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Comparison of Hemodynamics between Completely and Incompletely Dilated Flow Diverters in Simple Vascular Models

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***Abstract*—Poor vessel wall apposition of flow diverter (FD) stents poses risks for complications when treating intracranial aneurysms. We performed computational fluid dynamics (CFD) simulations on simple vascular models to compare the hemodynamics when FDs completely and incompletely dilated. As a result, when FD is incompletely dilated, some hemodynamic parameters such as *WSS*, pressure, and *EL* are significantly increased due to inadequate diversion effects, which might cause complications such as delayed rupture.**

***Clinical Relevance*—This study numerically showed that incompletely dilated FD is likely to enhance the detrimental therapeutic effects on cerebral aneurysms.**

I. Introduction

Flow Diverter (FD) has been widely used to treat large, fusiform, or wide-neck cerebral aneurysms which were difficult to treat with conventional methods such as coil embolization. However, it has been reported that FDs did not dilate completely in cerebral arteries with high curvature [1]. Incompletely dilated FDs may impede blood flow in parent arteries and prevent thrombosis inside aneurysms. The incompleteness of the deployment may lead to complications such as thromboembolism. Nonetheless, there are few studies investigating hemodynamics with incompletely dilated FDs. The purpose of this study is to clarify the hemodynamic impact of incompletely dilated FDs by conducting computational fluid dynamics (CFD).

II. Methods

In order to eliminate hemodynamic differences due to patient-specific arteries, simple vascular models were created imitating giant cerebral aneurysms developed in the internal carotid artery using ZW3D 2015 (ZWCAD Software Co., Ltd., Guangzhou, China). The models consisted of the following three types: one with an aneurysm placed at the apex of the parent artery (Center Aneurysm), one with an aneurysm displaced 45 degrees to the distal side (Distal Aneurysm), and one with an aneurysm displaced 45 degrees to the proximal side (Proximal Aneurysm). The Pipeline™ (Covidien/Medtronic, Irvine, CA, USA) was deployed according to the following three situations: completely dilated FD (Complete) modeled by our virtual stenting program, incompletely dilated FDs on the distal and proximal sides (Incomplete-D and Incomplete-P) obtained from Abaqus/Explicit ver.6.14 (Dassault Systèmes Simulia Corp., Providence, USA). We conducted four CFD simulations for each simple vascular model, including no FD deployed pattern (Pre-Deploy) using ANSYS CFX 2020R1 (ANSYS, Inc., Canonsburg, USA). Therefore, we performed 12 simulations in total. Four hemodynamic parameters, volume flow rate into aneurysm neck surfaces (*VF*), maximum value of wall shear stress at aneurysm walls (WSS_{max}), mean value of static pressure in aneurysms (*SP*), and energy loss due to FDs (*EL*), were calculated, and their change rates (*CR*) based on the value of each Pre-Deploy pattern were compared.

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III. Results

Table 1 shows the *CR* of hemodynamic parameters in each pattern. The averaged *CR* of *VF* and WSS_{max} in the Completes were -52.7% and -34.7%, respectively, whereas they increased in several patterns of the Incompletes. In addition, the *CR* of *SP* and *EL* were relatively small in the Completes, although they increased significantly by an average of +34.8% and +86.6%, respectively, in the Incompletes.

TABLE I. *CR* OF HEMODYNAMIC PARAMETERS

		VF [%]	WSS_{max} [%]	*SP* [%]	*EL* [%]
Center Aneurysm	Pre-Deploy	Standard Value of Center Aneurysm			
	Complete	−51.6	−29.2	−0.286	−5.80
	Incomplete-D	+23.6	+70.3	+44.3	+67.4
	Incomplete-P	−8.90	+5.56	+14.6	+67.4
Distal Aneurysm	Pre-Deploy	Standard Value of Distal Aneurysm			
	Complete	−64.2	−44.0	−0.226	+4.47
	Incomplete-D	−23.8	+23.1	+17.7	+90.2
	Incomplete-P	−8.90	−14.6	+9.66	+110
Proximal Aneurysm	Pre-Deploy	Standard Value of Proximal Aneurysm			
	Complete	−42.2	−30.9	+1.58	+1.67
	Incomplete-D	−46.4	−46.7	+68.1	+91.5
	Incomplete-P	+39.4	−21.8	+54.5	+92.9

IV. Discussion & Conclusion

Incomplete dilation of FDs may lead to an insufficient flow diversion effect. In addition, incomplete deployment may accelerate blood flow and increase *WSS* due to a narrow gap between the FD and the vessel wall, thereby stressing vascular walls. The increase of *SP* with incompletely dilated FDs may lead to a delayed rupture with pressure increase. Therefore, incompletely dilated FDs may have adverse effects on the treatment of cerebral aneurysms.

References

[1] B. M. Kim, et al. “Pipeline Embolization Device for Large/Giant or Fusiform Aneurysms: An Initial Multi-Center Experience in Korea”, *Neurointervention,* vol. 11, no. 1, 2016, pp. 10-17.