A generic material model of the passive porcine coronary artery

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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 that describes the arterial wall behavior of the passive porcine coronary artery.

Material & methods

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

Fiber reinforced Neo-Hookean model with 4 fit parameters:

\[
\begin{align*}
\sigma &= -p + \tau + \sum_{i=1}^{n} \phi_i (r_i - \phi_i \cdot \tau \cdot \delta \cdot r_i) + \tau_i \\
\tau &= \lambda_p (\lambda_p - 1) \\
\delta &= \frac{h}{r} \\
\end{align*}
\]

Model fit of P-r and P-ΔF relations giving the optimal parameter set \(\Psi_i\) (i=1-7) and the generic sets \(\Psi_m\) and \(\Psi\).

Model approximation of \(r_i\) at physiological pressure (P_p) and stretch using \(\Psi_m\) and \(\Psi\) and generic mean values for the geometric parameters \(\phi_m\) collagen fiber fraction, \(\lambda_m\) and wall thickness to \(r_i\) ratio \(\gamma\) with:

\[
\begin{align*}
\lambda_m &= 1.39 \\
\phi_m &= \frac{h}{r} = 0.4 \\
\gamma &= \frac{h}{r} = 0.09 \\
\end{align*}
\]

Compare deviations of model approximations from experimentally measured P-r and P-ΔF relations (δ_i & δ resp.) using \(\Psi_m\) and \(\Psi\).

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 \(\Psi_m\) and \(\Psi\) and their values.

The different parameter sets \(\Psi_i\), \(\Psi_m\), and \(\Psi\) show spread in the parameter values (fig. 2). The experimental P-r and P-ΔF relations can be fitted well with the model using \(\Psi_i\) (fig.3 & table). The deviation \(\delta_i\) increased when a generic set was used (0.5%≈6 μm to 2%≈30 μm). \(\delta_i\) was comparable for \(\Psi_i\) and \(\Psi_m\) (0.47 vs 0.59≈30 mN), whereas \(\delta_i\) increased when \(\Psi\) was used.

Fig. 3: Example of the P-r and P-ΔF relation of a porcine LAD measured experimentally, the optimal model fit using \(\Psi_i\) and the generic model approximation using \(\Psi_m\) and \(\Psi\).

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(\Psi_i)</th>
<th>(\Psi_m)</th>
<th>(\Psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\delta_i)</td>
<td>0.005 ± 0.003</td>
<td>0.019 ± 0.01</td>
<td>0.019 ± 0.01</td>
</tr>
<tr>
<td>(\delta_m)</td>
<td>0.47 ± 0.23</td>
<td>1.47 ± 0.94</td>
<td>0.59 ± 0.20</td>
</tr>
</tbody>
</table>

Conclusion

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