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Stent graft performance in the treatment of abdominal aortic aneurysms: The influence of compliance and geometry

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ABSTRACT

The long-term success of the endovascular procedure for the treatment of Abdominal Aortic Aneurysms (AAAs) depends on the secure fixation of the proximal end and the geometry of the stent–graft (SG) device. Variations in SG types can affect proximal fixation and SG hemodynamics. Such hemodynamic variations can have a catastrophic effect on the vascular system and may result from a SG/arterial wall compliance mismatch and the sudden decrease in cross-sectional area at the bifurcation, which may result in decreased distal perfusion, increased pressure wave reflection and increased stress at the interface between the stented and non-stented portion of the vessel. To examine this compliance mismatch, a commercial SG device was tested experimentally under a physiological pressure condition in a silicone AAA model based on computed tomography scans. There was a considerable reduction in compliance of 54% and an increase in the pulse wave velocity of 21%, with a significant amount of the forward pressure wave being reflected. To examine the SG geometrical effects, a commercial bifurcated geometry was compared computationally and experimentally with a geometrical taper in the form of a blended section, which provided a smooth transition from the proximal end to both iliac legs. The sudden contraction of commercial SG at the bifurcation region causes flow separation within the iliac legs, which is known to cause SG occlusion and increased proximal pressure. The blended section along the bifurcation region promotes a greater uniformity of the fluid flow field within the distal legs, especially, during the deceleration phase with reduced boundary layer reversal. In order to reduce the foregoing losses, abrupt changes of cross-section should be avoided. Geometrical tapers could lead to improved clinical outcomes for AAA SGs.

1. Introduction

Abdominal aortic aneurysms (AAA) constitute a serious health problem in both the US and Western Europe (Coggon et al., 1996; Brown et al., 2003; Vorp and Vande Geest, 2005). The endovascular procedure is an alternative treatment to standard open aneurysm repair. This treatment involves a surgical exposure of the common femoral arteries, where the endovascular device can be inserted by over the wire techniques (Calligoro et al., 1999; Brewster et al., 2003). It offers the economic advantage of short hospital stays as well as a reduction in the need for postoperative intensive care and is, therefore, attractive to both patients and physicians (Coggon et al., 1996; Lazaridis et al., 2009). Since the first performed endovascular repair of AAA, more than a decade ago, initial results have been promising but the long-term results are not so encouraging with stent–graft (SG) migration, endoleaks and aneurysm rupture all being reported (Blum et al., 2001; Jacobs et al., 2003; Hinnen et al., 2007; Corbett et al., 2008; Mattes et al., 2012). Secure proximal and distal fixation of SG is pivotal to the long-term success of the endovascular procedure (Morris et al., 2004a, 2006a; Wever et al., 2000; Donayre et al., 2011). Problems due to SG fixation can lead to Type I endoleaks, late SG migration and gradual enlargement of the proximal neck leaving the aneurysm exposed to systemic blood pressure. These are well known complications beyond 12 months of implantation which can eventually lead to rupture (Marin and Hollier, 2000; Holzenbein et al., 2001; White et al., 2001; Makaroun and Deaton, 2001; Steingruber et al., 2006; Lazaridis et al., 2009; Albuquerque et al., 2010; Mattes et al., 2012).

These reported issues after SG placement can be attributed to variations in SG types that can affect proximal fixation and SG hemodynamics. Such hemodynamic variations can have a catastrophic effect on the vascular system and may result

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from a SG/arterial wall compliance mismatch and the sudden decrease in cross-sectional area at the bifurcation. The compliance mismatch can be attributed to the suprarenal fixation found in some SG designs, while other SG devices incorporate hooks and barbs for added fixation. Commercially available SG geometries have tubular proximal and distal leg portions, which merge at the bifurcation point via a quickly tapered transition. These geometries at the bifurcation introduce a sudden cross-sectional area transition. The compliance mismatch and rapidly tapered transition could result in decreased distal perfusion, increased pressure wave reflection and increased pulsatile mechanical stress at the interface between the noncompliant stented vessels and the native artery (Back et al., 1994; Helal and Watts, 1994; Alderson and Zamir, 2004; Tortoriello et al., 2004).

The elasticity of the SG/arterial wall interface and the SG geometry, especially, at the bifurcation region is responsible for the modification of wave reflections. The early arrival of a reflected wave affects both ventricular emptying and driving pressure for coronary perfusion (Zannoli et al., 1999; Dobson et al., 2006), which eventually leads to low cardiac output, heart failure and shock (Wilkinson et al., 2000; Nichols and Edwards, 2001; Dobson et al., 2006; Nichols and O'Rourke, 2005).

Most in vivo or in vitro dynamic studies have been conducted on small calibre vessels with little or no emphases on the fixation characteristics of SG devices (Back et al., 1994; Rolland et al.,

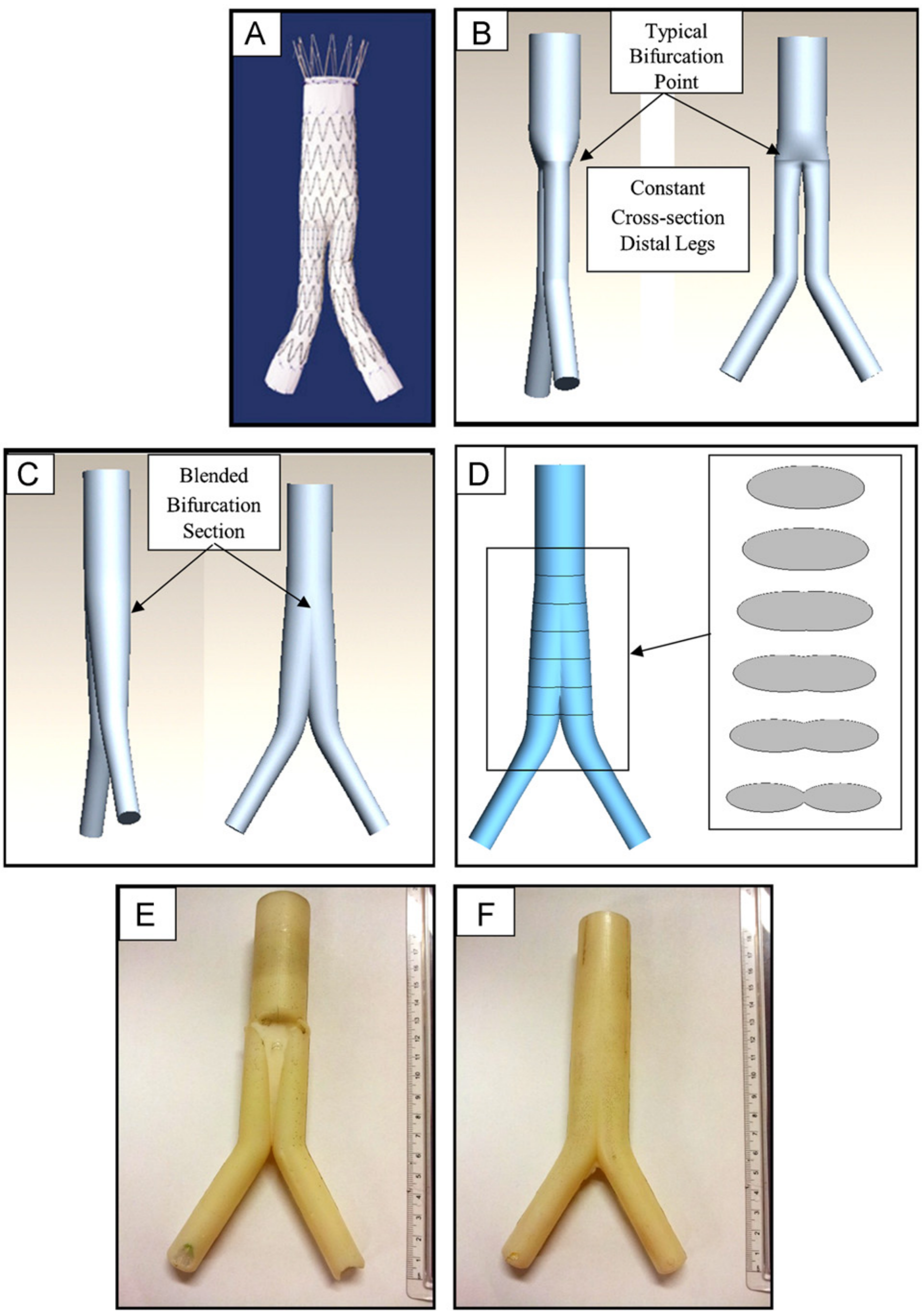

Fig. 1. (A) Commercially available Zenith^{TM} bifurcated stent–graft device, (B) commercially available SG geometry, (C) blended bifurcated geometry (Both of these SG geometries have a 60° iliac leg angle, proximal diameter of 24 mm and distal leg diameters of 12 mm), (D) cross-sectional slices of the blended geometry along the bifurcation region, (E) rapid prototyped commercial SG and (F) rapid prototyped blended SG.