Hemodynamic Alteration after Flow Diversion in Complex Intracranial Aneurysms: Utilization of a Computer-generated, Virtual Pipeline Embolization Device

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Introduction

Flow diversion via Pipeline Embolization Device (PED) represents the most recent advancement in endovascular therapy of intracranial aneurysms. However, the exact mechanism by which flow diversion leads to aneurysm thrombosis remains unclear. This study explores the intra-aneurysmal hemodynamic changes after PED placement and their relationship with aneurysm occlusion.

Methods

In this proof of concept study, a digital PED stent, along with its mechanical deployment process in silico, was recapitulated using our recently developed high fidelity virtual stenting algorithm. The virtual PEDs were applied to aneurysm models constructed from rotational angiography of 3 patients who were treated in real-life with PEDs. Pre- and post-treatment aneurysmal hemodynamics were analyzed using computational fluid dynamics (CFD) simulation. Flow-stasis parameters were correlated with the clinical outcome of aneurysm occlusion.

Learning Objectives

To understand hemodynamic alternations after PED deployment contributes significantly to aneurysm

Results

Virtual PED stents were successfully generated for 3 patients with complex intracranial aneurysms who were treated with PEDs in real-life. The mean age at time of surgery was 58.7 years and 2 were female. The average aneurysm size was 10.7 mm, including a vertebral artery dissecting aneurysm, a giant supraclinoid internal carotid artery (ICA) aneurysm, and two tandem aneurysms at ICA ophthalmic segment. Two patients were treated with 1 PED and the other with giant ICA aneurysm had 2 PEDs. CFD simulation with virtual stent demonstrated that each PED placement resulted in 54.3% reduction of average wall shear stress (WSS) and 40.5% reduction of aneurysm inflow rate. Hemodynamic changes from each PED is highly variable, with decrease in WSS ranging between 27.3% and 84.4% among different aneurysms. Three aneurysms were completely occluded after 6 months, all of which had greater than 50% and 30% reduction in WSS and inflow rate, respectively.

Conclusions

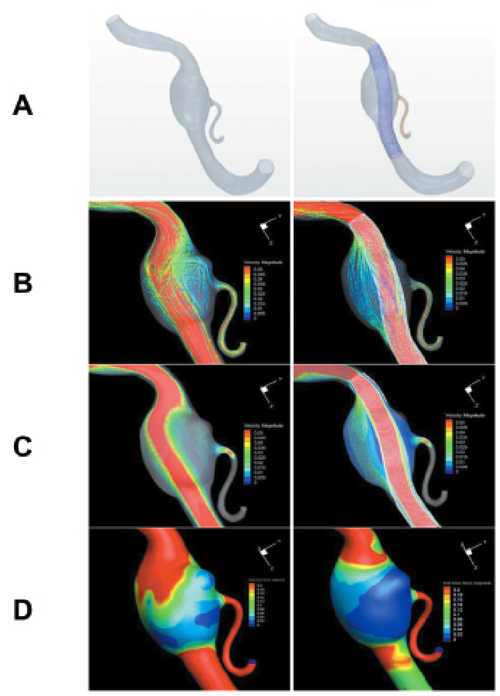
In this proof of concept study, we demonstrated that a virtual PED stent can be combined with CFD analyses in patient-specific aneurysm models to estimate intra-

Table 1. Demographic and clinical information

Patient Number	Age	Gender	Aneurysm location	Aneurysm type	Aneurysm size (mm)	PED placement	Outcome
Patient 1	66	Male	Right VA	Fusiform, dissecting	13x10mm	4.5x25mm	Complete occlusion
Patient 2	65	Female	Left ICA	Saccular, giant	20x16mm	4.5x20mm, 4.5x14mm	Complete occlusion
Patient 3	45	Female	Right ICA	Saccular, tandem	Aneurysm a:5x4mm Aneurysm b:5x6.5mm	3.75x20mm	Aneurysm a: complete occlusion; Aneurysm b: partial occlusion

Illustrative case 1

Figure 1



Initial imaging Figure 2 3-month follow-up

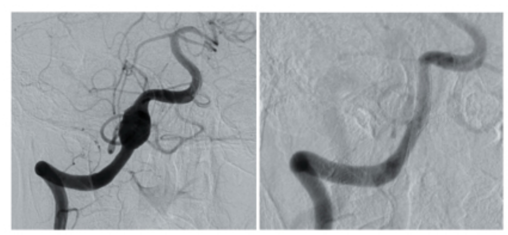
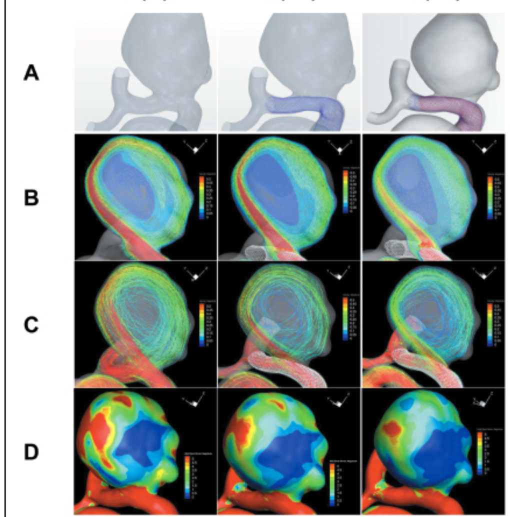


Table 2. Relative hemodynamic parameters for the three aneurysms

Aneurysm Case	Scenario	Average Aneurysmal Velocity	Inflow Rate	Turnover Time	Average WSS
Aneurysm I	I (U)	100.0%	100.0%	100.0%	100.0%
	I (T)	23.7%	17.5%	572.1%	26.0%
Aneurysm II	II (U)	100.0%	100.0%	100.0%	100.0%
	II (T1)	79.7%	80.0%	125.0%	68.2%
	II (T2)	60.6%	61.4%	163.0%	40.9%
Aneurysm III	III a (U)	100.0%	100.0%	100.0%	100.0%
	III a (T)	22.3%	47.0%	213.0%	15.6%
	III b (U)	100.0%	100.0%	100.0%	100.0%
	III b (T)	62.0%	71.6%	139.6%	49.1%

Illustrative case 2

Figure 3



Initial imaging Figure 4 4-month follow-up