Uniaxial Tensile Test of Perivascular Adipose Tissue

Tereza Voňavková, Lukáš Horný, Markéta Kulvajtová, Rudolf Žitný

Abstract - **In contrast to the constitutive modelling of elastic arteries, only a little attention has been paid to mechanical properties of surrounding tissue. This article presents preliminary results obtained during investigation of the biomechanics of extravascular environment. The elastic modulus of human perivascular adipose tissue was determined from uniaxial tensile tests performed with six rectangular samples obtained from abdominal aortic site. Samples were excised during the autopsy of two males aged 41 and 71. Strongly nonlinear stress-strain relationship was observed. It was found that highly compliant response characterized with the initial elastic modulus of about 0.0170 ± 0.0182 MPa (mean ± standard deviation) is exhibited approximately up to the stretch of 1.05. Initial linear response is followed by gradual stiffening which subsequently continues with hardened linear region. Tangential elastic modulus of about 0.3210 ± 0.1183 MPa was observed in the hardened region at the stretches from 1.076 to 1.135.**

Index Terms - **Abdominal aorta, Elastic modulus, Perivascular adipose tissue, Tensile test.**

I. INTRODUCTION

HIGH mortality caused by cardiovascular diseases (heart attack, cerebrovascular diseases, etc.) leads to intensive research in the bioengineering field. Great attention is devoted to parts of the circulatory system such as the heart, coronary arteries and aorta. But only a few studies dealt with the biomechanics of surrounding tissue [1-7, 13-19, 21-25]. Nevertheless, perivascular tissue plays an important role in arterial physiology and mechanobiology. The role of the perivascular tissue should be properly considered for example in the boundary value problems of abdominal aorta solved in computational simulations focused on the determination of a growth and rupture of aneurysms or in *in vivo* constitutive modeling [8-11]. The perivascular adipose tissue fills the retroperitoneal space and contributes to lipid metabolism, glucose metabolism, and endocrine function [12]. The adipose tissue adheres to adventitia via unclear interface which enables the diffusion of adipokines and cytokines into the arterial wall and subsequently may contribute to the endothelial dysfunction or to the hypercoagulability [2]. In the study [4], the microstructure of porcine adipose tissue was investigated by scanning electron and confocal microscopy. The results revealed two collagen-based structures–a collagen network surrounding adipocytes referred to as the reinforced basement membrane, and a predominantly type I collagen fiber networks (the interlobular septa).

Mechanical properties of the perivascular tissue can be obtained from the uniaxial or multiaxial tensile test, the compression test and the indentation test [17-25]. These experiments have shown nonlinear behavior at large strain as well as anisotropy [18-21]. A non-linear stress versus strain response during the uniaxial compression test has the same character as the uniaxial tensile test [4]. However, most of the studies neglect the effect of the perivascular tissue on the abdominal aorta. It is because experimental data characterizing constitutive behavior of this tissue are rare in the literature.

The goal of this study is to determine the elastic modulus of the perivascular tissue surrounding human abdominal aorta.

II. MATERIALS AND METHODS

The samples of human abdominal aorta with fat tissue were obtained from the Faculty Hospital Královské Vinohrady in Prague. This study has been approved by the Ethics Committee of the Faculty Hospital Královské Vinohrady. After a transport to the laboratory, the perivascular tissue was manually separated by a scalpel from the aortic wall and trimmed to approximately rectangular samples. The representative of tested samples is depicted in Figure 1.

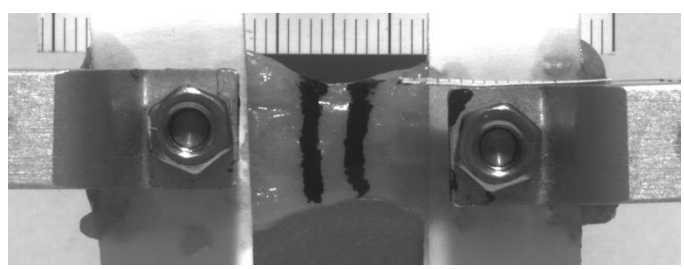

Figure 1 Configuration of the specimen in the jaws of the testing machine with transverse marks for the strain measurement.

Uniaxial tensile tests of perivascular tissue were performed with multipurpose testing machine (Zwick/Roel, Ulm, Germany). The sample was clamped in the jaws and

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transverse marks were created on its surface by a liquid eyeliner (Figure 1). The marks were used by a built-in video extensometer in optical strain measurement. During the experiment, current force and distance between marks were recorded into the controlling computer. Four loading cycles were realized at constant velocity of the clamp 0.2 mm/s. U9B (± 25 N, HBM, Darmstadt, Germany) load cells were used in the force measurement.

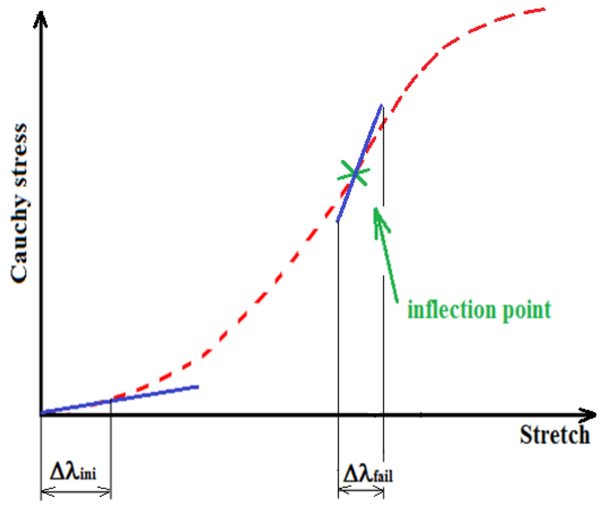

Figure 2 Evaluation of the elastic moduli.
Stress–stretch curve (red), the tangents (blue),
Stretch intervals ($\Delta\lambda_{ini}$, $\Delta\lambda_{fail}$), inflection point (green).

The Cauchy stress σ in uniaxial tension is given by

$$\sigma = \frac{f}{a}, \tag{1}$$

where f is applied force and a is current cross-sectional area of perivascular tissue sample.

Assuming incompressible behavior of the adipose tissue, current cross-sectional area can be expressed as

$$a = \frac{LA}{l} = \lambda^{-1}A\,, \tag{2}$$

where l and L are current and reference lengths between the transverse marks on the specimen, respectively. A is the reference cross-sectional area. $\lambda = 1 + \varepsilon = 1 + \frac{l-L}{l}$ is the stretch ratio in the direction of applied load. ε is engineering deformation.

By combining equations (1) and (2), the Cauchy stress is obtained as

$$\sigma = \lambda\frac{f}{A}. \tag{3}$$

The elastic modulus is defined as the slope of the tangent to the stress-strain curve at a point. In our study, initial elastic modulus (IEM) and elastic modulus before the initiation of a failure (EMF) were identified by linear regression of a stress-stretch curve. In the IEM determination, the linear regression was conducted at the interval $\Delta\lambda_{ini}$ of the initial deformation ($|\Delta\lambda_{ini}| \leq 0.05$). In the EMF determination, $\Delta\lambda_{fail}$ was used. $\Delta\lambda_{fail}$ was of the average length 0.014. See Figure 2 for details.

Table 1 Reference geometry of the samples (mean ± SD).

Number of sample	Reference thickness [mm] ± SD	Reference width [mm] ± SD	Reference cross-section [mm^2]
1	6.71 ± 1.32	9.30 ± 1.23	62.40
2	4.32 ± 0.45	8.86 ± 1.56	38.23
3	6.60 ± 0.46	7.06 ± 0.96	46.63
4	8.69 ± 1.07	12.98 ± 1.09	112.75
5	7.08 ± 0.45	8.83 ± 0.73	62.51
6	6.65 ± 0.36	7.97 ± 0.88	52.97

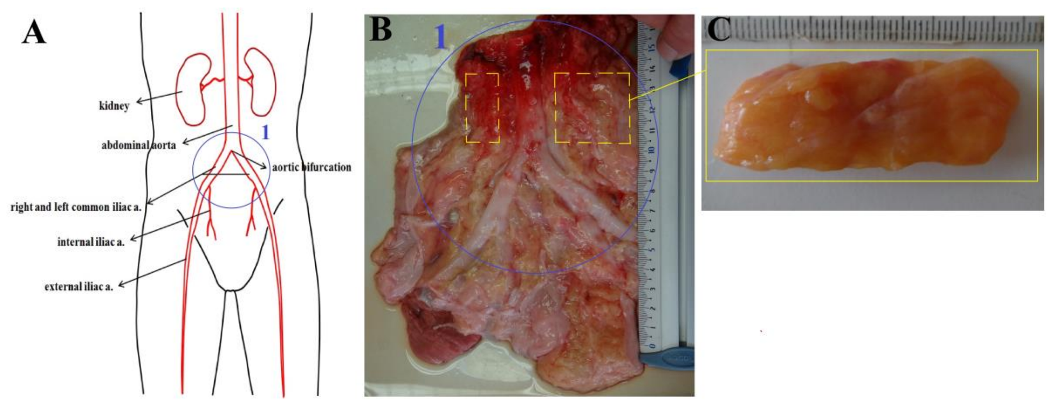

Figure 3 A Scheme of the descending aorta. **B** Sample of the abdominal aorta with iliac arteries and perivascular tissue. **C** Specimen of adipose tissue.

Table 2 IEM, EMF and interval of the stretch for elastic mudulus determination.

Number of sample	IEM [MPa]	Interval of stretch [-] ($\Delta\lambda_{ini}$)	Mean [MPa]	SD	EMF [MPa]	Interval of stretch [-] ($\Delta\lambda_{fail}$)	Mean [MPa]	SD
1	0.0095	<1, 1.033>	0.0170	0.0182	0.2657	<1.076, 1.082>	0.3210	0.1183
2	0.0108	<1, 1.05>			0.1725	<1.12, 1.135>		
3	0.0109	<1, 1.03>			0.2759	<1.08, 1.091>		
4	0.0023	<1, 1.025>			0.4577	<1.105, 1.114>		
5	0.0571	<1, 1.02>			0.5032	<1.08, 1.095>		
6	0.0111	<1, 1.036>			0.2509	<1.078, 1.105>		

III. RESULTS AND DISCUSSION

Six specimens from two donors, 41 and 71 years old men, were tested at post mortem interval 59 and 38 hours, respectively. Figure 3 illustrates obtained abdominal aorta with surrounding tissue. The location scheme of the abdominal aorta in the human body is represented in Figure 3A. The excised abdominal aorta, iliac arteries and perivascular tissue are shown in Figure 3B. The cut sample is displayed in Figure 3C.

Reference dimensions of the samples, i.e. width, thickness and cross-section area are included in Table 1. The samples were geometrically non-uniform (Figure 3C). Dimensions are given as a mean value of six measurements and it is supplemented with standard deviation (SD).

Determined results are summarized in Table 2. The value of IEM varies from 0.0023 to 0.0111 MPa, and EMF was obtained in the range of 0.1725 – 0.5030 MPa. The mean values and standard deviations of IEM and EMF are 0.0170 MPa ± 0.0182 and 0.3210 MPa ± 0.1183, respectively.

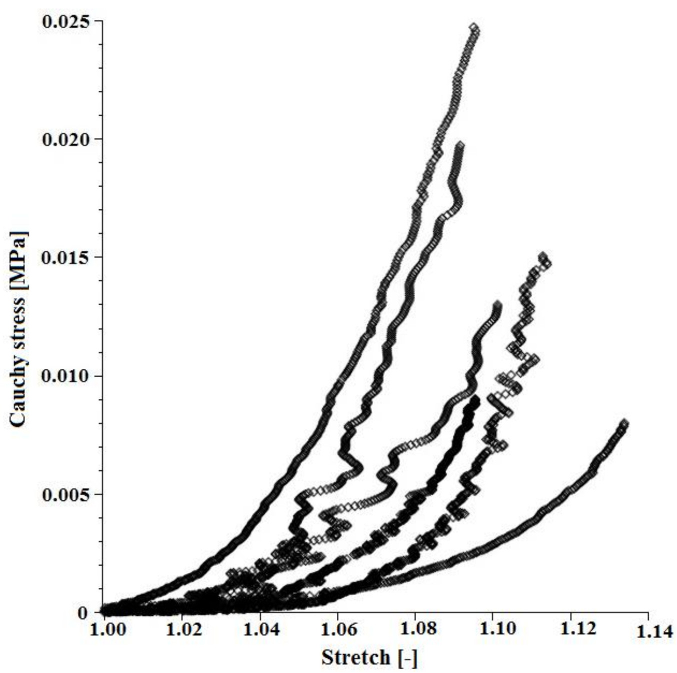

Figure 4 The uniaxial tensile test results of 6 samples.

Present paper reports preliminary results of our study dealing with mechanical properties of the perivascular tissue surrounding abdominal aorta. The values of elastic moduli and experimental stress-strain relationships were presented. The uniaxial tensile tests demonstrated nonlinear behavior of the perivascular tissue (Figure 4). It confirms observations available in the literature [17, 23, 24].

Samani et al. [24] found, using indentation tests, the elastic modulus of normal breast adipose tissue to be about 3 kPa. This result corresponds approximately to our IEM. In the study [4], the elastic moduli obtained in the compression tests of the porcine adipose tissue at the initial and large deformations respectively were about 0.0006 MPa and 0.003 MPa. It shows that elastic moduli in the compression are about two orders of magnitude smaller than our moduli measured in the tension.

Our preliminary results suggest that the perivascular tissue is much more compliant in comparison with human coronary arteries, human abdominal aorta, and human pericardium [27, 28, 29, 30]. Our study will continue with further data collection to reach the cohort exhibiting statistical significance, and methods of nonlinear continuum mechanics will be employed to determine appropriate constitutive model for the perivascular tissue.

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