Mechanical characterization of the coronary artery including smooth muscle tone

Mechanical characterization of the coronary artery including smooth muscle tone

C.N. van den Broek, M.C.M. Rutten and F.N. van de Vosse
Eindhoven University of Technology, Department of Biomedical Engineering

Introduction

Atherosclerosis of the coronary artery is a frequently occurring heart disease in adults. Knowledge of coronary mechanical properties increases the understanding of e.g. aging and atherosclerosis, and provides additional insight into the effect of angioplasty and stenting. For this, a constitutive model of the coronary artery, including the contribution of the smooth muscle tone, is needed. To determine the material parameters, inflation tests were performed in an in vitro culture model [1] on porcine coronary arteries with varying smooth muscle tone.

Material and methods

To induce a varying smooth muscle tone, arterial cell integrity should be maintained during arterial excision and culture. Five left anterior descending coronary arteries (LADs) were excised and tested for endothelial cell (EC) presence by performing an immunohistochemical (IHC) procedure with the von Willebrand factor antibody.

Four porcine coronary arteries were cultured for 48h in an in vitro culture device. Arterial morphology was evaluated by performing an H&E and Masson Trichrome staining, and an IHC staining for CD31, an EC membrane protein. Inflation tests with varying smooth muscle tones, by adding the direct vasoconstrictor norepinephrine (NE), the endothelium-dependent vasodilators acetylcholine (ACh, LAD A) and bradykinin (Bk, LAD B-D), and the direct vasodilator papaverine (Pap), respectively, were performed at t=0h and 48h. Internal arterial diameter was measured with an ultrasound scanner during 5 pressure-cycles. EC and smooth muscle cell (SMC) functionality were tested by measuring the diameter change at a pressure of 70 mmHg. Also, the extent of viscous behaviour was measured by determining the angle β of the tangent line of the average pressure-diameter (PD) curve at a pressure of 70 mmHg (fig. 1a). A smaller angle β indicates more elastic behavior (fig. 1b).

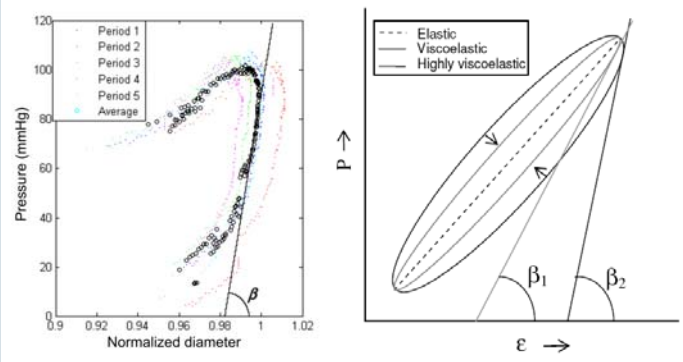

Figure 1 *Left: Angle β as a measure of viscous behavior; Right: Smaller β indicates more elastic behavior.*

Results

ECs were still present after the excision procedure (fig. 2).

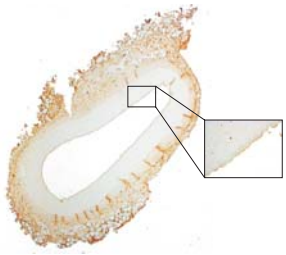

Figure 2 *vWf IHC staining for ECs after arterial excision. Darker inner lining indicates EC presence.*

Wall shear stress was 20-80% lower than a physiological wall shear stress of 1.0-1.5 Pa. Minimum pressure was 0 mmHg instead of 80 mmHg. Diameter (D) data has been filtered. Nevertheless, D data was still very limited for all measurements. Results of the cell functionality tests, the extent of viscous behavior and cell presence are given in table 1.

Table 1 *Changes in D and β at t=0h and t=48h and cell presence at t=48h. Expected or unexpected increase (↑)/decrease (↓)/no change (-) in D | β; Diameter or β could not be determined*

	t=0h (D¦β)						t=48h (D¦β)						
LAD	NE		ACh/Bk		Pap		NE		ACh/Bk		Pap		ECs?
A	↑	↓	↓	↑	↑	–	↓	–	↑	–	–	–	Yes
B													No
C	↑	–	↓		↑	–	↑	–	–	–	–	↑	No
D	↓	–	↓	–	↓	–	↓	–	↑	↓			Yes?

Changes in the extent of viscous behavior were very limited (table 1). 3 out of 4 significant changes were according to observations by Dobrin (1969) ($D_1 > D_2 \Rightarrow \beta_1 < \beta_2$).

Conclusions

ECs were maintained during the excision procedure. However, ECs were lost for 2 out of 4 cultured LADs, SMC presence was decreased for 1 cultured LAD. After 48h cells functioned as expected for LAD A and D, for which arterial morphology was unchanged. Cell integrity may be increased by inducing a higher wall shear stress by increasing medium viscosity, and by an increase of the minimum pressure.

To determine the material parameters for the constitutive model, diameter measurement should be enhanced. This may be achieved by decreasing the power settings of the ultrasound scanner.

References:

[1] van den Heuvel, L. (2005): PhD Thesis (TU/e)

[2] Dobrin, P. and Rovick, A.: *Am. J. Physiol. 217(6), 1644-1651*

PO Box 513, 5600 MB Eindhoven, the Netherlands