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Mechanical Properties of Perivascular Adipose Tissue and its Effect on Biomechanics of Abdominal aorta

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Doctoral study program: Mechanical Engineering
Field of study: Biomechanics

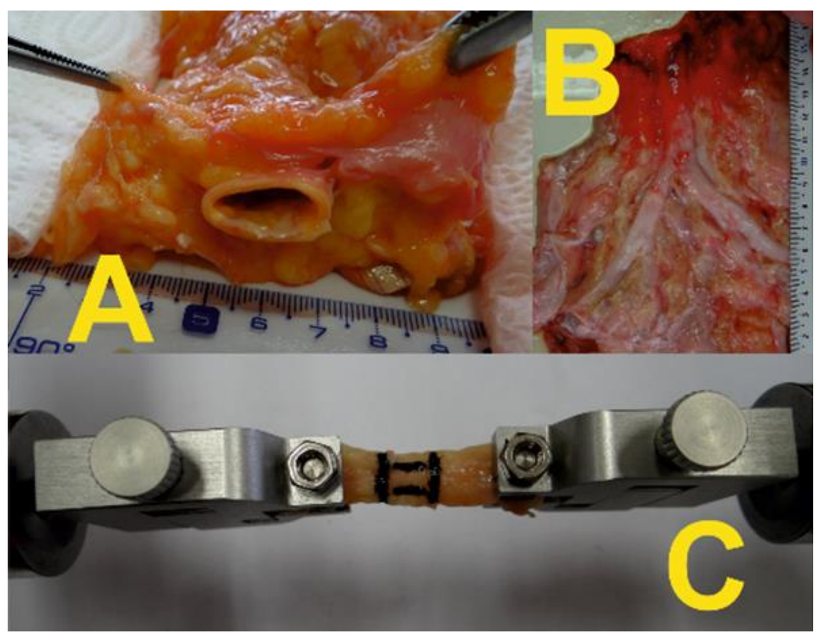
The perivascular adipose tissue may significantly change the mechanical state of the abdominal aorta. To this end, uniaxial tensile tests with perivascular fat tissue were carried out. In the subsequent regression analysis, stress-strain data were fitted by the polynomial strain energy density. A constitutive model of adipose tissue was used in the analytical simulation of the inflation-extension behavior of the human abdominal aorta. The computational model was based on the theory of the bi-layered thick-walled tube. In addition to the effect of perivascular tissue, the effect of axial prestretch was also studied. It was found that the presence of perivascular tissue reduces the distensibility of the aorta. Axial prestretch applied to aortas embedded in adipose tissue had an effect opposite to that of adipose tissue. Axially prestrained aortas exhibited higher distensiblity than non-prestrained aortas. It was also shown that the perivascular envelope bears some portion of the pressure loading and thus reduces the mechanical stresses inside the wall of aorta. A similar effect was found for axial prestretch.

Aim of the Study

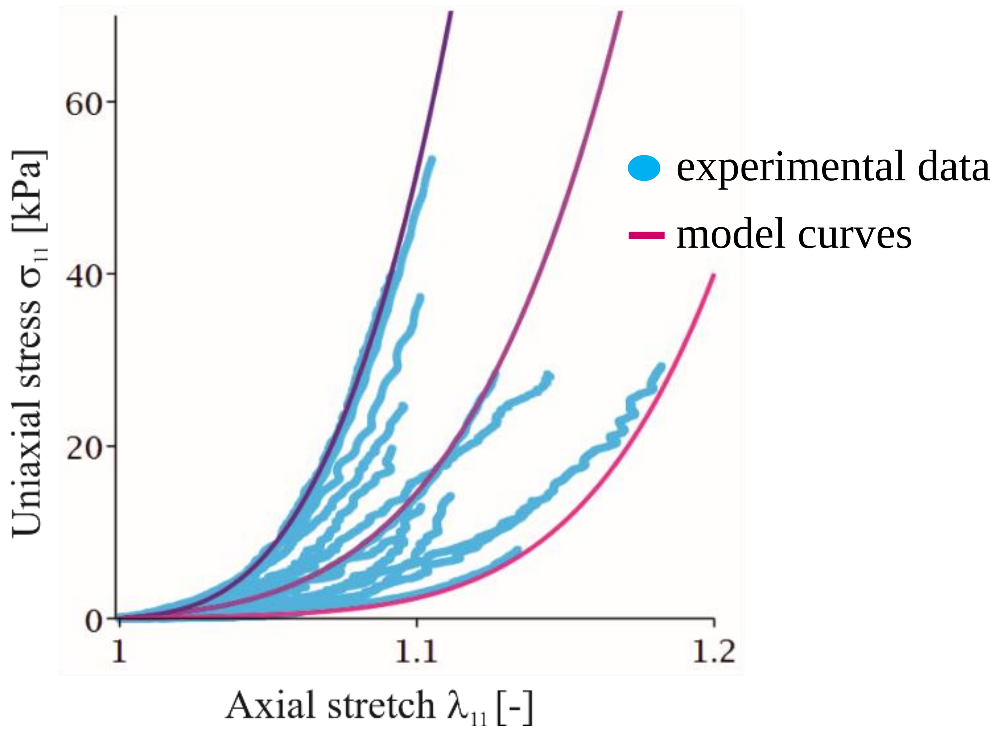
The work aims to confirm the significant influence of boundary conditions on the mechanical condition of the abdominal aorta. To confirm this hypothesis was considered:

- mechanical interaction of the abdominal aorta with human perivascular adipose tissue on its outer radius in order to obtain that it is necessary:
  - to identify mechanical properties by perform experiments with human perivascular adipose tissue,
  - to identify constitutive model of perivascular adipose tissue and then it is necessary to create analytical model by simulation of inflation-extension test of bilayer tube (abdominal aorta surrounded by perivascular adopise tissue).
- application of axial prestretch on ends of the abdominal aorta which is surrounding by perivascular adipose tissue in order to achieve investigation under realistic conditions.

Uniaxial tensile tests with 15 PVAT samples



Perivascular tissue surrounds aorta
A - Transversal plane, B - frontal plane
C - Sample of PVAT in uniaxial tension



- The experimental data was fitted with hyperelastic model:

$$W_{\mathrm{PT}} = c_1(I_1 - 3) + c_2(I_1 - 3)^2,$$

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2$$

The multipurpose testing machine

Constitutive model for abdominal aorta

$$W_A = W_{\mathrm{isotropic}} + W_{\mathrm{anisotropic}} = \frac{\mu}{2}(I_1 - 3) + \sum_{i=4,6}\left(\frac{k_1}{2k_2}e^{k_2(K_j-1)^2} - 1\right)$$

$$K_j = \kappa I_1 + (1 - 3\kappa)I_i, \qquad i = 4, 6 \qquad I_4 = M_1(CM_1) = M_2(CM_2) = I_6$$

$$\boldsymbol{M}_1 = \left(0, cos(\beta), sin(\beta)\right)^T, \boldsymbol{M}_2 = \left(0, cos(-\beta), sin(-\beta)\right)^T$$

Selected of author´s publications

Voňavková and Horný (2020) Effect of axial prestretch and adipose tissue on the inflation-extension behavior of the human abdominal aorta. Computer Methods in Biomechanics and Biomedical Engineering 23(3):81-91.

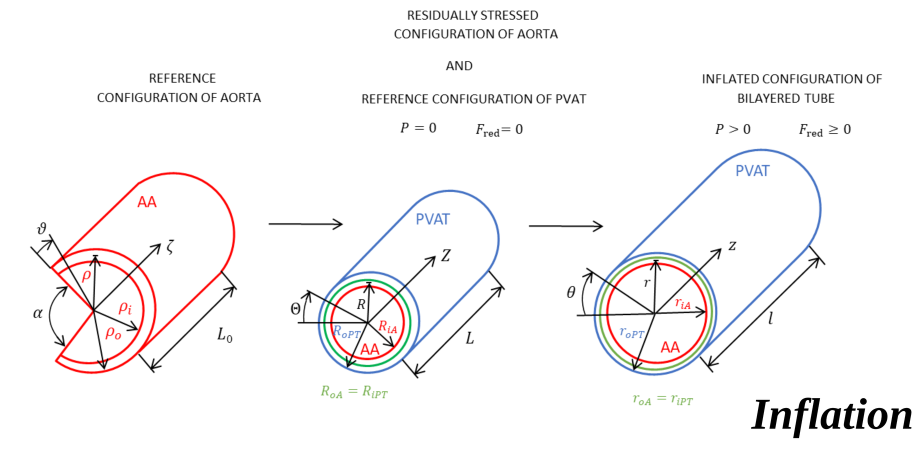
Vonavkova, T., Horny, L., Vesely, J., Adamek, T., and Zitny, R. (2016) Effect of perivascular tissue on inflation-extension behavior of abdominal aorta. ECCOMAS Congress 2016: VII European Congress on Computational Methods in Applied Sciences and Engineering. p. 6616-6624.

Vonavkova, T., Horny, L., Adamek, T., Kulvajtova, M.,Zitny, R. (2015) Constitutive modelling of human perivascular adipose tissue. A: COMPLAS XIII. "COMPLAS XIII: proceedings of the XIII International Conference on Computational Plasticity: fundamentals and applications". CIMNE ed. Barcelona: CIMNE, p. 463-470.

Voňavková T., Horný L., Kulvajtová M., Žitný R. (2014). Uniaxial tensile test of perivascular adipose tissue. Bulletin of Applied Mechanics 10(36):11-14. ISSN 1801-1217.

Inflation-extension simulation

Abdominal aorta surrounded by PVAT
Bilayer tube thick-walled tube



PVAT thickness
- $H_{PT} = 0.2$, 1.22, 40 mm

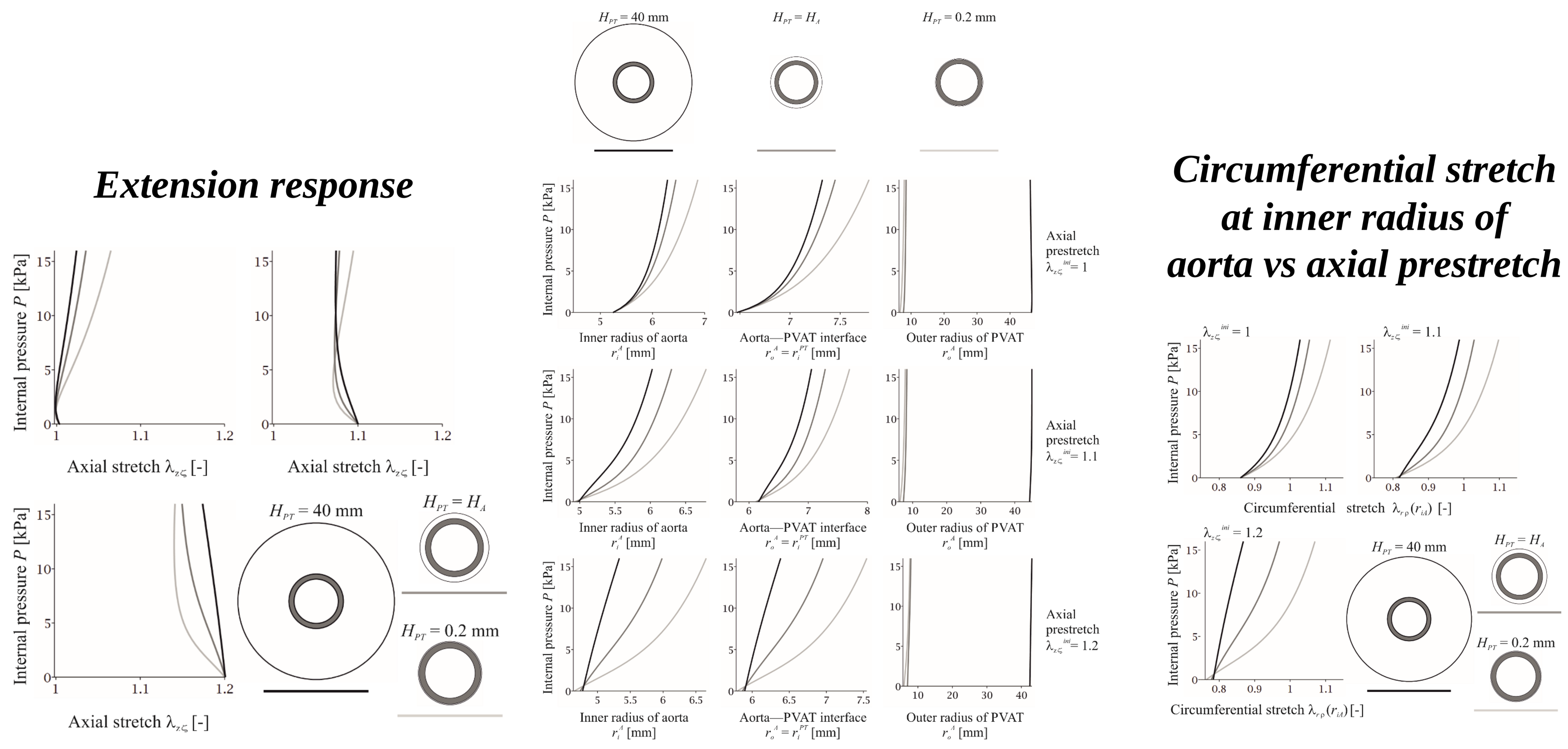
Inner pressure
- $P = 0 - 16$ kPa

Axial prestretch applied to bilayer tube
- $\lambda_{z\zeta}^{ini} = 1$, 1.1, 1.2

Inflation response

Extension response

Circumferential stretch at inner radius of aorta vs axial prestretch

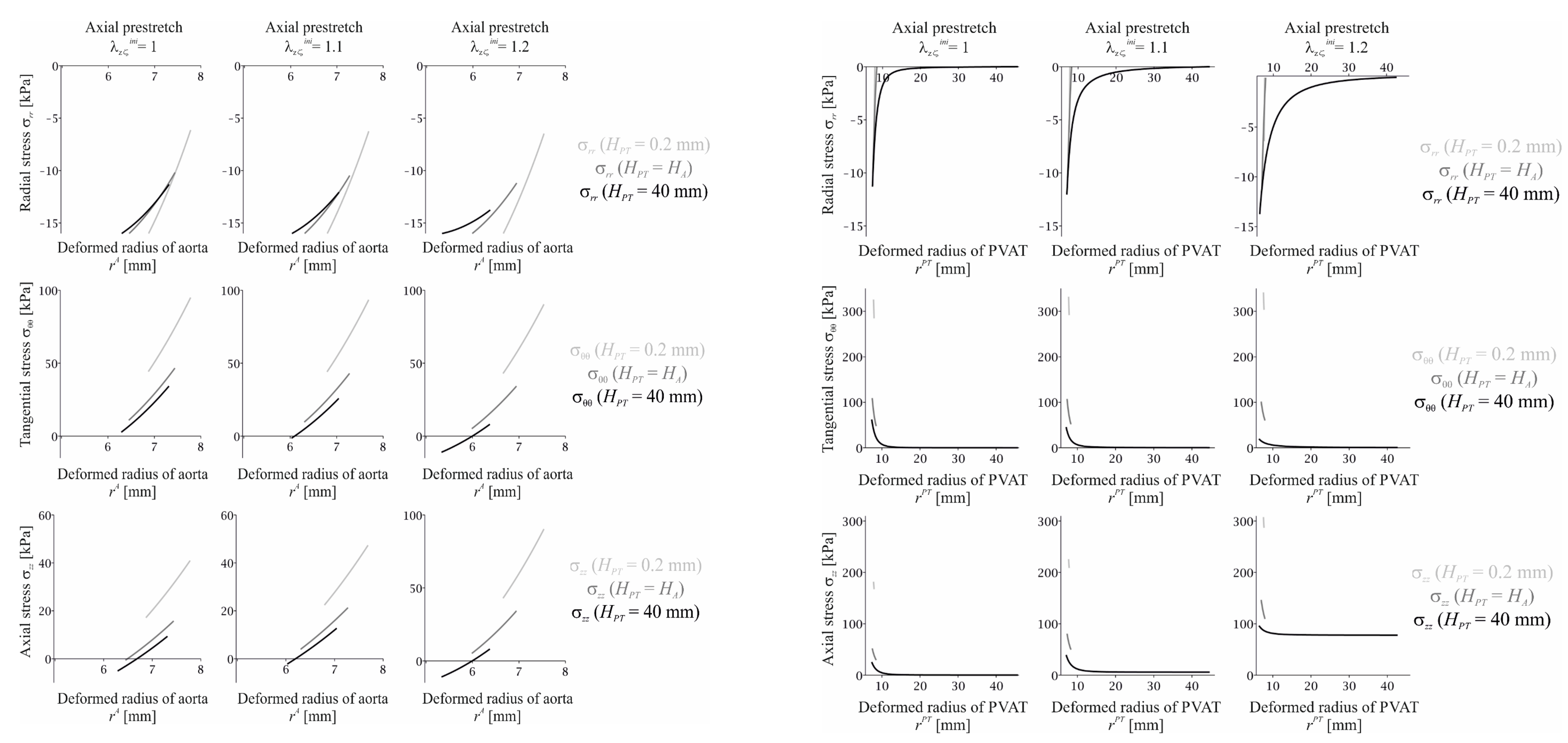


Distribution of in-wall stresses in bilayer tube

Radial, circumferential and axial stress

Stresses in abdominal aorta wall

Stresses in PVAT wall



Conclusion

Constitutive parameters of perivascular adipose tissue were found. The obtained material parameters were subsequently used in the analytical solution of the bi-layer thick-walled tube problem simulating the mechanical effect of PVAT on the abdominal aorta. Simultaneous with examining the effect of PVAT, the effect of axial prestretch was also studied.

The presence of PVAT reduces the distensibility. Axial prestretch applied to the aorta embedded in PVAT had an opposite effect. Axially prestrained aortas exhibited higher distensiblity than non-prestrained aortas.

The perivascular envelope bears some portion of the pressure loading and thus reduces the mechanical stresses inside the wall of the aorta. A similar effect was found for axial prestretch.

The results suggest that perivascular adipose tissue is mechanically advantageous, due to it reducing wall stresses, and that decreased arterial distensibilty is compensated for by axial prestretch in the aorta.