INVESTIGATING THE GROWTH & REMODELING MODEL PARAMETERS INFLUENCE ON A HYPERELASTIC ARTERY

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Introduction

Predicting the evolution of an ascending thoracic aortic aneurysm (ATAA) is a challenge. Today the decision to perform surgery is based on the aneurysm diameter and more recently, on its evolution, measured on follow-up longitudinal images. However due to the complexity of both the aortic geometry, the tissue behavior and the blood flow, these criteria may over- or under-estimate the risk of rupture or dissection in some cases. Numerical simulation of aneurysm growth could provide additional information on the tissue state to identify the unstable cases requiring surgery.

In this work we implemented an existing Growth and Remodeling (G&R) model based on the constrained mixture theory [1,3] and applied it to a generic tube geometry, to investigate the interaction between the model parameters.

Materials and Methods

The G&R model includes elastin, 4 collagen fiber families (axial, circumferential and two oblique) and Smooth Muscle Cells (SMCs) oriented in the circumferential direction. The strain energy density function of the tissue is written as:

$$W = \rho^e\left(\frac{\mu}{2}(\bar{I}_1 - 3) + K(J-1)^2\right) + \rho^c \frac{c_1}{2c_2}\left(e^{c_2(I_4^c-1)^2} - 1\right) + \rho^m \frac{m_1}{2m_2}\left(e^{m_2(I_4^m-1)^2} - 1\right) \quad (1)$$

Where superscripts e, c and m stand for elastin, collagen and SMCs respectively, ρ is the constituent mass density and $\mu, K, c_1, c_2, m_1, m_2$ are material parameters.

Following [2], elastin and collagen degrade due to ageing, but only collagen can be deposited. The deposition rate for collagen is :

$$\dot{\rho_t^c} = \rho_t^c \kappa_\sigma \frac{\sigma_t^c - \sigma_h^c}{\sigma_h^c} \quad (2)$$

Where $\dot{\rho_t^c}$ is the deposition rate, κ_σ is a gain parameter, σ_t^c is the current time stress and σ_h^c is the homeostatic stress. The model is formulated so that growth occurs when the tissue is out of the homeostatic state, defined by a homeostatic stretch λ for each constituent [1].

This G&R model was implemented as a user-subroutine in ANSYS APDL and applied to a single-layer tube (length = 180mm, inner radius = 10mm, thickness = 1.41mm). Growth is driven by a localized and progressive loss of elastin, and can only happen in the radial direction; therefore, the thickness and inner radius of the tube evolve with growth. G&R simulation could be computed over 8 years. The influence of several parameters, such as the deposition and degradation parameters for collagen and elastin, was investigated.

Results

Figure 1 illustrates the effect of the gain parameter κ_σ on G&R for a given elastin degradation. We could observe that a larger κ_σ corresponded to a higher compensation of the elastin loss, even far from the elastin defect; this is emphasized by a smaller average inner diameter and larger thickness. We could also observe that thickness does not have a monotonic evolution depending on the relative growth and degradation rates of both collagen and elastin. As shown in [2], parameters configurations can lead to stabilization or unstable growth of the vessel diameter.

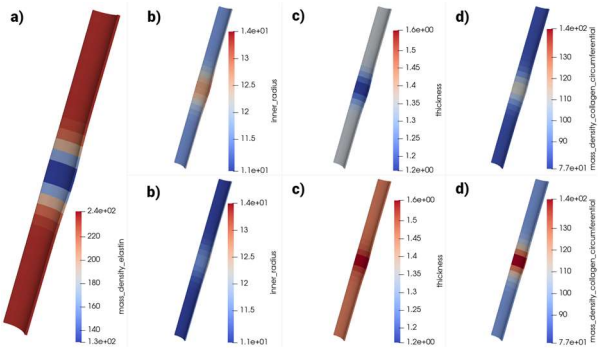

Figure 1: Distributions after 1000 days of: a. elastin mass density, and for $\kappa_\sigma = 0.05$ (first line) and $\kappa_\sigma = 0.15$ (second line): b. inner radius, c. thickness and d. collagen mass density in the circumferential direction

Discussion and Conclusions

Our study aims to understand the relative influence of the different parameters on the structure evolution, as G&R models include a large number of parameters. This could help interpreting simulation results on more complex geometries such as patient-specific ones.

Acknowledgments

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References

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