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A generic material model of the passive porcine coronary artery
Chantal van den Broek, Arjen van der Horst, Marcel Rutten & Frans van de Vosse

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 a 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-\(r_i\)) and P-\(\Delta F\) relations at physiological stretch (\(\lambda_i\)) of the porcine left anterior descending coronary artery (LAD) and the material model. Coronary artery under loading: Fiber reinforced Neo-Hookean model with 4 fit parameters:

\[
\sigma = -\lambda + \tau + \sum_{i=1}^{3} c_i (\lambda_i - 1) + \frac{1}{\lambda_i} + \frac{1}{\lambda_i} - 1
\]

\[
\tau = \sqrt{\lambda_i} - 1
\]

\[
\tau = \sqrt{\lambda_i} - 1
\]

\[
\tau = \cos(\delta) \sin(\beta)
\]

Model fit of P-\(r_i\) and P-\(\Delta F\) 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-\(r_i\)) and stretch using \(\Psi_m\) and \(\Psi\) and generic mean values for the geometric parameters \(\lambda_m\), collagen fiber fraction \(\phi\), and wall thickness to \(r_i\) ratio \(\gamma\) with:

\[
\lambda_m = 1.39 \quad \phi = \frac{h}{(h)} = 0.4 \quad \gamma = \frac{h}{(r_i)} = 0.09
\]

Compare deviations of model approximations from experimentally measured P-\(r_i\) and P-\(\Delta F\) relations (\(\delta_m\) & \(\delta\) resp.) using \(\Psi_{1-7}\), \(\Psi_m\) 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-\(r_i\) and P-\(\Delta F\) relations can be fitted well with the model using \(\Psi_i\) (Fig. 3 & table). The deviation \(\delta_m\) increased when a generic set was used (0.5%≈6 μm to 2%≈30 μm). \(\delta_m\) was comparable for \(\Psi_i\) and \(\Psi_m\) (0.47 vs 0.59≈30 mN), whereas \(\delta_m\) increased when \(\Psi\) was used.

![Fig. 1: Protocol used to obtain the generic model parameters.](image)

![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.](image)

![Fig. 3: Example of the P-\(r_i\) and P-\(\Delta F\) relation of a porcine LAD measured experimentally, the optimal model fit using \(\Psi_i\), and the generic model approximation using \(\Psi_m\) and \(\Psi\).](image)

Table: Mean deviations ± SD of the model approximations from the experimental P-\(r_i\) and P-\(\Delta F\) relations using the different parameter sets.

<table>
<thead>
<tr>
<th>Parameter set (\Psi)</th>
<th>(\Psi_i)</th>
<th>(\Psi_m)</th>
<th>(\Psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\delta_m)</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-\(r_i\) and P-\(\Delta F\) relations of the porcine LAD with an accuracy of 30 μm and 30 mN on average.

[1] van den Broek (2009), Symposium Rotterdam.