Proceedings of the ASME 2011 Summer Bioengineering Conference
SBC2011
June 22-25, Nemacolin Woodlands Resort, Famington, Pennsylvania, USA

SBC2011- 53245

ASSESSMENT OF AORTIC GRAFT IMPACT ON HEMODYNAMICS

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ABSTRACT

In vivo studies have revealed that aortic grafts augment heart load and alter blood pressure and flow waveforms [1]. A one-dimensional model of the arterial tree was developed in order to analyze the different mechanisms by which proximal and distal aortic grafts affect hemodynamics. Graft compliance and properties were based on *in vitro* tests. Predicted pressures at the aortic root were compared for the control, proximal and distal graft case. Pulse pressure increased by 21% and 10% in presence of a proximal and distal graft, respectively. The distal graft resulted in a wave reflection coefficient of 0.62 while for the proximal graft the wave reflection coefficient was 0.46. The physiological mechanism behind the rise of pressure is dual and it is critically affected by the graft's compliance and position. In case of a proximal graft, the primary reason for aortic pressure increase is the augmentation of aortic characteristic impedance, which augments the forward running pressure wave, while for the distal graft the wave reflections are major contributors to the total pressure wave. Overall, the proximal graft altered hemodynamics to a greater extent than a distal aortic graft.

INTRODUCTION

Synthetic grafts have been used to repair the diseased aorta for over 50 years. These grafts have been successful in reducing risk of rupture in patients with aortic aneurism and dissection. However, aortic grafts also augment systolic pressure (P_{syst}) and pulse pressure (PP) [2, 3]. Research has indicated that approximately half of the total arterial compliance is located at the proximal aorta [1]. Implantation of an inelastic aortic graft is expected to have an important impact on global hemodynamics depending on the implant location and mechanical properties.

METHODS

The model developed by Reymond et al. [4] was adapted to include the graft geometry and properties. For our study, we focused on Dacron grafts used in open aneurism repair. Endovascular grafts were not assessed. The pressure-diameter relationship for a 17 mm diameter Dacron graft was formulated based on *in vitro* pressure-diameter tests [5].

$$D = \frac{1}{a + b \cdot \left(1 - e^{-\frac{P^c}{d}}\right)} \quad (1)$$

Where D is graft diameter (mm), P is pressure (mmHg) and a=3.71, b=16.33, c=0.12 and d=0.77 are constants. Distensibility was calculated as the normalized area compliance.

$$Distensibilty = \frac{dA}{dP} \cdot \frac{1}{A} = 2 \cdot \frac{dD}{dP} \cdot \frac{1}{D} \quad (2)$$

The diameter was set to 30 and 16 mm, for the proximal and distal graft, respectively. Graft viscoelasticity was considered to be zero. The impact of the graft was assessed in terms of six parameters: 1) peak systolic pressure, 2) pulse pressure, 3) pulse wave velocity (PWV), 4) aortic characteristic impedance, 5) pulse pressure of the forward and backward pressure wave, and 6) reflection coefficient. These parameters were calculated for a proximal and distal graft and for the control case having identical vascular geometry and properties except at the graft location. All parameters were calculated at the aortic root with the exception of PWV. PWV was calculated based on travel time of the foot of the aortic wave between the ascending aorta and distal abdominal aorta. Characteristic impedance (Z_c) was calculated with Eq. (3) by averaging the impedance modulus (Z_{in}) between the fourth and fifteenth harmonic [6]. The forward and backward pressure waves, $P^f(t)$ and $P^b(t)$, were determined by Eq. (4a) and Eq. (4b):

$$Z_{in} = \left|\frac{\mathcal{F}(P(t))}{\mathcal{F}(Q(t))}\right| \tag{3}$$

$$P^f = Z_c \cdot Q^f = \frac{P(t) + Z_c \cdot Q(t)}{2} \tag{4a}$$

$$P^b = -Z_c \cdot Q^b = \frac{P(t) - Z_c \cdot Q(t)}{2} \tag{4b}$$

The reflection coefficient was calculated with Eq. (5) as the ratio of the backward to the forward pulse pressure.

$$\Gamma^* = \frac{PP^b}{PP^f} \tag{5}$$

RESULTS

Table 1 summarizes results for the control, proximal, and distal graft. The forward pressure wave PP increased by 33% in presence of a proximal graft and by 6.4% in the case of distal graft. Inversely, for the proximal graft the backward pressure wave PP increased by 11% whereas for the distal graft it increased by 18%. Figure 1 shows the pressure wave reflection analysis results calculated for the proximal graft (left column) and distal graft (right column).

Table 1. Results summary.

	Control Case	Proximal graft	Distal graft
Psyst [mmHg]	109.17	115.37	112.24
PP [mmHg]	28.75	34.76	31.63
PP Forward Pressure wave [mmHg]	19.27	25.68	20.50
PP Backward Pressure wave [mmHg]	10.70	11.95	12.64
Γ*	0.55	0.46	0.62
Zc [mmHg/ml/s]	0.0305	0.0483	0.0313
PWV [m/s]	4.74	5.16	7.90

Characteristic impedance for the proximal graft was 58 % higher than the control case while for the distal case there was a minute 2.6% increase. Furthermore, the foot-to-foot pulse wave velocity was found to be substantially higher in presence of a distal graft and unaffected in the case of a proximal graft.

DISCUSSION

Overall, the proximal graft resulted in a greater increase in aortic systolic and pulse pressure than in the case of a distal aortic graft. This is expected because pulse pressure and in consequence systolic pressure are inversely proportional to total systemic compliance and the loss of compliance is greater in the case of a proximal graft, since most of arterial compliance resides in the proximal aorta. However, the systolic pressure increase mechanism is different in the case of a proximal or a distal graft. A proximal graft leads to an increase in the characteristic impedance of the proximal aorta, thereby augmenting proportionally the forward pressure wave. Hence most of the increase in pulse pressure is due to augmented forward wave. For the distal graft, the pressure increase mechanism is different. Wave reflections are augmented due to compliance mismatch between the abdominal aorta and the graft, leading to an increased backward pressure wave.

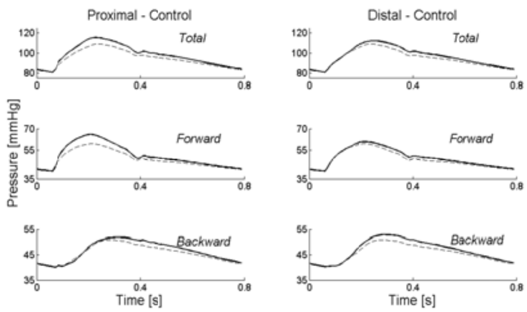

Figure 1. Comparison of the pressure waves for the proximal, distal and control case. Dashed lines represent the control case. Solid lines represent the grafted cases.

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Comment [nS1]: REFERENCE FORMAT NOT CORRECT