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IN VITRO AND COMPUTATIONAL EVALUATION OF DRAG FORCE ON AORTIC STENTGRAFTS

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INTRODUCTION

Endovascular grafting, an alternative to open surgery procedure, is a minimally invasive technique used for the treatment of aortic aneurysms (AA). However, post-operation complications like stentgraft migration, endoleaks and stentgraft failure still occur. The migration of stentgraft seen after endovascular repair raises concern over the long-term durability of these devices.

The primary reason for migration of stentgraft relates to the drag force imparted to the device from pulsatile flow on the stentgraft. When the drag force exceeds the fixation force, the device becomes unstable.Li [1] showed the peak drag force of 4N for a stented aneurysm model using fluid structure interaction. Chong et al [2] visualized the flow patterns in an *in vitro* aneurysm model for a commercial bifurcated stentgraft.

The purpose of this study is to evaluate the drag force on a stentgraft using an *in vitro* model and validate the results by compliant artery model using FSI formulation. These forces can be used as design guidelines for the fixation force needed at the proximal end of the stentgraft under physiological pulsatile flow. The peak drag force obtained for *in vitro* and compliant model is 2.11N and 2.45N with the percentage difference of 16%. Thus, in comparison to past studies on hemodynamics of aortic stentgrafts, this study is unique since the drag force has been studied both by experimental and numerical means.

METHODS

Experimental setup

Figure 1 shows a single pulse wave elastic tube *in vitro* model. A transonic flow probe is used to obtain the velocity profile proximal to the stentgraft. An internal pressure guide wire (Radi Medical systems, MA) is used to obtain the pressure distal to the stentgraft. Placing the tube in a water bath eliminates the effect of contact stresses between the elastic tube and bath surface.

The test fluid was Newtonian with a density of 1700 kg/m^3 and a viscosity of 0.04 Poise. The elastic tube was made up of elastomer (Sylgard 184, Dow corning, Midland, MI). The stentgraft was an iliac limb of a Zenith AAA endovascular graft. The stentgraft was placed inside an 80 cm elastic tube at ¼ of a distance from the distal end.

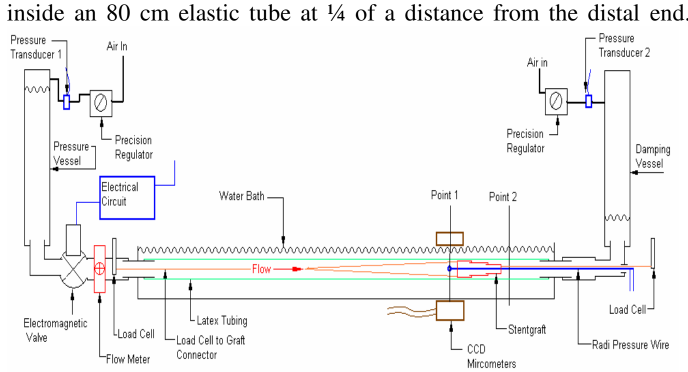

Figure 1. *In-vitro* experimental set up

The *in vitro* model has been developed to simulate the forces that would be encountered following the implantation procedure (i.e. the artery wall has healed and the stentgraft is fully expanded). Only a straight artery model was considered rather than a bulging aneurysm model [1].The elastic tubing here mimics the artery in the physiological condition, which has stentgraft fixed on its inner wall. Activating an electromagnetic valve for approximately 80 ms and maintaining a pressure differential of 150 mm Hg between two reservoirs generates a single pulse wave. When the desired flow and pressure is reached, the velocity is measured at the inlet of the stentgraft at point 1. Pressure is measured at the outlet of the stentgraft at point 2. The force acting on the proximal end of the stentgraft is measured by a load cell. The data of interest is the peak drag force acting on the stent-graft model. The peak pressure and flow allowed into the *in vitro* model are 130 mm Hg and 75 cm/s close to the physiological pulse used by Di Martino et al [3]. The sensors are monitored by a data acquisition unit and data is recorded onto a computer.

Compliant FSI Model

Computations are carried out assuming no endoleaks, homogeneous material properties, and using a linear elastic model. Figure 2 shows an axi–symmetric model of the stentgraft along with pulsatile fluid flow domain and stagnant fluid domain in between the elastic tube and inner stentgraft. The compliant model computations were performed using finite element method [4]. The fluid and solid equations using Arbitrary Lagrangian-Eulerian scheme were previously described in Banerjee et al [5]. The fluid is assumed to be Newtonian, which is acceptable for large arteries such as the aorta [6]. The thickness of the stent-graft and elastic tube is 0.254 mm and 0.752 mm, respectively. Table 1 shows the material properties.

Table 1: Material properties of stentgraft and elastic tube

Material properties	*Elastic tube*	*Stentgraft*
Young's Modulus	1.8 MPa	10 GPa
Poisson Ratio	0.49	0.27 [1]
Density	1.12 g/cm^3 [1]	6 g/cm^3 [1]

In vitro velocity profile in figure 3 is specified at the stentgraft inlet. The time varying pressure profile in figure 3 is specified at the outlet. The stentgraft was fixed in axial direction at the proximal end while the distal end is left free. Radial displacements were allowed for both stentgraft and elastic tube at inlet and outlet. Radial displacement of the axis is fixed.

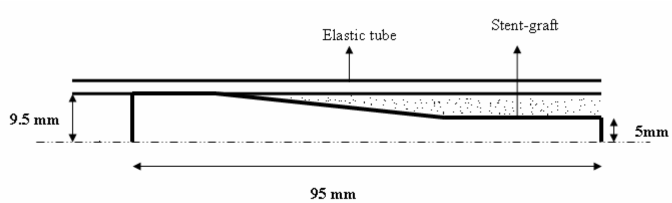

Figure 2. An axi-symmetric model of stentgraft along with elastic tube.

RESULTS AND DISCUSSION

Force and displacements are transferred along the interfaces between luminal fluid flow and stentgraft wall, and also between stagnant fluid and outer elastic tube. Figure 4 shows the comparison between the experimental drag force measured by the load cell and the force from the compliant model.

For the time up to 0.6s, there is a good agreement between the *in-vitro* and compliant model drag force data (4% difference). The peak drag force in the *in vitro* model was about 2.11 N while for compliant model it is about 2.45 N. The percentage difference between these two peaks is about 16%. Resch et al [7] showed maximum fixation force of about 4.5 N for commercial stentgrafts. For proper placement of the stentgraft, the drag force must be less than the fixation force. The drag force at time 1s is 0.67 N in the *in vitro* model and 1.6 N in the compliant model showing considerable difference. Thus, to obtain better agreement between the *in vitro* and compliant model, more accurate simultaneous acquisition of pressure and flow data in the *in vitro* model is needed.

The variation of the drag force with different dimensions of the stentgraft and change in outlet pressure profile is presently underway.

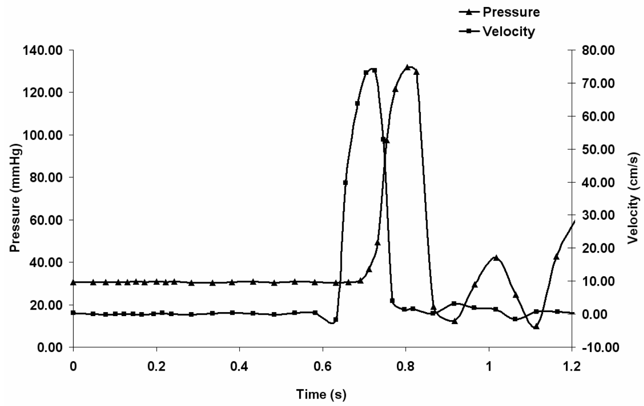

Figure 3. Pressure and Velocity profile from the *in-vitro* model

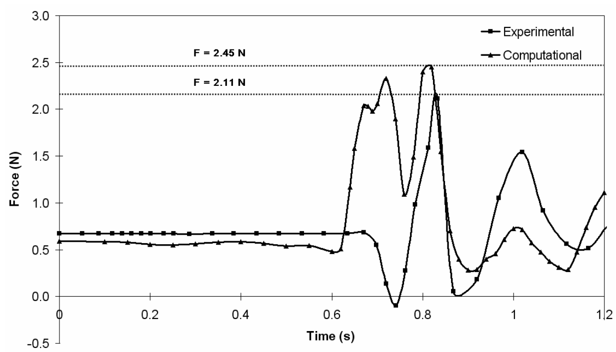

Figure 4. Comparison of Experimental and Computational Drag Force.

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