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An Idealized Carotid Siphon Model for Assessment of Braid Deformation in Flow-Diverter Stents

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1. Introduction

The introduction of flow-diverter stents represented a significant breakthrough in the endovascular treatment of intracranial aneurysms. This stent allows reconstruction of the arterial wall by occluding the aneurysm neck, thereby promoting arterial healing and progressive aneurysm occlusion over the following months.

Braid deformation and incomplete wall apposition after flow-diverter implantation are associated with adverse clinical outcomes, yet their mechanical determinants remain poorly understood (Popica et al., 2025). Existing bench-top protocols rely predominantly on global radial force measurements, which do not reproduce the anatomically constrained, local loading conditions believed to drive deformation in clinical practice (Fiehler et al., 2025). We developed an idealized carotid siphon model for the characterization of braid deformation propagation under local radial loading and evaluated five flow-diverter designs using this framework.

2. Methods

An idealized vascular model was constructed from average anatomical parameters derived from digital subtraction angiography of five patients, capturing mean vessel curvature and the proximal-to-distal diameter taper of the carotid siphon. Three lateral access ports were incorporated at predefined locations along the model, proximal, intermediate, and distal (Figure 1, images A&B), to enable controlled local constriction via a circumferential polypropylene wire, acting as a belt, connected to a tensile testing machine. Five flow-diverter stents, differing in wire count, material composition (cobalt-chromium, nitinol-based drawn filled tube [DFT], or cobalt-chromium DFT, platinum [PtW]), and end design (standard vs. flared), were tested under identical conditions at 37°C (Table 1). Device behavior under local compression was recorded synchronously by two high-resolution cameras. Braid deformation geometry was quantified at peak loading using motion-analysis software, with measurement of diameters at the compression point, the midpoint of the deformed segment, and the distal free segment, as well as axial deformation length. A set of geometric indices, including a recovery index, taper ratio, relative luminal area deformation, and normalized distal diameter, was derived to characterize the extent and shape of deformation propagation. Testing within the anatomical model was preceded by a structured preliminary characterization protocol comprising flat-plate radial compression, three-point bending, cantilever flexibility at the device extremities, and local radial force measurement in unconstrained conditions, to contextualize anatomical model results against standard mechanical parameters (Velvaluri et al., 2021).

3. Results and discussion

The anatomical model discriminated between device behaviors that standard bench-top characterization could not distinguish. Three-point bending, cantilever

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Table 1. Structural characteristics of the investigated flow-diverter stents and maximum constriction force recorded at the point of peak compression, corresponding to the instant of deformation measurement.

STENT	Stent diameter (mm)	Stent length (mm)	Wires number and composition	PROXIMAL Max Force mN	INTERMEDIATE Max Force mN	DISTAL Max Force mN
Pipeline Flex	4	14	36 CoCrNi+ 12 PtW	141.1±1.9	145.3±0.3	111.9±2.6
Pipeline Vantage	4	14	DFT 48 CoCrNi (Pt core) + 16 CoCrNi	49.8±0.5	118.7±0.8	67.9±0.3
Silk Vista	4	30	DFT 48 NiTi (Pt core)	95.6±2.9	98.9±1.2	84.9±1.1
Surpass Evolve	4	17	54 CoCr+ 12 PtW	70.9±1	134±0.7	95±1.6
Derivo 2	4	25	DFT 48 NiTi (Pt core)	103.2±1.3	105.5±0.8	74.8±0.9

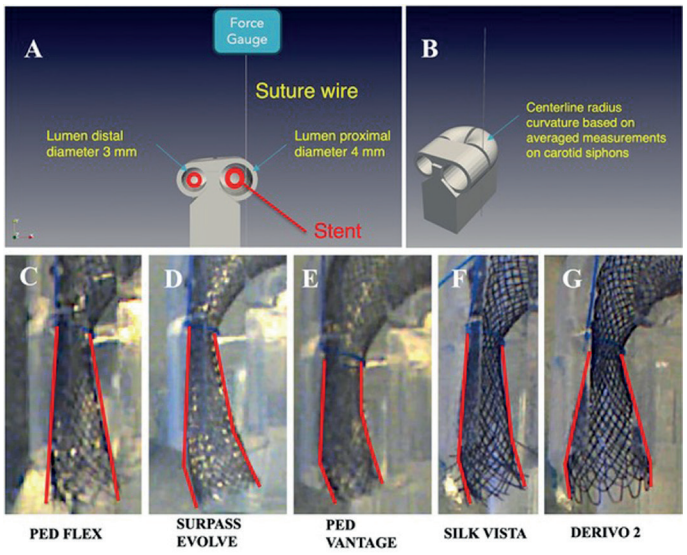

Figure 1. Idealized vascular model (A-B). Braid deformation under local radial compression in the anatomical model, with different geometric parameters (C-G).

flexibility at the device extremities, and flat-plate radial compression provide single-value descriptors of global stiffness and radial force, but these parameters do not capture how a device responds to the spatially localized, anatomically constrained loading encountered in vivo: devices with comparable global mechanical values diverged substantially once tested within the constrained curved model. Local radial compression induced markedly different deformation propagation patterns across devices (Figure 1). Devices incorporating DFT wire technology and those with higher wire counts demonstrated greater axial extension of deformation beyond the loading point, assuming a tubular configuration rather than the funnel-shaped profile associated with favorable braid adaptation. The device with the highest wire count showed the most pronounced tubular collapse at both proximal and distal compression sites, consistent with the reduced capacity of high-density braids to redistribute local loading through inter-wire sliding (Shapiro et al., 2014; Jun et al., 2024). Conversely, the device featuring flared ends maintained a funnel-shaped profile distal to the compression point, indicating that end design may limit axial propagation of deformation toward the device margins.

4. Conclusions

The idealized carotid siphon model provides a reproducible and anatomically calibrated framework for the assessment of flow-diverter mechanical behavior. Whereas standard bench-top tests quantify global stiffness and radial force in isolation, they cannot predict device behavior in an anatomy-like context; the present model reveals device-specific vulnerabilities that remain concealed under conventional characterization. Local radial compression applied to the implanted devices could induce and propagate braid deformation, and the extent of this propagation was shaped by device architecture, specifically DFT wire composition, wire count, and end design.

Conflict of Interest Statement

PM is consultant for Stryker and Medtronic.

Contributor Roles

GB, OB, PR, PM, HL, FJ: Conceptualization, Methodology, Writing original draft, Methodology,

Validation, Writing- review & editing; PM, HL, FJ: Supervision.

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