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Biomechanical simulations and 3D printing for endovascular device testing

Michele Conti, Stefania Marconi, Ferdinando Auricchio

DICAr Department, University of Pavia, Pavia, Italy

Abstract

Endovascular aortic repair is a minimally invasive procedure to treat aortic diseases such as aneurysms and dissections. Thanks to technological advancements, such procedure has steadily shifted from the abdominal aorta towards the ascending part, *i.e.*, near the heart, calling for an extensive and comprehensive benchmarking of (novel) endografts. Given such considerations, we have exploited porcine aorta with a pulse duplicator to analyse the mechanical interaction between the endovascular device and the native tissue.

Our results have implications for using the porcine aorta as a model for human aorta in research. Particularly, the combination of *in vitro* tests performed using *ex-vivo* tissue, integrated validated patient-specific numerical simulations, mock arteries manufactured by 3D printing, can offer important insight on biomechanical impact of endograft design on post-operative aortic mechanical response.

Introduction

Endovascular aortic repair (EVAR) is a minimally invasive procedure to treat aortic diseases such as aneurysms and dissections. Thanks to technological advancements, such a procedure has steadily shifted from the abdominal aorta towards the ascending part, *i.e.*, near the heart, calling for an extensive and comprehensive benchmarking of (novel) endograft. Given such considerations, we have exploited porcine aorta with a pulse duplicator to analyse the mechanical interaction between the endovascular device and the native tissue.

Materials and Methods

We have investigated the effect of thoracic endovascular aortic repair (TEVAR) on aortic stiffness by measuring aortic pulse wave velocity (PWV) in an *ex vivo* porcine model.[1] In particular, fifteen fresh porcine thoracic aortas were connected to a benchtop pulsatile. Intraluminal pressures were recorded in the ascending aorta and at the celiac trunk using a needle connected to a pressure sensor. The distance between the needles was divided by the time difference between the base of the pressure peaks to calculate aortic PWV at baseline and after stent-graft deployment and distal stent-graft extension (Figure 1).

Similarly, twenty fresh thoracic porcine aortas were connected to a mock circulatory loop driven by a centrifugal flow pump. A high definition camera captured diameters at five different pressure levels (100, 120, 140, 160, and 180 mmHg), before and after TEVAR,[2] as function of different degree of oversizing. Moreover, we have consistently and systematically compared published data on porcine and human thoracic aortic stiffness from different studies.[3]

Results

In our *ex-vivo* experimental setup, aortic stiffness increased after stent-graft deployment, dependent on the percentage of the aorta that was covered by stent graft. TEVAR stiffened the thoracic aorta by 2-fold. Such segmental stiffening may diminish the Windkessel function considerably and might be associated with TEVAR-related complications, including stent-graft-induced dissection and aneurysmal dilatation. Furthermore, our results show that the stiffness of young porcine aortas is similar to that of human tissue aged under 60 years and less stiff than human tissue aged 60 years or more.

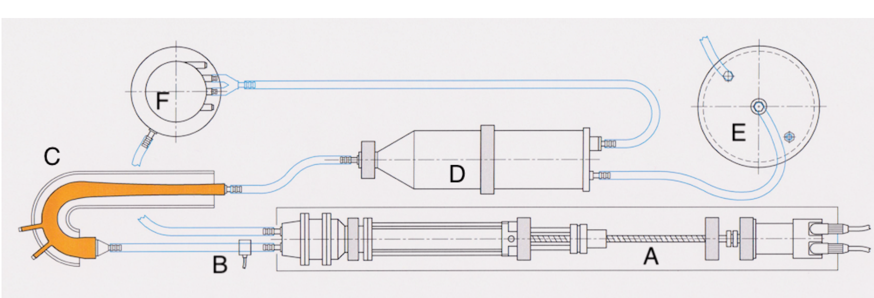

Figure 1. Schematic representation of the pulsatile system. A, pump; B, flow meter; C, ex-vivo porcine aortic specimen; D, resistance chamber; E, windkessel compartment; F, water reservoir.

Correspondence: Michele Conti, DICAr Department, University of Pavia, Pavia, Italy.
E-mail: michele.conti@unipv.it

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Conclusions

Our results have implications for using the porcine aorta as a model for human aorta in research. In particular, the combination of *in vitro* tests performed using *ex-vivo* tissue, integrated validated patient-specific numerical simulations,[4] mock arteries manufactured by 3D printing,[5] can offer important insight on biomechanical impact of endograft design on post-operative aortic mechanical response.

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