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Displacement Forces in Stent Grafts: Influence of Diameter Variation and Curvature Asymmetry

H. Roos [a,*], M. Tokarev [b], V. Chernoray [b], M. Ghaffari [d], M. Falkenberg [c], A. Jeppsson [d,e], H. Nilsson [b]

[a] Department of Hybrid and Interventional Surgery, Unit of Vascular Surgery, Sahlgrenska University Hospital, Gothenburg, Sweden
[b] Department of Applied Mechanics, Chalmers University of Technology, Gothenburg, Sweden
[c] Department of Radiology, Sahlgrenska University Hospital, Gothenburg, Sweden
[d] Department of Cardiothoracic Surgery, Sahlgrenska University Hospital, Gothenburg, Sweden
[e] Department of Molecular and Clinical Medicine, Institute of Medicine, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden

WHAT THIS PAPER ADDS

Flow induced displacement forces were assessed in an experimental model in EVAR iliac stent grafts in relation to distal diameter and asymmetric stent graft curvatures. Forces were particularly high at the distal end of bell-bottom grafts. Patients treated with bell-bottom grafts may require more vigilant surveillance and improved graft fixation.

Objectives: Long-term durability after endovascular aortic repair is influenced by stent graft migration causing types I and III endoleaks. Flow induced displacement forces have been shown to have the potential to cause migration. In this study, the influence of the distal diameter of iliac limb stent grafts and the shape of graft curvature on flow induced displacement forces, were investigated.
Methods: In an experimental pulsatile flow model mimicking aortic conditions in vivo, flow induced displacement forces at the proximal and distal ends of iliac limb stent grafts were studied at different angles (0—90°) and perfusion pressures (145/80, 170/90, 195/100 mmHg). Bell-bottomed, tapered, and non-tapered stent grafts and also asymmetric stent graft curvatures at 90° bend were studied. Measurements of graft movement were performed at all studied angulations and graft shapes.
Results: For all stent graft diameters, flow induced displacement forces increased with higher pressure and increased stent graft angulation. Forces in the bell-bottom graft were considerably higher than in tapered and non-tapered grafts, with a markedly elevated peak force at the distal end (proximal end, 2.3 $\pm$ 0.06 N and distal end, 6.9 $\pm$ 0.05 N compared with 1.7 $\pm$ 0.08 N and 1.6 $\pm$ 0.08 N in non-tapered grafts; $p < .001$ both). Peak forces in tapered and non-tapered grafts were not significantly different between the proximal and distal end. In asymmetric stent graft curvatures, a significant increase in displacement forces was observed in the attachment zone that was closest to the stent graft bend. Graft movement increased with greater displacement forces.
Conclusion: Flow induced displacement forces in iliac limb stent grafts are significant and are influenced by distal stent graft diameter and the shape of the graft curvature. The displacement forces are particularly high at the large distal end of bell-bottom grafts. Wide iliac arteries treated with bell-bottom stent grafts may require more vigilant surveillance and improved stent graft fixation.

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INTRODUCTION

Treatment for abdominal aortic aneurysms (AAAs) with endovascular aortic repair (EVAR) is well established, and today an increasing number of AAAs are being treated by the endovascular technique. EVAR has lower short-term morbidity and mortality than open repair, but the rate of re-intervention and late complication is higher.[1—7] Previous studies have shown that implantation of an additional iliac limb stent graft after EVAR is one of the more frequent re-interventions.[8,9] The re-intervention rate is higher when sideways movement of the stent graft can be detected on follow up imaging.[10] Bell-bottom grafts have been shown to have a higher incidence of distal type I endoleaks and greater vessel tortuosity.[11] Furthermore, it has been shown previously that flow induced stent graft displacement forces are significant, dependent on graft angulation and perfusion pressure, and of similar magnitude at both ends of a non-

* Corresponding author. Department of Hybrid and Interventional Surgery, Unit of Vascular Surgery, Sahlgrenska University Hospital, SE-413 45 Gothenburg, Sweden.
E-mail address: hakan.roos@vgregion.se (H. Roos).
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tapered iliac stent graft.[12] Forces of a magnitude of 1.8 N were found, which is close to the force previously shown to be able to displace a stent graft.[13—17] There is a high correlation between the degree of pulsatile movement of the stent graft and the magnitude of displacement forces.[12] The aim of the present study was to investigate how flow induced displacement forces and stent graft movement depend on the distal diameter of iliac limb stent grafts and asymmetric graft curvatures.

MATERIAL AND METHODS

Aortic perfusion model

An experimental aortic perfusion model was used to simulate the aortic pressures and pulsatile flow that would be expected under physiological conditions in an iliac limb stent graft. Measurements of forces acting on the stent graft and of graft movement were performed. The experimental set up has previously been described in detail.[12] Briefly, pulsatile flow was achieved with a computer triggered pump, which was connected to a closed circuit (Fig. 1). The pressure curves obtained had high periodicity, were highly reproducible, and were relatively similar to physiological aortic pressure curves. Pressure pulse measurements were performed with Safedraw transducer blood sampling set (Argon critical care systems, Singapore). Zero calibration to air was done at the distal stent graft end. Stent grafts were anchored at both ends to strain gauge load cells (Tadea-Huntleigh, model 1004; Vishay Transducers, PA, USA) and inserted into the flow model. Load cell error was 0.0007% and calibration was done with weights. The water filled container inducing peripheral resistance was filled to achieve a pressure which allowed for diastolic pressures of 80 mmHg once the pump was running. Zero leveling of forces was done in a pressurized graft without flow. The pressure at leveling of forces was approximately 60 mmHg. The stent graft was anchored to the load cells via rigid connectors with diameters corresponding to the respective stent graft. The graft was placed on the outside surface of the connectors and secured with ligatures to ensure maximal transfer of the force at the stent graft ends to the load cells (Figs. 1—3). The direction of measured forces defined as positive is shown in Fig. 4.

Gore excluder iliac limb stent grafts were used (W.L. Gore & Associates, Inc., Newark, DE, USA). Traction free connection between load cells and the closed circuit was achieved with grafts of diameters corresponding to the connectors. Fluid pressure was adjusted with water filled containers in combination with pinch valves. Measurements of graft movement were performed at all studied angulations and graft shapes. Video recordings of the experiments were carried out with a high resolution video system, Imager pro X 4M (Lavision, Goettingen, Germany). Stent graft movement was measured with an accuracy of 0.005 mm. The graft movement was calculated for the whole stent graft side area by recording its image and correlating it with the image of the stent graft with static pressure without pulsation. The mean movement over seven pulses was calculated. The results correspond to the maximum displacement within the stent graft's side area during one pulsation. All measurements of forces and graft movement were performed during stable pulsatile conditions.

Tapered, non-tapered, and bell-bottom stent grafts. The stent grafts used had a diameter of 16 mm at the proximal end, and distal end diameters of 12 mm (tapered graft), 16 mm (non-tapered graft), or 27 mm (bell-bottom graft) (Fig. 2). The stent graft lengths were 140, 135, and 140 mm, respectively. Connectors with diameters corresponding to the iliac limb stent grafts were used. When a distal diameter of 27 mm was used, an additional connector with a diameter of 27 mm was used for fixation of the tubing distal to the strain gauge load cell, to mimic the clinical situation of a

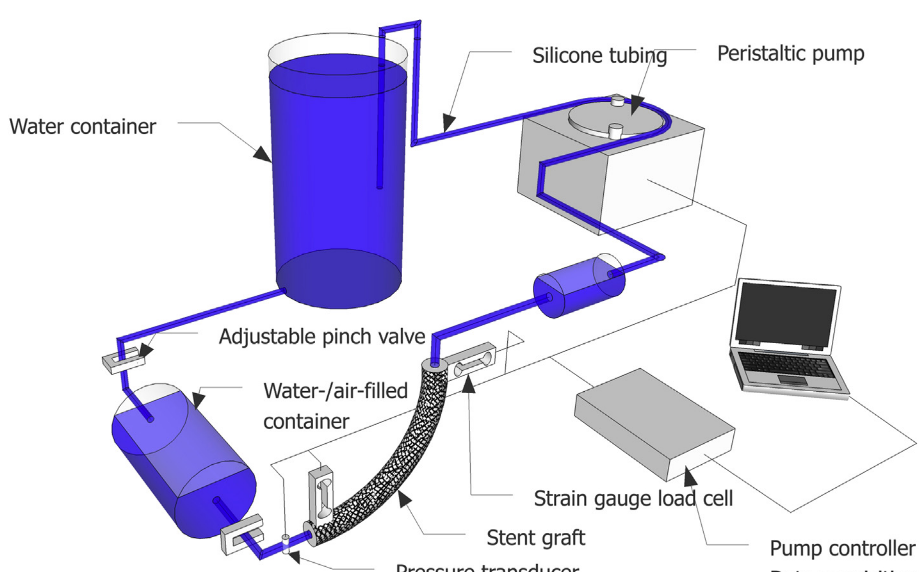

Figure 1. Schematic presentation of the aortic perfusion model.