High Fidelity Medical Device Simulations for the Pre-Planning of Endovascular Cerebral Aneurysm Treatments

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INTRODUCTION

A cerebral aneurysm (CA) is an abnormal ballooning of the vessel wall in the brain that occurs in approximately 5% of the general population [1]. Ruptured CAs cause death in nearly 45% of cases [1–2].

Figure 1: An example of a cerebral aneurysm (a) and endovascular stent treatment (b)

Endovascular treatment is the most common treatment option for CAs. Unfortunately, current endovascular planning paradigms are primarily qualitative and driven by prior training, experience, and convention. Treatment planning is also unsuccessful in many cases; intra-procedure mortality rates of nearly 10% and reintervention rates as high as 22% [3].

Therefore, there is critical need to improve endovascular treatment planning. Preoperative evaluation of different treatment strategies and outcomes presents a promising means toward that end.

Figure 2: Treatment planning simulation workflow

We present a simulation workflow that leverages real patient data, high fidelity finite element medical device models, and computational fluid dynamics to simulate treatment for each unique patient case. Device deployment and fluid dynamic simulations in multiple CAs are validated against experimental data.

METHODS

COMPUTATIONAL MODEL CONSTRUCTION

– CAs were segmented from patient CT image data using Mimics software (Materialize, Ann Arbor, MI, USA)
– 3D masks were exported from Mimics in STL file format

Figure 3: CT image data (a), reconstructed computational aneurysm model (b), printed physical core model (c), and transparent model used in flow experimentation

Figure 4: Finite element simulation of a commercial braided stent deployment in a patient-specific aneurysm model

PHYSICAL MODEL CONSTRUCTION

– A ZPrinter 650RP system (ZCorporation, Burlington, MA, USA) was used to print physical cores of the CA models
– The printed cores were cast in urethane then evacuated, producing lost-core flow models for experimentation

FLOW EXPERIMENTATION

– The lost-core CA models were connected to a flow loop
– Three different medical devices were separately deployed into each model
– Flow velocities inside the aneurysm were measured using particle image velocimetry

FINITE ELEMENT MEDICAL DEVICE SIMULATIONS

– Fundamental mechanical and material test validations were previously performed for each finite element medical device model
– Device deployment was simulated using EVIS (EndoVantage LLC, Scottsdale, AZ, USA)
– Simulations considered the (i) structural properties of the device and delivery system, (ii) catheter navigation, and (iii) clinical deployment procedure

COMPUTATIONAL FLUID DYNAMIC SIMULATIONS

– Pre- and post-treatment fluid dynamics were simulated using ANSYS Fluent (ANSYS Inc., Lebanon, NH, USA)
– A range of flow rates representing normal and diseased flow conditions were investigated in each model

RESULTS & DISCUSSION

DEVICE DEPLOYMENT COMPARISONS

– 3D comparisons of the simulated and (microCT scanned) physically treated models were performed to evaluate:
– Vessel wall coverage by the medical device
– Device diameter along the centerline of the device
– Volume occupied by the device
– Device cell area after deployment
– Preliminary analysis of the listed metrics shows good agreement between simulated and physical deployments

Figure 5: High resolution images of a simulated (a) and physically treated (b) CA model

Figure 6: 3D models of a simulated (a) and (microCT-scanned) physically treated (b) CA model

FLOW VELOCITY COMPARISONS

– Flow structures and velocity magnitudes in the simulated and physically treated models showed good agreement
– For example, in one CA model a 25.5% reduction in mean aneurysmal flow velocity magnitudes was found in the post-treatment simulations, which agreed with a 22.1% measured reduction in the experimental data

Figure 7: Flow velocity magnitudes in a CA model. Results are shown for the simulated (a & c) and experimental (b & d) cases. Pre- and post-treatment results are also presented.

FUTURE WORK

– Future work will focus on additional validations of the simulation workflow
– Device deployment and post-treatment flow simulations will also be compared to clinical data

REFERENCES