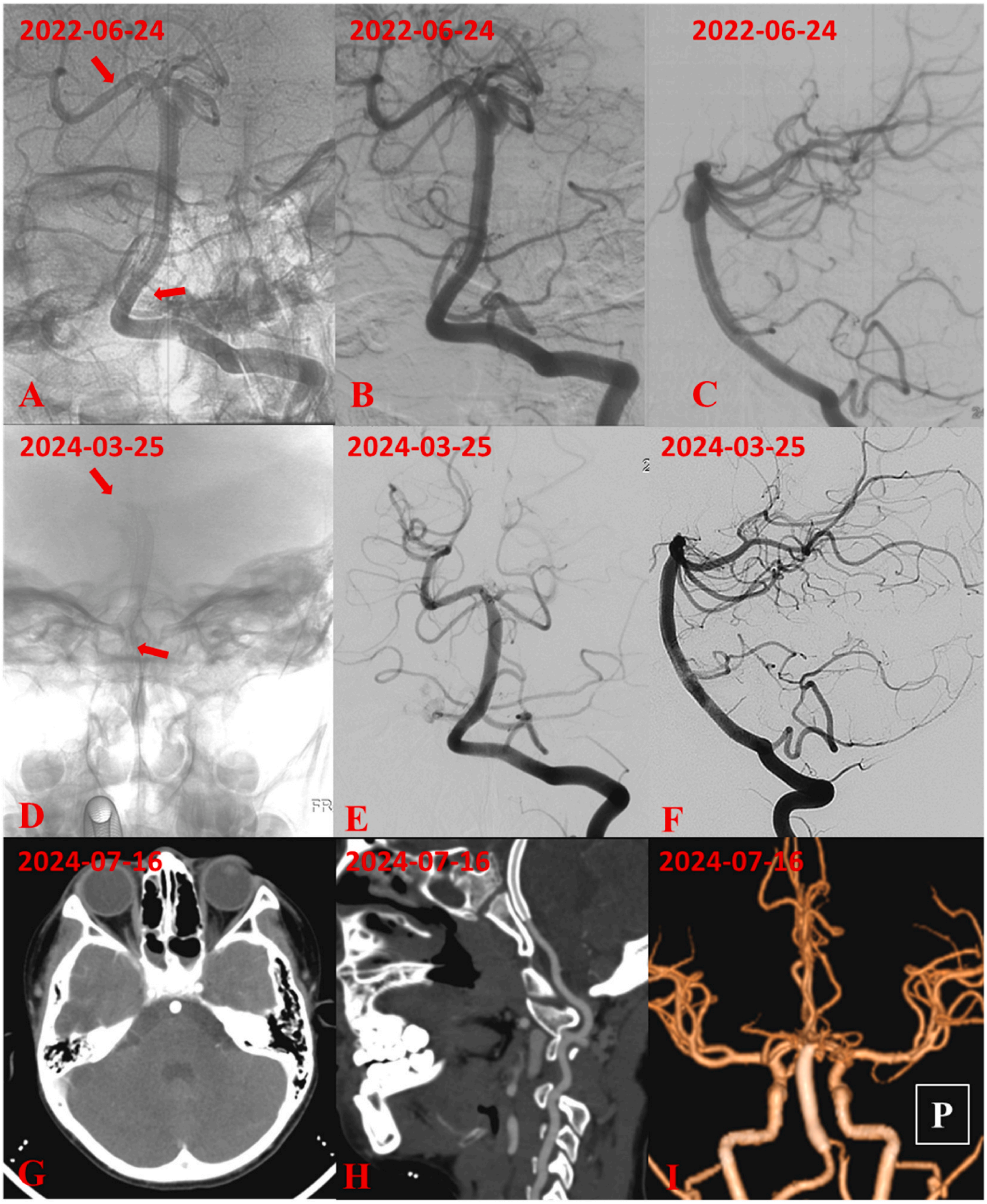

Fig. 2. (A–C) A 7-month follow-up DSA indicated a residual aneurysm sac (4.6*3.7*5.6 mm) with the patency of parent vessels. Pipeline (4.0*35 mm) showed good wall apposition with no migration. (D–F) A 28-month post-surgery DSA showed the great healing of the residual aneurysm sac, and no stenosis within the FD. (G–I) Subsequent CTA images illustrated significant relief of the compression on the brainstem.

aneurysm wall was uniformly thickened with a subsequent enhancement without conspicuous mural thrombus in the aneurysm sac. Digital subtraction angiography (DSA) images confirmed a dissecting aneurysm in the upper-middle segmental BA with no definable neck (Fig. 1D). AneuPlan software was used for virtual stent implantation [5]. A 3D DSA image was used to reconstruct the 3D model of the vessel. By using finite element analysis (FEA) technology, pre-constructed FD models with different sizes were virtually deployed in the vascular model, and the hemodynamics after stent release were obtained through computational fluid dynamics (CFD) simulation. A 4.0*35mm pipeline embolization device (PED, Medtronic, Minneapolis, Minnesota, USA) obtained the best hemodynamic result (Fig. 1E). The aneurysm wall shear stress (WSS), velocity, and high WSS area (WSS > 2Pa) were decreased from 0.411 Pa, 0.023 m/s, and 35.304 mm^2 to 0.171 Pa, 0.007 m/s, and 12.255 mm^2. The simulation revealed the complex flow pattern with jet impingement before operation (Fig. 1F). After the virtual stent deployment, the blood flow was mostly constrained in the FD (Fig. 1G). However, there is a high flow velocity area located near the top of the aneurysm outside of FD, indicating a risk of high flow velocity flow hindering occlusion in this area.

Aspirin enteric-coated tablets (25 mg per day) and clopidogrel (25 mg per day) were administered for 6 days before treatment. After general anesthesia, the 6F Tethys intermediate catheter (Achieva Medical, Shanghai, China) was superselected directly to the vertebrobasilar confluence via the right femoral artery. The Phenom 27 microcatheter was advanced over a Synchro 2 microwire (Stryker Neurovascular, Fremont, California, USA) into the P2 segment of the right posterior cerebral artery (PCA). A 4.0 * 35mm PED was deployed from distal to proximal fashion, starting from the P1 segment of the right posterior cerebral artery (PCA) and then along the BA and the V4 segment of the left VA distal to the posterior inferior cerebellar artery. PED showed good wall apposition with complete expansion using the 'push-pull' implantation technique (Fig. 1H and I). The entire process treatment was uneventful.

The immediate postoperative headache disappeared entirely after a 4-day complementary treatment of steroids (40 mg per day). A 7-month DSA examination demonstrated the residual aneurysm near the left superior cerebellar artery characterized by good wall apposition and minimal in-stent intimal hyperplasia (Fig. 2A and B & 2C). Excitingly, the follow-up DSA at 28 months indicated that the residual sac of the aneurysm was no longer visible, and there was no stenosis observed within the FD (Fig. 2D and E & 2F). Additionally, the subsequent CTA images from the external hospital illustrated a significant alleviation of the compression on the brainstem, and no obvious mass effect was observed around the FD (Fig. 2G and H & 2I). The child has been currently recovering well, with negative neurological examination.

3. Discussion

Although IAs are relatively rare in children, intracranial arterial dissection has a high risk of inducing ischemic or hemorrhagic stroke. Arterial ischemic stroke events are estimated to occur in 1.2–8 per 100,000 children per year, with 15–22 % occurring in the posterior circulation, and 7 % are caused by vertebral artery dissection (VAD) [6–8]. Subarachnoid hemorrhage (SAH) and brain stem infarction have a high disability and mortality rate, and extreme dilation of the lumen can also cause mass effects, leading to compression symptoms. About 24 % of patients with basilar artery dissection have brain stem compression symptoms, which can also cause trigeminal neuralgia, facial neuralgia, facial muscle spasms, etc. [9] In recent years, most patients with intracranial artery dissection without SAH have been treated medically and offered acute stroke treatment and long-term prevention of ischemic stroke [10]. Endovascular treatment is undertaken if the dissecting aneurysm has increased in size, to prevent rupture, or more rarely to reduce signs of brain stem compression [11,12]. Despite the optimal treatment strategy for aneurysms in children is not as clear-cut as for those in adults, the use of flow diverters for the treatment of aneurysms in children may be safe [13]. A meta-analysis of 56 aneurysms in children showed a 75 % occlusion rate of PED treatment [14]. Another retrospective analysis of 39 patients revealed similar results [15]. In our case of a child, PED was selected for the treatment of basilar artery dissection aneurysm.

The selection of FD size is critical for safety and cure rate. For those aneurysms with particularly longer necks, telescopic FD deployment or oversizing FDs can ensure complete coverage of aneurysm necks. Oversizing braided stents will lengthen in small blood vessels. Conversely, over-expansion or pushing technique will cause shortening in the fusiform aneurysm necks, so the labeled length is not a powerful predictor of the actual deployment length. A previous study showed that the average elongation of implanted PEDs reached 32.6 % [16]. At present, there are already several planning tools available for FD planning. Different teams have conducted validation studies on algorithms and clinical applications based on these tools and have shown high accuracy in predicting the length of deployed FDs [17–20]. With the assistance of these softwares, surgeons may choose FDs whose sizes are different from their experience [18,19,21], and benefit from surgical efficiency [22]. AneuPlan simulates the state of an FD after release in blood vessels using the finite element method (FEM), taking into account the geometric and material characteristics of FDs, and presents visualized virtual treatment results [23]. In this case, considering the increasing diameter of intracranial vessels in pediatric patients, FDs may shorten or cause relative stenosis in later stages theoretically. We utilized AneuPlan to simulate several plans by virtually deploying FDs with different sizes, and a 4.0 * 35 mm PED was eventually recommended. The PED was successfully implanted with good apposition and adherence, and the actual length was in high accordance with the simulated length (51.4 mm vs. 50.5 mm).

The variability in clinical outcomes underscores the importance of a more detailed analysis of hemodynamic changes after FD implantation. Hemodynamics plays an important role in the lifecycle of aneurysms. The wall shear affects the internal elastic lamina damage and endothelium-mediated proinflammatory responses [24]. The blood flow jet inside the aneurysm affects the formation of thrombosis and occlusion [25]. Compared with traditional embolization treatment methods, the mechanism of FD treatment is more dependent on changes in hemodynamics. Our team applied micro-CT to reproduce the morphologies of FDs implanted in rabbits realistically and found a post-stenting decreased wall shear stress and a reduced blood flow of the aneurysm sac [26]. Computational fluid dynamics (CFD) provides a convenient and feasible tool for evaluating hemodynamics and predicting prognosis [27,28]. Hemodynamic studies have shown that high wall shear stress (WSS), large high flow volume (HFV), and high average velocity in the aneurysm after interventional treatment are risk factors for aneurysm recurrence [29,30]. Visualized simulation results help surgeons have a more intuitive understanding and prediction of local blood flow changes after FD implantation, which is more valuable in large aneurysms [31]. AneuPlan rapidly evaluates the hemodynamic changes by simulating the flow field before and after the virtual deployment of FD. In this case, the postoperative simulation result showed that a region high flow area (velocity >0.05 m/s) was concentrated in the upper-left segment of the aneurysm, which was a sign of the main residual blood flow. This prediction was entirely consistent with the changes in the residual lumen of the aneurysm during the follow-up period. This analysis will facilitate formulating case-specific treatment strategies and predicting treatment outcomes accurately. At present, due to differences in patient conditions and simulation methods, the sample size of research related to virtual therapy is often small, making it difficult to establish reliable, unified standards to assist in surgical planning. With the release of larger sample datasets with clinical evidence and simulation data, virtual therapy may further demonstrate its value in surgical planning and be applied in clinical practice.

4. Conclusion

Flow diverters are effective, simple, and safe option for pediatric dissection aneurysms in the BA. And AneuPlan software can be doctors' crystal ball, which is helpful for accurate FD sizing, ensuring good device wall apposition, and optimizing the deployed FD's length. Moreover, rapid and accurate simulation of hemodynamic changes pre- and post-virtual stent deployment can benefit patient-specific intervention and prediction of treatment outcomes.

CRediT authorship contribution statement

Shijie Zhu: Writing – original draft, Data curation. **Rong Zou:** Writing – original draft, Validation, Software, Methodology, Investigation. **Zhiwen Lu:** Methodology. **Yazhou Yan:** Investigation. **Yina Wu:** Data curation. **Jianping Xiang:** Writing – review & editing, Conceptualization. **Qinghai Huang:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization.

Ethics statement

The patient and his guardians provided consent and agreed for all images, clinical data and other data included in the manuscript to be published. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the ethics committee of Shanghai Changhai Hospital Ethics Committe Board (Approval Number: CHEC2017-073).

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Data and code availability statement

Data will be made available on request. For requesting data, please write to the corresponding author.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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