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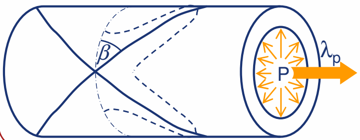
Introduction

A mechanical model of the vascular tree would facilitate the improvement of (balloon-)catheters and stents. The aim of this research is to propose generic model and geometric parameter values for a fiber-reinforced material model[2] that describes the arterial wall behavior of the passive porcine coronary artery.

Material & methods

Measurement pressure-inner radius (P-r_i) and P-Δ axial force (P-ΔF) relations at physiological stretch[1] (λ_p) of the porcine left anterior descending coronary artery (LAD) and the material model.

Coronary artery under loading:



Fiber reinforced Neo-Hookean model[2] with 4 fit parameters:

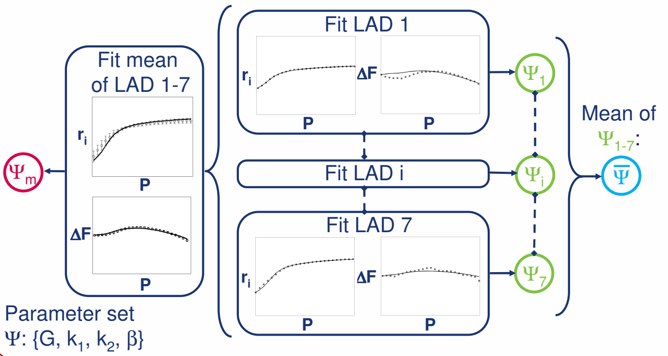
$$\sigma = -p\mathbf{I} + \tau + \sum_{i=1}^{n} \phi_{f_i}[\tau_{f_i} - \vec{e}_{f_i} \cdot \tau \cdot \vec{e}_{f_i}]\vec{e}_{f_i}\vec{e}_{f_i}$$

$$\tau = G(\mathbf{B} - \mathbf{I})$$

$$\tau_{f_i} = k_1 \lambda_{f_i}^2 (\lambda_{f_i}^2 - 1) e^{k_2(\lambda_{f_i}^2 - 1)^2}$$

$$\vec{e}_{f_i} = [0 \;\; \cos(\beta_i) \;\; \sin(\beta_i)]^T$$

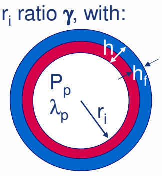
Model fit of P-r_i and P-ΔF relations giving the optimal parameter set Ψ_i (i=1-7) and the generic sets Ψ_m and $\overline{\Psi}$.



Parameter set
Ψ: {G, k_1, k_2, β}

Model approximation of r_i at physiological pressure (P_p) and stretch using Ψ_m & $\overline{\Psi}$ and generic mean values for the geometric parameters λ_p, collagen fiber fraction ϕ_f, and wall thickness to r_i ratio γ, with:

$\overline{\lambda}_p = 1.39$ $\quad \overline{\phi}_f = \overline{\left(\frac{h_f}{h}\right)} = 0.4$ $\quad \overline{\gamma} = \overline{\left(\frac{h}{r_i}\right)} = 0.09$



Compare deviations of model approximations from experimentally measured P-r_i and P-ΔF relations (δ_r & δ_F resp.) using Ψ_{1-7}, Ψ_m and $\overline{\Psi}$.

Fig. 1: Protocol used to obtain the generic model parameters.

Results

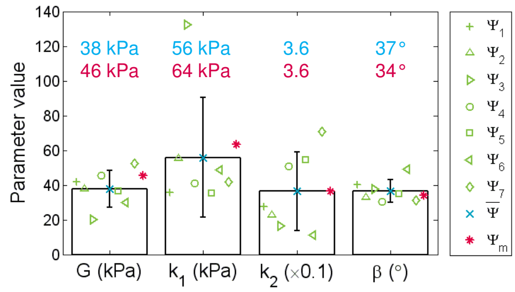


Fig. 2: Parameter values resulting from the material model fits to the experimental data set of each LAD, the mean values ±SD (bars & error bars) and the generic parameter sets Ψ_m and $\overline{\Psi}$ and their values.

The different parameter sets Ψ_i, Ψ_m, and $\overline{\Psi}$ show spread in the parameter values (fig. 2). The experimental P-r_i and P-ΔF relations can be fitted well with the model using Ψ_i (fig.3 & table). The deviation $\overline{\delta}_r$ increased when a generic set was used (0.5%≈8 μm to 2%≈30 μm). $\overline{\delta}_F$ was comparable for Ψ_i and Ψ_m (0.47 vs 0.59≈30 mN), whereas $\overline{\delta}_F$ increased when $\overline{\Psi}$ was used.

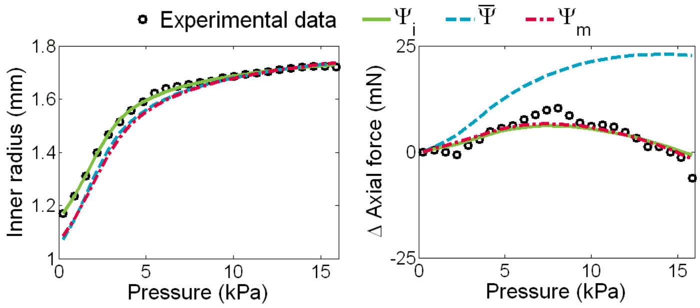


Fig. 3: Example of the P-r_i and P-ΔF relation of a porcine LAD measured experimentally, the optimal model fit using Ψ_i, and the generic model approximation using Ψ_m and $\overline{\Psi}$.

Table: Mean deviations ± SD of the model approximations from the experimental P-r_i and P-ΔF relations using the different parameter sets.

	Ψ_i	$\overline{\Psi}$	Ψ_m
$\overline{\delta}_r$	0.005 ± 0.003	0.019 ± 0.01	0.019 ± 0.01
$\overline{\delta}_F$	0.47 ± 0.23	1.47 ± 0.94	0.59 ± 0.20

Conclusion

Two generic parameter sets in combination with generic geometric values have been proposed of which the set Ψ_m shows a better approximation of the experimental data. Applying this generic model, using the set Ψ_m, to a single radius measurement at physiological loading, allows prediction of the P-r_i and P-ΔF relations of the porcine LAD with an accuracy of 30 μm and 30 mN on average.

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[1] van den Broek (2009), Symposium Rotterdam.
[2] Driessen et al. (2005), *J Biomech Eng* **127**, p.494-503.