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Analysis of multiple intracranial aneurysms with different outcomes in the same patient after endovascular treatment

Linkai Jing, MS[1,*], **Jian Liu, MD**[1,*], **Ying Zhang, MD**[1], **Nikhil Paliwal, B.Tech.**[2,3], **Hui Meng, PhD**[2,3,4], **Shengzhang Wang, PhD**[5], and **Xinjian Yang, MD, PhD**[1]

Linkai Jing: linkai_jing@163.com; Jian Liu: jianliu_ns@163.com; Ying Zhang: yingzhang829@163.com; Nikhil Paliwal: npaliwal@buffalo.edu; Hui Meng: huimeng@buffalo.edu; Shengzhang Wang: szwang@fudan.edu.cn; Xinjian Yang: yang-xj@163.net

[1]Beijing Neurosurgical Institute, Beijing Tiantan Hospital, Capital Medical University, Beijing, China

[2]Department of Mechanical & Aerospace Engineering, University at Buffalo, The State University of New York, Buffalo, New York

[3]Toshiba Stroke and Vascular Research Center, University at Buffalo, The State University of New York, Buffalo, New York

[4]Department of Biomedical Engineering, University at Buffalo, The State University of New York, Buffalo, New York

[5]Department of Mechanics and Engineering Science, Fudan University, Shanghai, China

Abstract

Background—Aneurysm recanalization after coiling, with or without stent assistance, remains a major issue in the endovascular management of intracranial aneurysms. Multiple intracranial aneurysms with different outcomes after endovascular treatment may represent a useful disease model in which patient-specific risk factors can be balanced to investigate possible features linked to aneurysm recanalization. In the present study, we evaluated the aneurysm-specific, treatment-related, and hemodynamics-related factors on multiple aneurysms, and aimed to explore the reason as one aneurysm recanalized, and the other did not.

Methods—Between 2010 and 2015, 326 patients with 763 multiple intracranial aneurysms were diagnosed by digital subtraction angiography. Among them, thirteen pairs of multiple

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Corresponding authors: Xinjian Yang. Department of Interventional Neuroradiology, Beijing Neurosurgical Institute, Beijing Tiantan Hospital, Capital Medical University, TiantanXili 6, Dongcheng Distict, Beijing, China, 100050. yang-xj@163.net. Tel: +8610-67098852. Fax: +8610-67018349.

[*]The same contribution to the study.

Competing Interests

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

Author's contribution

LJ and JL contributed equally to the preparation of the manuscript and data collection and statistical analysis. YZ, XY conceived and designed the research. SW did the CFD simulation. PN and HM designed in-house software and developed virtual stent-deployment technique.

aneurysms with different outcomes (recanalized or stable) in the same patient were retrospectively collected and analyzed. Patient-specific models were constructed and analyzed by a computational fluid dynamics method. The virtual stent deployment method was used accordingly and the coils were simulated by a porous medium model. Factors were evaluated for significance with respect to recanalization.

Results—Aneurysm size (p=0.021), neck width (p=0.027), ruptured aneurysms (p=0.002), reduction ratio of averaged velocity (p=0.008) and wall shear stress (p=0.024) were significantly associated with aneurysmal recanalization. By contrast, the aneurysm location, all of treatment-related factors (packing density, duration of follow-up, stent use, initial angiographic result) and the reduction ratio of averaged pressure were not significantly associated (p>0.05).

Conclusions—Small aneurysm size and neck width, unruptured aneurysm, and perianeurysmal hemodynamics with marked reduction maybe important factors associated with the mid-term durability of aneurysm embolization.

Keywords

intracranial aneurysms; endovascular treatment; recanalization; cerebral hemodynamics

Introduction

Endovascular treatment of intracranial aneurysms is an accepted alternative to microsurgical clipping, with lower morbidity and mortality rates (1). However, the relatively higher rate of recanalization is a major issue for endovascular treatment (1–4). The mechanisms that lead to aneurysm recanalization are complex and mainly affected by patient-related factors, aneurysm-specific factors, treatment-related factors, and hemodynamics-related factors (2–21).

However, not all studies controlled for patient-related factors (patient age, sex, smoking, drinking, hypertension, antiplatelet drugs), disregarding those as confounding factors for aneurysm recanalization, when comparing the aneurysm-specific and/or treatment-related factors among different patients. Recently, to remove the confounding effect of patients' characteristics on the aneurysm rupture risk, some studies introduced multiple intracranial aneurysms (22, 23). Similarly, the analyses between recanalized and stable aneurysms in the same patient are of great value, since the multiple aneurysms with different outcomes after the same initial treatment method, as endovascular embolization, are extremely rare and the findings may provide an important reference.

To our knowledge, this was the first study to evaluate the aneurysm-specific, treatment-related, and hemodynamics-related factors associated with aneurysm recanalization on multiple intracranial aneurysms, with the strict inclusion criteria, and to explore the reason as one aneurysm recanalized, and the other did not. Such study design is of great value as eliminating the inherent confounding effects and the results may be more valid.

Methods

Patients and aneurysms

All medical data were acquired for diagnostic purposes, and the ethics committee of our hospital approved the retrospective study. Between 2010 and 2015, 326 patients with 763 multiple intracranial aneurysms were diagnosed by digital subtraction angiography (DSA) at our institution. Patients were screened retrospectively based on the following inclusion criteria: 1) for comparison in each patient, at least two saccular aneurysms were occluded by endovascular treatment and evaluated at follow-up by angiography; 2) aneurysms from the same patients showed different outcomes at follow up, either recanalized or stable; 3) the results were identified by angiograms in the best angle and/or 3D–DSA images; 4) the DSA images were adequate for computational fluid dynamics (CFD) analysis; and 5) the study was consented to by patients or their close relatives. The following aneurysms were excluded: 1) fusiform or dissecting aneurysms; 2) aneurysms were treated by microsurgical clipping; 3) aneurysms from the same patients that showed same outcomes at follow up; and 4) 3D–DSA images were too poor for CFD analysis.

A total of 26 aneurysms in 13 patients meeting the criteria were finally selected from our database. The angiographic results were classified according to the Raymond-Roy classification system (10). Aneurysm recanalization was defined as any increase in the size of the remnant, while initially incompletely coiled aneurysms that were stable on follow-up were not regarded as recanalization (5). All medical records, angiography, and radiographic images were evaluated by at least two experienced neuroradiologists, independent of the study, to analyze the occlusion status of the aneurysms. All the participants included in the present study had clear division, without knowing each other's data. The aneurysms were then divided into two groups (13 recanalized and 13 stable lesions) based on their evaluations. By reference to the previously mentioned papers (24, 25), inclusion criteria we considered for retreatment were as follows: younger age, large aneurysm size and neck width, residual aneurysm (according to the Raymond-Roy classification system), patient's requests due to fearing rupture, and so forth. Generally, coiling would be selected as an efficient retreatment strategy, especially for the recanalization due to coil compaction. General patient information and aneurysm characteristics are summarized in Table 1.

Computational modeling and CFD simulations

Patient-specific 3D–DSA data was obtained and imported into Geomagic studio software (version 12.0, Geomagic Inc., NC, USA) to repair, cut, and smooth. The surface geometries were then saved as standard tessellation language format. Geometric models of the Enterprise stent (CORDIS ENTERPRISE™ Vascular Reconstruction Device; Cordis Neurovascular, Miami, FL, USA: Figure 1 and Figure 2) were created and placed within the vascular models using an in-house virtual stent-deployment technique that we previously developed (26, 27). Briefly, the virtual stent deployment consisted of four steps: pre-processing, initial stent contour generation, stent contour expansion and termination, and 3D stent model construction. We prepared the 3D aneurysm geometry and initialized the simplex mesh within the parent vessel prior to its expansion. The parent vessel was isolated from the aneurysm and trimmed down to the deployable region. We obtained the parent vessel centerline and uniformed initial mesh with a small diameter along the centerline. Finally, using MATLAB (R2013a, The Mathworks, Natick, MA, USA), we extracted the maximum inscribed sphere diameter inside the parent vessel along its centerline and placed a series of circles. Then, the initialized simplex mesh was treated as a deformable simplex model and expanded inside the parent vessel in MATLAB. Finally, we determined the stent vertex coordinates on the deployed simplex mesh according to the stent pattern. We then connected the vertex coordinates into distinct wire curves, using an in-house python code based on FEM software Abaqus/Explicit 6.12 (Simulia, Providence, RI, USA). Finally these wires curves were swept into 3D strut structures to generate a 3D solid stent in the CAD program Creo Parametric 2.0 (PTC, Needham, MA, USA). The 3D strut structures were placed inside the original untrimmed 3D aneurysm geometry and meshed together for CFD analysis.

The aneurysmal sac with coils was modeled as a porous medium as described by Wang et al. (28) and Mitsos et al.(29). The volume of the coil was calculated and the algebraic equation was as follows: volume of the coil = $\pi \times (\text{diameter of coil}/2)^2 \times$ the length of the coil. Packing density was defined as the ratio between the volume of the coils and the volume of the aneurysms.

The CFD simulations were described previously (6, 7). Briefly, the deployed stent was merged with the aneurysm geometry in ICEM CFD version 14.0 (ANSYS, Inc., USA) to create finite volume tetrahedral elements for CFD simulation. The largest element size was 0.1mm and the element size on stent was set at 0.025mm in order to sufficiently present the stent geometry, which was approximately 1/3 of the width of the strut of the Enterprise stent (0.078 mm) (18, 30). Mesh sizes ranged between 3.0 and 6.0 million elements for the cases without stent and from 10.0 to 18.0 million elements for the cases with stent. After meshing, ANSYS CFX 14.0 software (ANSYS, Inc., USA) was used for simulation of hemodynamics. The vessel wall was assumed to be rigid with a no-slip boundary condition. Blood was modeled as a homogenous, laminar and incompressible Newtonian fluid (attenuation = 1060 kg/m^3, viscosity = 0.004 Pa•s). The governing equations underlying the calculation were the Navier–Stokes formulation. The pulsatile period velocity profile was obtained by transcranial Doppler from a normal subject and set as the inflow boundary condition. The flow waveforms were scaled to achieve a mean inlet WSS of 15 dyne/cm under pulsatile conditions (31, 32). To reduce initial transients, we computed two complete cardiac cycles, and data of the second cardiac cycle were collected.

Data collection and analysis

Several aneurysm-specific and treatment-related factors were analyzed, including aneurysm size, neck width, ruptured status (the ruptured aneurysm was identified by head computed tomography scan imaging), location (sidewall or bifurcation), packing density, length of follow-up period, stent use, and initial angiographic result.

After CFD simulations, the following hemodynamic variables at the peak systole were calculated and compared in the recanalized and stable aneurysms: (1) the reduction ratio in velocity on a fixed plane of the aneurysmal neck (reduction ratio = $100\times[V_{pre}-V_{post}]/V_{Pre}$, where V_{pre} is the velocity before treatment and V_{post} is the velocity after treatment); (2) the reduction ratio in wall shear stress (WSS) around the circumference of the aneurysm ostium (reduction ratio = $100\times[\mathrm{WSS}_{pre}-\mathrm{WSS}_{post}]/\mathrm{WSS}_{Pre}$), which is determined by a plane between the aneurysm and parent artery; (3) the reduction ratio in pressure on a fixed plane of the aneurysmal neck (reduction ratio = $100\times[P_{pre}-P_{post}]/P_{Pre}$) (6, 7, 33).

Statistical analysis was performed with an SPSS 17.0 package (IBM, Chicago, IL, USA). For quantitative data, the one-sample Kolmogorov–Smirnov test was used to test the normal distribution. Paired-sample t test was used for all the approximately normally distributed parameters with data expressed as mean ± SD. The Mann-Whitney *U* test was used for continuous variables and the McNemar's test was used for nominal factors. A *p*-value <0.05 was considered statistically significant.

Results

Characteristics of patients and aneurysms

Thirteen patients aged between 35–63 years (mean 51.62y) were analyzed, of which 11 (84.62%) were females and two (15.38%) were males (Table 1). The most common sites of aneurysms were the internal carotid artery (23/26). Eighteen aneurysms were treated by single Enterprise stent-assisted coiling and the others were treated by coiling only. Recanalized aneurysms underwent re-treatment with coils (cases 1, 6, 10 and 11) and Low-profile Visualized Intraluminal Support device (LVIS®; MicroVention-Terumo, Tustin, CA, USA; case 2), and the others were treated conservatively. The recanalized aneurysms in the five patients who received re-treatment achieved good clinical outcomes at the next follow-up in our hospital (cases 1, 2 and 6) or in local hospitals (cases 10 and 11).

Aneurysm-specific factors

The recanalized aneurysms had a significantly larger aneurysm size and neck width than the stable aneurysms (p=0.021 and 0.027, respectively) (Table 2; Figure 1; Figure 2). Additionally, ruptured aneurysms were recanalized more often than unruptured aneurysms (p=0.002), whereas the bifurcated aneurysms recanalized at a similar rate to sidewall aneurysms (p=0.774).

Treatment-related factors

There were no significant differences between packing density and aneurysm recanalization (p=0.632), between the duration of follow-up and recanalization (p=0.746), between stent use and recanalization (p=0.302), or between initial angiographic result and recanalization (p=0.129) (Table 2; Figure 1; Figure 2).

Hemodynamics-related factors

The overall blood flow patterns of aneurysms before treatment were similar in two groups (Figure 1A2; Figure 2A2 and D2). After treatment, the motion of blood flow into the aneurysm sac was markedly inhibited by stent and/or coils, especially for stable aneurysms, which confines the streamlines to the region beneath the aneurysm orifice (Figure 1B2; Figure 2B2 and E2). In addition, the velocity at the aneurysm neck can reflect the change of relative blood flow and the streamline of aneurysm maybe embody vascular resistance in the aneurysms pre- and post-treatment.

There were significant differences in the reduction ratios of the velocity at the aneurysmal neck and the WSS around the circumference of aneurysm ostium, while the reduction ratios of the pressure at the aneurysmal neck had no significant difference between the recanalized and stable groups (p=0.008, 0.024 and 0.604, respectively; Table 2; Figure 1A3, B3, A4 and B4; Figure 2A3-E3 and A4-E4).

In addition, we further analyzed the immediate angiographic results and hemodynamic results between the stent-assisted coiling patient and the coiled patient and found that the velocity at the aneurysmal neck was markedly reduced when the aneurysm was treated by stent-assisted coiling (p<0.001), while other factors were not statistical significance (p>0.05) (Table 3).

Discussion

The ultimate goal of endovascular treatment is to exclude the aneurysmal sac from the native intracranial circulation. Unlike clips, coils separate arterial tissue and keep the aneurysm orifice open, thus permitting perfusion of the aneurysm between the clefts of coil, which is not beneficial for endothelialization across the neck (34). Therefore, the aneurysm recanalization after endovascular treatment remains a major issue. To identify the recanalization-related factors and reduce the risk of confounding by patient specific characteristics (age, sex, smoking, hypertension, and antiplatelet drugs), the comparison of recanalized and stable aneurysms within the same patient may be a useful disease model.

Aneurysm-specific factors

Aneurysm size and neck width were previously identified as significant risk factors for aneurysm recanalization (5, 15, 16, 19, 20). Raymond et al.(5) retrospectively analyzed the risk factors of angiographic recanalization after endovascular treatment of 501 aneurysms, and found that large aneurysm (aneurysms ≥10 mm) and wide neck (neck >4 mm) were associated with aneurysm recanalization (p<0.001). This may be due to the piling up and crossing of parts of the coils in large aneurysms, causing dead space that cannot be filled, ultimately affecting the process of intra-aneurysmal clot organization. Additionally, it is unlikely that a wide neck would be able to be bridged by coils in order to reduce hemodynamic forces, exclude the aneurysm from the circulation, and allow the endothelium to cover the neck. In the present study, we examined the clinical significance of aneurysm size and neck width by applying the index on multiple aneurysms, and found that the recanalized group had a significantly higher size and wider neck than that in the stable group.

Ruptured aneurysms were previously reported to have a higher recanalization rate than unruptured aneurysms (5, 16). Ogilvy et al.(16) retrospectively reviewed the obliteration efficacy of 333 intracranial aneurysms in 305 patients who received endovascular treatment, and demonstrated that 50% of ruptured aneurysms needed retreatment, whereas 17% of unruptured aneurysms were associated with retreatment. Although the exact mechanism was not clear, it is possible that the coils may be not as tightly packed in ruptured aneurysms due to potential for rebleeding, and that the pathophysiology of ruptured aneurysms may affect the geometry and healing of aneurysms after treatment, thus affecting recanalization. In our study, all ruptured aneurysms (3/3) showed recanalization and 57% (13/23) of unruptured aneurysms were stable at angiographic follow-up, consistent with previous findings (5).

Location may also be an important factor for aneurysm recanalization, and bifurcation aneurysms are thought to have a higher risk because of the direct jet of hemodynamic forces pushing on the coils (16, 21). However, in the present study, the aneurysm location was not significant for recanalization, which may be related to the characteristics of small sample.

Treatment-related factors

Packing density, duration of follow-up, stent use, and initial angiographic result were previously reported to be significantly associated with aneurysm recanalization (5, 10–12, 14–16). The relationship between packing density and recanalization remains controversial (11, 12, 14). Sluzewski et al.(12) found that high packing density (>20–24%) prevented recanalization, and that large aneurysmal volume was associated with low packing density and frequent recanalization. By contrast, Piotin et al.(11) found no significant association between packing density and aneurysm recanalization. These differences may relate to the different number of aneurysms (145 *vs.* 255 aneurysms) that were followed-up over different time periods (mean 6 *vs.* 12 months). Additionally, the use of 2D angiographic images (12, 14) versus 3D reconstructed images (11) to measure the aneurysm volume may influence the calculation of packing density. In our series, the stable aneurysms showed a non-significant trend for higher packing density than the recanalized aneurysms.

The relationship between length of follow-up period and recanalization is also unclear (5, 11, 15, 17). Raymond et al.(5) and Piotin et al.(11) found that aneurysms assessed at long-term follow-up (12 months) were at more risk for recanalization than aneurysms assessed at mid-term follow-up (6 months). However, Murayama et al.(15) analyzed long-term clinical outcomes of 916 aneurysms, and found that recanalization usually occurred within 3 months, especially for aneurysms without complete occlusion at initial treatment. Gallas et al.(17) further evaluated the stability of occlusion of 705 ruptured aneurysms that were treated by coiling and followed up at 3 months, 1 year, and yearly examinations post-treatment, and demonstrated that 96% of aneurysms observed to be completely occluded at 12 months remained stable at final follow-up (mean 36 months). In our series, the length of follow up period was not a significant risk factor associated with recanalization, which might be attributed to the characteristics of multiple aneurysms in the same patient.

Previous studies demonstrated that stents can create a mechanical scaffold, markedly modify intra-aneurysmal flow, promote thrombosis, provide a matrix for endothelial growth, and decrease recanalization rate (3, 4, 9, 18, 35). Hong et al.(3) conducted a meta-analysis, and found that stent-assisted coiling treatment was associated with a higher progressive thrombosis rate (37.5% v*s.* 19.4%) and a lower recanalization rate (16.2% *vs.* 34.4%) compared with subjects with coiling only. In the present study, 44.4% (8/18) of aneurysms showed recanalization after treatment with stent-assisted coiling, while 62.5% (5/8) of aneurysms recanalized at angiographic follow-up after treatment with coiling only, although there was no significant difference between the groups.

Suboptimal initial angiographic results were also reported to be important for aneurysm recanalization (5–7, 10, 16). In the present study, 69.23% of patients in the recanalized group had non-complete occlusion (including residual neck and residual aneurysm) compare to 46.16% of the patients in the stable group after treatment. However, there was no significant difference, which may be because of our relatively small number of patients. In addition, 33.33% (5/15) of aneurysms without complete occlusion at initial treatment showing complete occlusion on follow-up angiograms, compared with 36.36% (4/11) of aneurysms with initial complete occlusion showing recanalization on follow-up angiograms. These changes at follow-up may be due to further aneurysmal thrombosis and alterations in perianeurysmal hemodynamics (6, 7, 36).

Hemodynamics-related factors

Histopathological studies suggested that thrombus formation and active inflammation occur within the aneurysm dome while the aneurysm neck remained perfused in the first month, while the aneurysm is then excluded from the parent vessel by formation of a neointimal layer across the aneurysm neck at several months following embolization (34, 37–39). Thus, hemodynamics at the aneurysm neck, which is in direct contact with blood flow, may be an important factor leading to aneurysm recanalization prior to neointimal layer formation.

Hemodynamic analyses using CFD methods showed that high velocity, WSS and pressure may contribute to aneurysm recanalization after coiling (6, 7, 29). This may relate to obstruction and slowing of intra-aneurysmal blood flow circulation by the coils, which promotes blood stagnation and thrombosis. However, when the aneurysm neck is exposed to high velocity, WSS and pressure, the local blood coagulation process and thrombosis are prevented, the formation of neointimal layer is delayed, and eventually, the permanent barrier cannot form, which results in recanalization of embolized aneurysms. In the present study, we found that the marked reduction of velocity and WSS at the aneurysm neck before and after treatment was favorable for the mid-term durability of aneurysm embolization.

Unlike previous studies, we analyzed the hemodynamic characteristics related to recanalization in multiple intracranial aneurysms in the same patient, in whom the patient-related genetics and environmental factors are naturally balanced. In addition, previous studies performed hemodynamic analyses on recanalization using aneurysms treated by coiling only, while the Enterprise stent can create a mechanical scaffold as well as alter perianeurysmal hemodynamics (3, 4, 6, 7, 9, 18, 35). Therefore, for aneurysms treated by stent-assisted coiling in our study, a patient-specific virtual stent-deployment technique was used to create and place the stents within the vascular models, which was more consistent with the clinical situation. We found that the velocity at the aneurysmal neck was significantly reduced in the stent-assisted coiling group than the coiling group ($p<0.001$). The stent not only possible modified the flow dynamics, but also may allow for better packing density although the initial angiographic results had no significance between two groups.

Limitations

There are some limitations of our study. The mean 11.46-month follow-up angiogram may be insufficient and the sample size was relatively small due to the strict inclusion criteria. Confirmation of our findings is required in a multicenter, randomized and controlled clinical trial with multiple regression analysis. Similar to most CFD simulation, the assumption of rigid walls, Newtonian blood properties, and physiological but not patient-specific flow-boundary conditions were used and some variables such as vascular resistance cannot quantitatively evaluated. Additionally, aneurysm recanalization is a multifactorial problem and cannot be elucidated simply by several factors. Future studies are required to assess more factors comprehensively.

Conclusions

Using a combination of aneurysm-specific, treatment-related, and hemodynamics-related analysis, we found that small aneurysm size and neck width, unruptured aneurysm, and perianeurysmal hemodynamics with marked reduction were important factors associated with the mid-term durability of aneurysm embolization. The multiple intracranial aneurysms with different outcomes after endovascular treatment may be a useful disease model in which patient-specific risk factors are balanced to investigate possible features linked to aneurysm recanalization.

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Abbreviations

CFD	computational fluid dynamics
DSA	digital subtraction angiography
WSS	wall shear stress

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Highlights

1. Thirteen pairs of multiple aneurysms with different outcomes (recanalized or stable) in the same patient were collected.
2. Patient-specific models were constructed and analyzed by a computational fluid dynamics method.
3. We evaluated the aneurysm-specific, treatment-related, and hemodynamics-related factors, and aimed to explore the reason as one aneurysm recanalized, and the other did not.
4. Small aneurysm size and neck width, unruptured aneurysm, and perianeurysmal hemodynamics with marked reduction maybe important factors associated with the aneurysm embolization.

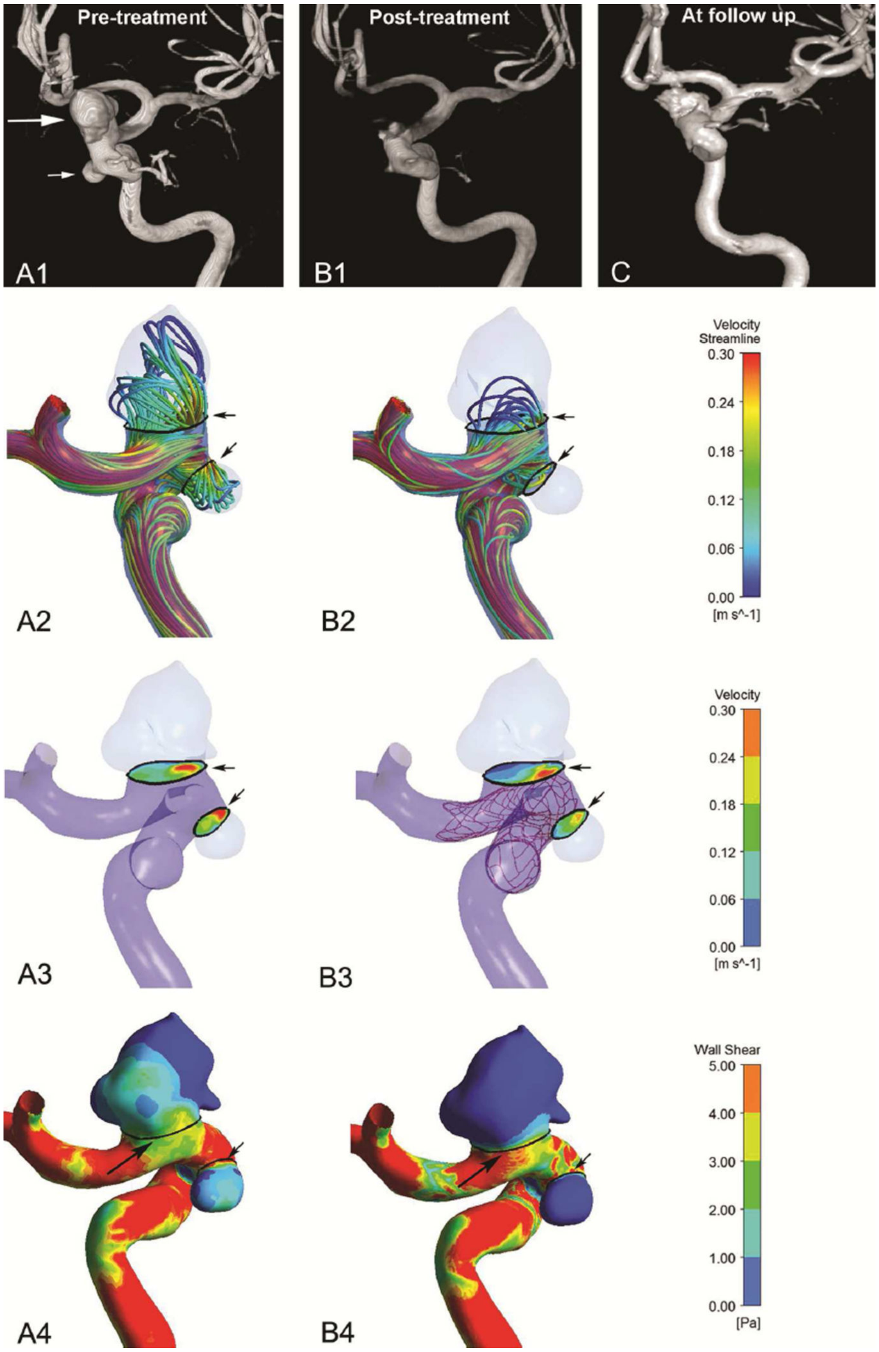

Figure 1. The hemodynamic analysis of multiple intracranial aneurysms with different outcomes (recanalized or stable) on the unilateral anterior circulation (case 1)

The angiograms of recanalized (A1, large arrow) and stable (A1, small arrow) aneurysms at pre-and post-treatment and follow-up were obtained. Hemodynamic analyses (streamline [A2 and B2], velocity [A3 and C3], and wall shear stress [WSS, A4 and B4] at the systolic peak) were conducted. Before treatment, the overall blood flow patterns of the two aneurysms were similar (A2, arrows). After treatment, the motion of blood flow into the aneurysm sac was inhibited by the stent and coils (B2, arrows). The reduction of velocity was more obvious at the stable aneurysm neck than for the recanalized aneurysm (65.82%

vs. 29.98%; A3 and B3, arrows). The WSS around the circumference of the aneurysm ostium in the stable aneurysm was markedly reduced (70.97%; A4 and B4, small arrows), whereas the recanalized aneurysm had a higher WSS than pre-embolization (−8.85%; A4 and B4, large arrows).

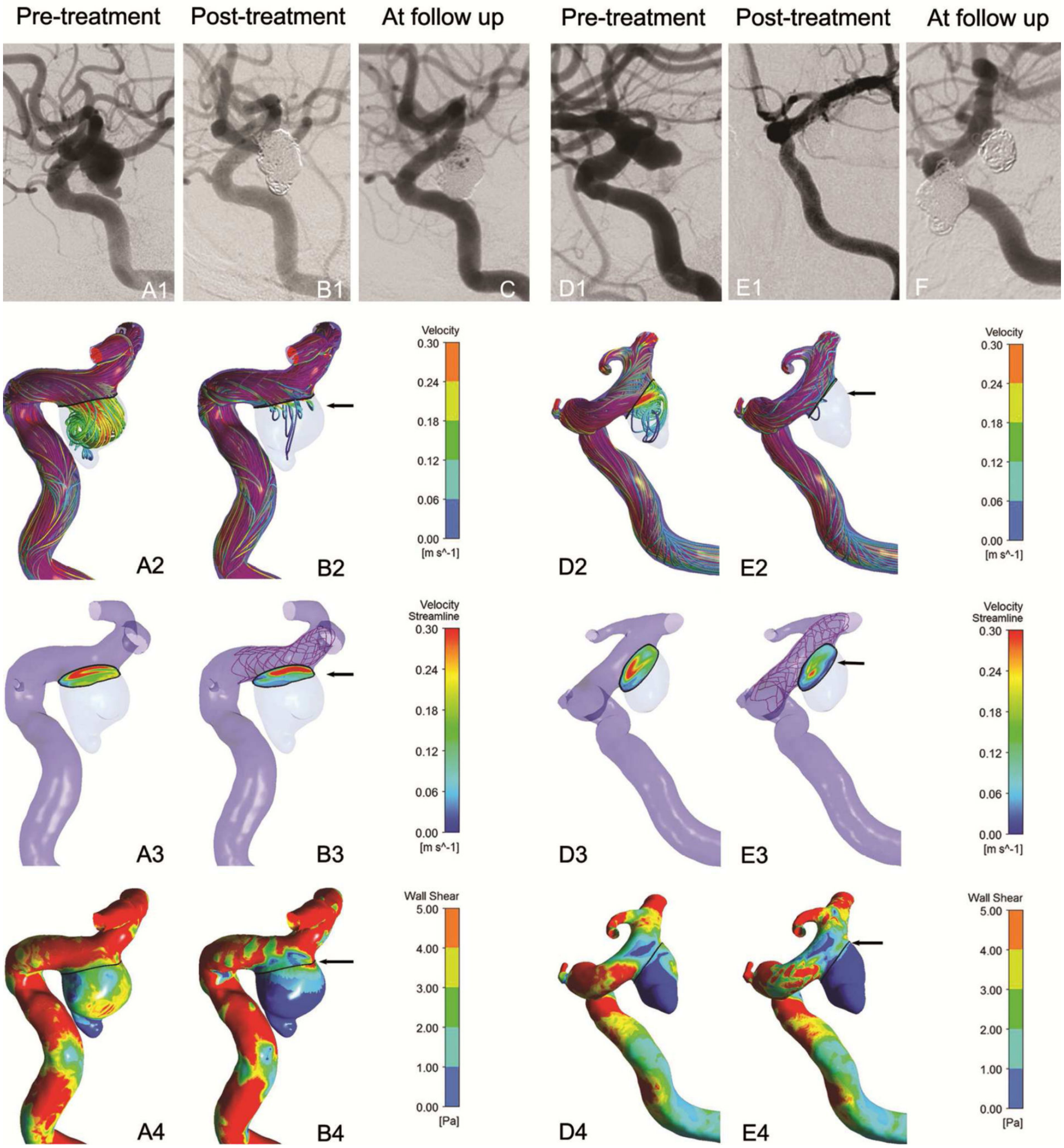

Figure 2. The hemodynamic analysis of mirror aneurysms with different outcomes on the bilateral ICA (case 6)

The angiograms of recanalized (A) and stable (D) aneurysms at pre- and post-treatment and follow-up were obtained. Hemodynamic analyses were conducted. Before treatment, the overall blood flow patterns were similar (A2 and D2). After treatment, the motion of blood flow into the aneurysm sac was inhibited by the stent and coils (B2 and E2, arrows). The reduction of velocity was more obvious at the stable aneurysm neck than for the recanalized aneurysm (51.81% *vs.* 43.88%; B3 and E3, arrows). The WSS in the stable aneurysm was markedly reduced than recanalized one (44.50% *vs.* 27.00%; A4-E4, arrows).

Table 1

Characteristics of patients and aneurysms

Case	Age, y	Sex	S/D	HTN	Site	Rupture	Operation	Initial angiographic result	Follow-up result		Follow-up time, month	Re-treatment
1	59	F	no/no	no	Lt C6	no	stent-assisted coiling	Residual neck	Residual aneurysm	Recanalization	5	Coiling
					Lt C5	no	stent-assisted coiling	Residual neck	Residual neck	Stable	5	
2	36	F	no/no	no	Lt C7	no	stent-assisted coiling	Residual neck	Residual aneurysm	Recanalization	30	LVIS only
					Lt C6	no	stent-assisted coiling	Residual aneurysm	Complete occlusion	Cure	30	
3	48	F	no/no	yes	Rt C6	no	stent-assisted coiling	Complete occlusion	Residual neck	Recanalization	5	Further observation
					Rt C7	no	stent-assisted coiling	Complete occlusion	Complete occlusion	Stable	5	
4	49	F	yes/yes	yes	Rt C7	yes	coiling	Residual neck	Residual aneurysm	Recanalization	25	Further observation
					Lt C7	no	stent-assisted coiling	Complete occlusion	Complete occlusion	Stable	15	
					Lt C6	no	no					
5	54	F	no/no	yes	Lt C4	no	stent-assisted coiling	Residual aneurysm	Residual aneurysm	Recanalization	7	Further observation
					Rt C4	no	stent-assisted coiling	Residual aneurysm	Complete occlusion	Cure	13	
6	63	F	no/no	yes	Lt C7	no	stent-assisted coiling	Complete occlusion	Residual aneurysm	Recanalization	11	Coiling
					Rt C7	no	stent-assisted coiling	Complete occlusion	Complete occlusion	Stable	11	
7	58	M	yes/yes	yes	Rt C6	no	coiling	Residual neck	Residual aneurysm	Recanalization	5	Further observation
					Lt C6	no	stent-assisted coiling	Residual neck	Complete occlusion	Cure	5	
8	55	F	no/no	yes	Lt C7	yes	coiling	Residual neck	Residual aneurysm	Recanalization	8	Further observation
					Rt C7	no	coiling	Complete occlusion	Complete occlusion	Stable	8	
9	58	F	no/no	no	Lt ACA	no	stent-assisted coiling	Complete occlusion	Residual neck	Recanalization	25	Further observation
					Lt PCA	no	stent-assisted coiling	Residual aneurysm	Complete occlusion	Cure	25	
10	62	F	no/no	yes	Lt C7	yes	coiling	Residual neck	Residual aneurysm	Recanalization	11	Coiling
					Rt C7	no	stent-assisted coiling	Complete occlusion	Complete occlusion	Stable	11	
11	32	F	no/no	yes	Lt ACoA	no	coiling	Complete occlusion	Residual neck	Recanalization	5	Coiling
					Rt C7	no	coiling	Complete occlusion	Complete occlusion	Stable	5	
12	62	F	no/no	yes	Lt C6	no	stent-assisted coiling	Residual neck	Residual aneurysm	Recanalization	7	Further observation
					Rt C7	no	coiling	Complete occlusion	Complete occlusion	Stable	7	
13	35	M	no/yes	no	Rt C6	no	stent-assisted coiling	Residual neck	Residual aneurysm	Recanalization	7	Further observation
					Lt C6	no	stent-assisted coiling	Residual neck	Complete occlusion	Cure	7	

ACA, anterior cerebellar artery; ACoA, anterior communicating artery; C4, cavernous; C5, clinoid; C6, ophthalmic; C7, communicating; D, drinking; F, female; HTN, hypertension; LVIS, Low-profile Visualized Intraluminal Support device; M, male; PCA, posterior cerebellar artery; S = smoking.

Table 2

Analyses of the aneurysm-specific, treatment-related, and hemodynamics-related factors

Variables[*]	**Total (n=26)**	**Recanalized group (n=13)**	**Stable group (n=13)**	***p* value**
Aneurysm-specific factors				
Aneurysm size, mm	8.53 (5.34)	10.21 (5.22)	6.84 (5.10)	0.021
Neck width, mm	4.69 (2.02)	5.34 (2.06)	4.04 (1.82)	0.027
Rupture				
Yes (%)	3 (11.54)	3 (23.08)	0 (0.00)	0.002
No (%)	23 (88.46)	10 (76.92)	13 (100.00)	
Location				
Sidewall (%)	15 (57.69)	7 (53.85)	8 (61.54)	0.774
Bifurcation (%)	11 (42.31)	6 (46.15)	5 (38.46)	
Treatment-related factors				
Packing density, %	24.03 (5.01)	23.59 (5.03)	24.46 (5.15)	0.632
Duration of follow-up, month	11.46 (8.27)	11.62 (8.89)	11.31 (7.96)	0.746
Stent using				
Yes (%)	18 (69.23)	8 (61.54)	10 (76.92)	0.302
No (%)	8 (30.77)	5 (38.46)	3 (23.08)	
Initial angiographic result				
Complete occlusion (%)	11 (42.31)	4 (30.77)	7 (53.85)	0.129
Residual neck (%)	11 (42.31)	8 (61.54)	3 (23.08)	
Residual aneurysm (%)	4 (15.38)	1 (7.69)	3 (23.08)	
Hemodynamics-related factors				
Reduction ratio in velocity, %	34.67 (19.15)	26.66 (17.16)	42.68 (18.18)	0.008
Reduction ratio in WSS, %	21.77 (23.48)	12.16 (19.84)	31.37 (23.56)	0.024
Reduction ratio in Pressure, %	−13.71 (12.90)	−14.69 (12.37)	−12.74 (13.85)	0.604

WSS, wall shear stress.

[*] Paired-sample t test, Mann-Whitney *U* test or McNemar's test as appropriate.

Table 3

Analyses of the immediate angiographic results and hemodynamic results between the stent-assisted coiling and the coiling patients

	Stent-assisted coiling (n=18)	Coiling (n=8)	*p* value
Initial angiographic result			0.249
Complete occlusion (%)	7 (38.89)	4 (50.00)	
Residual neck (%)	6 (33.33)	4 (50.00)	
Residual aneurysm (%)	5 (27.78)	0 (0.00)	
Hemodynamics-related factors			
Reduction ratio in velocity, %	42.61 (15.73)	16.80 (13.46)	<0.001
Reduction ratio in WSS, %	21.24 (26.26)	22.95 (17.10)	0.867
Reduction ratio in Pressure, %	−16.78 (13.38)	−6.81 (8.98)	0.067