IMPORTANCE OF STRUCTURAL PARAMETERS IN CONSTITUTIVE MODELS OF AORTA

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Introduction

Constitutive models of aortic wall are important for its biomechanical analyses. Although structure based constitutive models are considered preferable, the lack of histological data on tissue structure is limiting and sometimes they are fitted to mechanical tests only [3]. This study compares the capability of different structure-based constitutive models to fit the mechanical tests with and without histological data. For this purpose, the most common models of arterial wall tissues were used, both postulating two fibre families, with (GOH [1]) and without (HGO [2]) dispersion of their directions. The differences between the investigated constitutive models are illustrated using finite element simulations of uniaxial and biaxial loading states of the arterial wall.

Methods

Samples of porcine aortas (size of 18×18 mm) were separated into two layers (adventitia and media) with similar thickness. Mechanical testing of the specimens was realized under equibiaxial extension in saline solution (37°C) with five cycles ensuring specimen preconditioning. Polarized light microscopy with automatic algorithm for evaluation of collagen fibre directions (in ~10^5 points per histological slice) was used for analysis in 8 slices throughout the wall thickness and in both perpendicular planes. See [4] for more details.

Histological parameters necessary for the constitutive model (mean angle and dispersion in each fibre family) were obtained by fitting the histograms with the *von Mises* probability density function. The fitting procedure was performed in Curve Fitting Toolbox in MATLAB. Then we used Hyperfit software (www.hyperfit.wz.cz) to fit the models to mechanical data either without or with consideration of histological parameters. The goodness of the fit was evaluated using coefficient of determination R^2. Finite Element simulations (using ANSYS software) simulated uniaxial and equibiaxial tension test and inflation of aorta.

Results

In agreement with [3], the mechanical tests showed anisotropic response with significant strain stiffening (higher in circumferential direction) for both aortic layers. When fitted with the chosen models without histological data (non-structural models), the HGO model resulted in two directions close to ±45°, while GOH model tended to isotropic fibre distribution. Both results contradict histological data.

For both layers we obtained unimodal dominantly circumferential orientation of collagen fibres. However, the fit to biaxial tests with these fixed structural parameters was poor (R^2<0.77) in all cases. Only if we replaced the Neo-Hookean model (used for isotropic matrix in both GOH and HGO models) with 3rd order Yeoh model to introduce isotropic strain stiffening, we obtained a perfect fit (R^2>0.98).

Results of FE simulations of uniaxial tension (with the same force) presented in Figure 1 show significant differences in stiffness between the investigated models. Their impact in equibiaxial tension and in the aortic wall inflation with all the details can be found in [4].

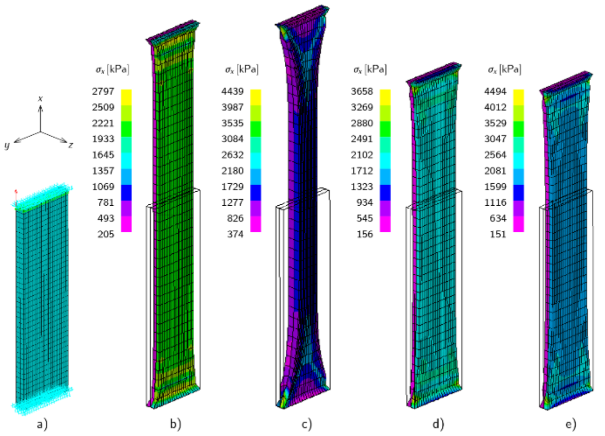

Figure 1: Distribution of 1st principal (Cauchy) stress in FE simulations of uniaxial tension test using different constitutive models: a) mesh with the applied boundary conditions, b) non-structural GOH model, c) non-structural HGO model, d) structural GOH model, and e) structural HGO model.

Conclusion

The presented simulations have shown the importance of histological analyses for structure based constitutive models. The structural parameters of the investigated models were in contradiction to histological information if estimated from mechanical tests only. In contrast, these models were not capable to reach a good fit to both mechanical and histological data. This shortcoming was overcome by the addition of isotropic strain stiffening to the original HGO and GOH models, i.e. by replacement of the Neo-Hookean description of the matrix with a 3rd order Yeoh model.

References

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