A generic material model of the passive porcine coronary artery

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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 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 (\(\lambda_p\)) 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:

\[
\sigma = -\lambda_p \sigma + \sum_{i=1}^{4} \phi_i \sigma_{i} = -\lambda_p \sigma + \sum_{i=1}^{4} \phi_i \sigma_{i}
\]

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\(_p\)) and stretch using \(\Psi_m\) and \(\Psi\) and generic mean values for the geometric parameters \(k_1\), collagen fiber fraction \(\psi\), and wall thickness to \(r_i\) ratio \(\gamma\) with:

\[
\lambda_p = 1.39, \quad \psi = \frac{\bar{h}}{\bar{r}} = 0.4, \quad \gamma = \frac{\bar{h}}{\bar{r}_i} = 0.09
\]

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 \(\Delta F\) increased when a generic set was used (0.5%≈30 mm) to 2%≈30 mm). \(\Delta F\) was comparable for \(\Psi_i\) and \(\Psi_m\) (0.47 vs 0.59≈30 mN), whereas \(\Delta F\) increased when \(\Psi\) was used.

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 \(\Psi\).

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</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Psi_i)</td>
<td>0.005 ± 0.003</td>
</tr>
<tr>
<td>(\Psi_m)</td>
<td>0.019 ± 0.01</td>
</tr>
<tr>
<td>(\Psi)</td>
<td>0.019 ± 0.01</td>
</tr>
<tr>
<td>(\Psi_i)</td>
<td>0.47 ± 0.23</td>
</tr>
<tr>
<td>(\Psi_m)</td>
<td>1.47 ± 0.94</td>
</tr>
<tr>
<td>(\Psi)</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 mm and 30 mN on average.

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