Predicting Pipeline Embolization Device Treatment Outcomes using Patient-specific Computational Fluid Dynamics Simulations

Cory Kelly BS; Michael C Barbour; Venkat K Chivukula PhD; Christian Geindreau PhD; Sabine Rolland du Roscoat; Alberto Aliseda PhD; Louis J. Kim MD; Michael Robert Levitt MD

University of Washington & Université Grenoble Alpes

CNS 2018 ANNUAL MEETING HOUSTON, TEXAS OCTOBER 6-10, 2018

Learning Objectives

By the conclusion of this session, participants should be able to:

1) Understand that the Pipeline Embolization Devices redirect blood flow along the parent vessel preventing recirculation in the aneurysm allowing for a thrombus initiation and subsequent parent vessel re-endothelialization.

2) Be familiar with the hemodynamic factors that contribute to aneurysm recurrence and may be associated with Pipeline Embolization Device treatment outcomes.

3) Recognize that a significantly greater reduction in aneurysm flow rate, aneurysm wall shear stress (WSS), and viscous dissipation, and a greater increase in neck plane shear stress is associated with Pipeline Embolization Device treatment success.

Introduction

Treatment of intracranial aneurysms with flow-diverting stents has become more prevalent, but the factors that contribute to treatment outcome are not yet clear. Computational simulations can elucidate mechanisms such as hemodynamic factors that contribute to aneurysm recurrence and treatment outcome. This is the first study to utilize patient-specific boundary conditions to improve model accuracy and determine hemodynamic variables associated with long-term treatment outcomes of the Pipeline Embolization Device (PED) (Medtronic,

Methods

19 patients with unruptured intracranial aneurysms treated with pipelines were included. Patient-specific blood pressure and velocity were obtained intraoperatively immediately prior to and following treatment via intravascular Doppler ultrasound to define the computational model boundary conditions. Stent geometry and porosity was obtained via ultra-high resolution Synchrotron X-ray microtomography. Pre-treatment and post-treatment hemodynamic values were calculated. Treatment outcome was determined at 18-month follow-up. Retreatment or recommendation for retreatment during this period was considered a failure.

Results

A significantly greater reduction in aneurysm flow rate, aneurysm wall shear stress (WSS), and viscous dissipation, and a greater increase in neck plane shear stress were associated with PED treatment success (Figure 1). Post-treatment aneurysm flow was not different between groups. No significant difference in averaged-aneurysm neck plane and averaged aneurysm volumes was found between outcome groups.

Conclusions

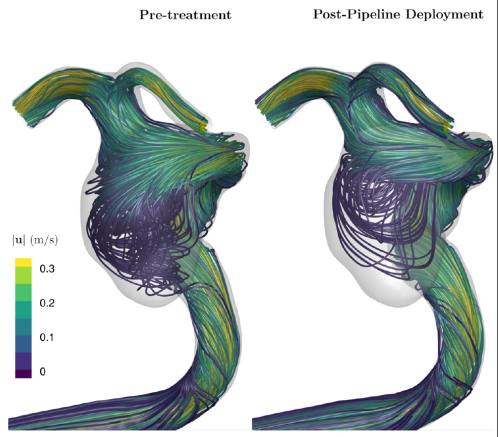
The results demonstrate that hemodynamic variables contribute to aneurysm recurrence and may be associated with PED treatment outcomes. The hemodynamic findings of the success group support the understanding that PED redirects blood flow along the parent vessel preventing recirculation in the aneurysm allowing for a thrombus initiation and subsequent parent vessel re-endothelialization (Figure 2). Contrarily, persistent flow in the failure group likely prevents this healing process. Proposed mechanisms for this treatment-resistant flow include demand from vessels originating in the aneurysm beyond the stent as well as increased stent porosity along highly-curved vessels.

Figure 1

		Success	Failure	p-value
Aneurysm Flow Rate	Systolic	-42.03	-27.3	0.07
	Time-Averaged	-48.6	-39.5	0.32
Aneurysm Dome WSS	Systolic	-46.4	-32.0	0.09
	Time-Averaged	-50.1	-40.1	0.31
Neck Plane Shear, $\lvert\tau_{neck}\rvert$	Systolic	50.8	39.1	0.8
	Time-Averaged	26.7	20.0	0.75
Viscous Dissipation	Systolic	-57.9	-41.9	0.08
	Time-Averaged	-64.4	-49.9	0.13
Aneurysm Average Velocity	Systolic	-46.6	-37.9	0.29
	Time-Averaged			

Post-treatment change in hemodynamic values of aneurysms treated with Pipeline Embolization Devices

Figure 2



Comparison of aneurysmal blood flow rate before treatment (left) and after treatment with a Pipeline Embolization Device (right).