Prosthetic Replacement of the Ascending Aorta Increases Wall Tension in the Residual Aorta

Michael Scharfschwerdt, Hans-H. Sievers, MD, Johanna Greggersen, Thorsten Hanke, MD, and Martin Misfeld, MD, PhD

Department of Cardiac Surgery, University Clinic of Schleswig-Holstein, Lübeck, Germany

Background. Prosthetic replacement of the ascending aorta with nonelastic vascular grafts impairs the local Windkessel function. Whether this increases wall tension in the remaining aorta is still a not completely investigated hypothesis but is of clinical relevance with respect to postprocedural development of aneurysms and dissections, especially in the proximal descending aorta.

Methods. Fresh porcine thoracic aortas, including the root, were set up in a mock circulation before and after prosthetic replacement of the ascending aorta. Cyclic changes in aortic dimensions were measured by ultrasonic micrometers at defined positions at the proximal part of the descending aorta. At the same positions, aortic pressures were recorded simultaneously using Millar tip manometers. Wall thickness was measured after pulsatile testing, and the resulting wall tension was calculated from the Laplace law.

Results. After prosthetic replacement of the ascending aorta, peak systolic pressure in the proximal descending aorta increased from 117.6 ± 6.1 mm Hg to 129.2 ± 6.3 mm Hg, resulting in a rise of wall tension by 12.4% ± 4.2% (p = 0.001). The maximum rate of pressure rise (dp/dtmax) increased by 42.6% ± 16.4% (p < 0.001).

Conclusions. Replacement of the ascending aorta with noncompliant prosthetic material significantly increases wall tension and rate of pressure rise in the residual aorta. This may have clinical impact with respect to a sudden and sustained rise of mechanical load, especially at the vulnerable proximal descending aorta.

We hypothesized that the prosthetic graft used for the replacement of the ascending aorta induces an additional pathophysiologic aspect promoting the development of postprocedural abnormalities in the remote aorta. The noncompliant prosthetic material causes a local loss of Windkessel function that may change the aortic hemodynamics; that is, augmentation of pressure amplitude and thereby induction of additional mechanical load to the residual aorta that may be of clinical relevance, especially in the vulnerable proximal part of the descending thoracic aorta. We therefore investigated wall tension in the proximal descending aorta after prosthetic replacement of the ascending aorta in an in vitro model.

Material and Methods

Preparation

Fresh porcine thoracic aortas, including the root, were collected from a local abattoir and used for the experiments within 4 hours of slaughter. The aortas were carefully dissected from the remaining left ventricular muscle and mounted in the test circuit. Supraaortic branches were ligated, and the descending aorta was shortened to a length of approximately 15 cm distal of the left subclavian artery. The descending aorta was then fixed to the distal mounting of the test circuit.

Replacement of the ascending aorta was performed using the reimplantation technique [2]. In brief, the aorta

© 2007 by The Society of Thoracic Surgeons
Published by Elsevier Inc

doi:10.1016/j.athoracsur.2006.10.056
was cut at the height of the first supraaortic branch and resected down to the three sinuses of Valsalva, leaving a rim of sinus tissue of 2 mm to the crown-shaped aortic annulus. Then the aortic valve was implanted into a Dacron (DuPont, Wilmington, DE) prosthesis (Boston Scientific Corp, Wayne, NJ) using interrupted U-shaped 4-0 Prolene suture (Ethicon, Norderstedt, Germany) at the annulus in a planar fashion and a continuous 4-0 Prolene suture for attachment of the valve from inside the prosthesis. Finally, the graft was distally connected to the aortic arch by a continuous 4-0 Prolene suture.

Data Acquisition and Analysis
Aortic diameters were measured by ultrasonic micrometric crystals (Sonometrics Corp, London, Ontario, Canada) placed around the proximal descending aorta at distances of 1 cm and 3 cm from the left subclavian artery. At the same positions, microtip catheter pressure transducers (Millar Instruments Inc, Houston, TX) were inserted into the central lumen of the vessel to determine aortic pressures (Fig 1). After pulsatile testing, wall thickness was measured from excised circumferential pieces of the aorta by a stereomicroscope with eyepiece micrometer (Carl Zeiss GmbH, Göttingen, Germany). The resulting wall tension was calculated from the Laplace law \[ T = \frac{(p \times d)}{(2 \times w)} \], where \( T \) is wall tension; \( p \) is pressure; \( d \) is diameter, and \( w \) is wall thickness.

Experimental Setup
Measurements were performed in a pulsatile flow simulator, details of which have been described previously [9]. Sixteen aortas with a descending aortic diameter of 21 to 25 mm were mounted in a fluid reservoir. They were tested native and also after prosthetic replacement of the ascending aorta at a heart rate of 64 cycles/min with a stroke volume of 54 mL for a systemic pressure of 120/80 mm Hg. Peripheral resistance and remote vascular compliance were set to physiologic values. Two different aortic curvatures (8-cm and 5-cm radius) were configured by variation of the distal connector height. Data were collected from five consecutive cycles each, and measurements were repeated 10 times for each aorta and test condition.

Results
Peak systolic pressure in the proximal descending aorta significantly increased after prosthetic replacement of the ascending aorta from 117.6 ± 6.1 mm Hg to 129.2 ± 6.3 mm Hg (\( p < 0.001 \)). Similarly, maximum systolic aortic diameter increased slightly, both resulting in a rise of wall tension from 111.5 ± 8.5 kPa to 124.2 ± 9.9 kPa (\( p = 0.001 \)). The positioning of the probes at 1 cm and 3 cm distally from the left subclavian artery and also the degree of aortic curvature showed no significant effect on the results.

Notable changes were found for the maximum rate of pressure rise (\( dp/dt_{\text{max}} \)), which increased by more than 42% compared with the native aortic condition (632.3 ± 83.4 mm Hg/s versus 446.2 ± 70.1 mm Hg/s, \( p < 0.001 \)). Representative changes in descending aortic pressure are depicted in Figure 2.

Comment
We demonstrated in our in vitro model that loss of distensibility at the ascending aorta by reason of prosthetic replacement results in an abrupt increase of wall tension in the proximal descending aorta.

After prosthetic replacement of the ascending aorta,
the Windkessel function of this dominant part of the aorta disappears because of the minimal distensibility of common prosthetic material [10]. Effects of this reduced aortic compliance on left ventricular performance [11] and on aortic root hemodynamics [12, 13] have been described before; however, little is known about the implications on the proximal descending aorta.

As Simon-Kupilik and colleagues [12] have demonstrated for the aortic root, pressure amplitude and diameter increased markedly and calculated wall stress index increased in vitro and in vivo by 22% and 16%, respectively. This can also be confirmed by our experiments for the proximal descending aorta. Furthermore, a significant increase of the pressure-time differential dp/dt could be observed. These findings indicate that in case of prosthetic replacement of the ascending aorta, an acute and sustained additional load is applied to the residual aorta that may promote the development of further aortic pathologies such as aneurysms and type B dissections.

Whether this observation reaches clinical significance will need further investigations. In this context some recent studies reported a higher incidence of descending aortic aneurysm formation in patients who received operations on the ascending aorta for type A dissections [14]. Engelfriet and colleagues [15] described a fourfold increased risk for dilatation of the distal aorta in Marfan patients with previous elective aortic surgery [15].

Typically, the site of tears in acute type B aortic dissection is near the distal circumference of the left subclavian artery. It can be speculated that one weak point of the descending aorta is located in this area, where the aortic arch turns into the descending aorta and the continuity of the aortic arch is interrupted by the left subclavian orifice. The pressure at this site in the convexity of the aortic arch is also somewhat increased compared with that at the concavity owing to centrifugal forces and momentum. During measurements only minor pressure gradients were observed between the inner and outer curvature of the arch.

We used fresh and healthy aortic tissue in our experiments, and wall tensions were calculated from these variables. Diameters are increased in aneurysms, however, and the Laplace wall tension will tend to have even higher values. In patients with risk factors for developing type B dissection, especially in patients with Marfan syndrome or preexisting descending aortic aneurysm, the incidence of rupture of the intimal layer is furthermore increased owing to the structural weakness of the aortic wall [4]. On the other hand, the compliance in the atherosclerotic aorta is decreased compared with our experimental setting. This may attenuate the observed effect of increased pulse pressure amplitude; however, it must be considered that pulse pressure is increased in the stiffer atherosclerotic aorta anyway.

**Clinical Implications**

It is known that patients undergoing replacement of the ascending aorta need regular follow-up, not only for evaluation of valve function in cases of valve-sparing procedures but also to assess the fate of the remaining aorta. This is especially mandatory in patients with residual pathologies of the aorta, such as Marfan patients or those with a descending aortic aneurysm or remaining dissection [5, 16–18]. Because there is a nonnegligible risk of reoperation in these patients, some authors favor total arch replacement in patients with dissection of the ascending aorta [16]. Others recommend total arch replacement, leaving an “elephant trunk” in patients with Marfan syndrome and aortic dissection [19]. However, the prolonged operation time with these strategies increases the overall operative risk.

The strategy in our department in cases of acute type A aortic dissection is to treat the dissection predominantly with valve-sparing techniques, perform a close follow-up, and electively treat emerging complications. Although the data presented in this study may support the concept of prophylactic arch replacement and leaving an elephant trunk to cover the zone of risk in the proximal descending aorta also in acute cases, we believe the operative procedure in these situations should be kept as short as possible, with close follow-up of patients. However, in patients with elective surgery of the ascending aorta and residual pathologies of the aortic arch or descending aorta, or both, a more liberal approach to a complete surgical treatment of the aortic arch and especially of the proximal descending aorta, may be in favor of improved long-term outcome.

Further studies are necessary to substantiate these considerations. In view of conservative treatment, there is evidence that regulation of blood pressure in Marfan patients, especially the use of a β-blocker, is of importance to reduce the risk of postprocedural aortic pathologies after replacement of the ascending aorta [20]. Close follow-up of these patients is mandatory, preferably under the surveillance of specialized centers.

**Conclusion**

The loss of compliance of the ascending aorta abruptly increases wall tension of the proximal descending aorta. Especially in patients with residual pathologies of the descending aorta, these findings may have important implications on the strategy of their follow-up and probably also for replacement of the thoracic aorta.

**References**


Online Discussion Forum

Each month, we select an article from the *The Annals of Thoracic Surgery* for discussion within the Surgeon’s Forum of the CTSNet Discussion Forum Section. The articles chosen rotate among the six dilemma topics covered under the Surgeon’s Forum, which include: General Thoracic Surgery, Adult Cardiac Surgery, Pediatric Cardiac Surgery, Cardiac Transplantation, Lung Transplantation, and Aortic and Vascular Surgery.

Once the article selected for discussion is published in the online version of *The Annals*, we will post a notice on the CTSNet home page (http://www.ctsnet.org) with a FREE LINK to the full-text article. Readers wishing to comment can post their own commentary in the discussion forum for that article, which will be informally moderated by *The Annals* Internet Editor. We encourage all surgeons to participate in this interesting exchange and to avail themselves of the other valuable features of the CTSNet Discussion Forum and Web site.

For March, the article chosen for discussion under the Pediatric and Adult Cardiac Dilemma Sections of the Discussion forum is:

**Predicting Outcome of Pulmonary Valve Replacement in Adult Tetralogy of Fallot Patients**

Ivo R. Henkens, MD, Alexander van Straten, MD, Martin J. Schalij, MD, PhD, Mark G. Hazekamp, MD, PhD, Albert de Roos, MD, PhD, Ernst E. van der Wall, MD, PhD, and Hubert W. Vliegen, MD, PhD

Tom R. Karl, MD

*The Annals* Internet Editor

UCSF Children’s Hospital

Pediatric Cardiac Surgical Unit

505 Parnassus Ave, Room S-549

San Francisco, CA 94143-0118

Phone: (415) 476-3501

Fax: (212) 202-3622

e-mail: karlt@surgery.ucsf.edu

© 2007 by The Society of Thoracic Surgeons

Published by Elsevier Inc