Inflation tests were performed on a screw-driven high precision tensile testing machine. The samples were immersed in a container filled with Krebs buffer maintained at 37±0.1°C by a heater-circulation unit. After mounting, samples were first stretched to an axial pre-stretch of 50%. Next, the samples were subjected to a saw-tooth profile of three loading and unloading cycles of the internal pressure $P_{\text{exp}}$ ranging from 0 to 20 kPa at a speed of 20 Pa/s, during which the axial force $F_{\text{exp}}$ and the outer radius $r_o$ were continuously recorded.

**Parameter fitting**

A nonlinear optimization was performed in Matlab R2010a. Thereby, the lsqnonlin routine and the ‘trust-region-reflective’ optimization algorithm was used with the optimization function:

$$
\Phi = (\mathbf{P-P}_{\text{exp}})^T + w \cdot (\mathbf{F-F}_{\text{exp}})^T
$$

with:

$$
\mathbf{P} = \int \lambda_3 \cdot \lambda_2 \cdot (\lambda_3 - 1) \cdot \frac{\partial w}{\partial \lambda_1} \cdot \lambda_1 d\lambda_1
$$

and

$$
\mathbf{F} = \pi \cdot R_i^2 \cdot \left(\lambda_3^2 \cdot \lambda_2^2 - 1\right)^\frac{3}{2} \cdot (2 \cdot \lambda_2 \cdot \frac{\partial w}{\partial \lambda_2} - \lambda_1 \cdot \frac{\partial w}{\partial \lambda_1}) \cdot \lambda_1 d\lambda_1
$$

where $\mathbf{P}_{\text{exp}}$ is a vector containing the pressure applied to the sample during the third loading cycle of the inflation experiment and $\mathbf{F}_{\text{exp}}$ is a vector containing the axial force measured during the third loading cycle. The weighting factor $w$ was set to bring the two errors related to pressure and force to the same order of magnitude. $\mathbf{P}$ and $\mathbf{F}$ were calculated analytically as a function of the principal stretches $\lambda_1$ and $\lambda_2$, which are in turn a function of the measured outer radius $r_o$ and axial length $L_i$, $\lambda_3$ and $\lambda_6$ are the circumferential stretches at the inner and the outer diameter, respectively. $R_i$ is the inner radius.

**Finite element model**

A three dimensional finite element model was built in Abaqus/Explicit 6.9. The initial geometry for the model was a cylinder with an outer radius of 0.58 mm, a wall thickness of 0.14 mm and an initial length of 0.2 mm. C3D8R elements were assigned to the mesh and the Holzapfel-material model, in Abaqus referred to as the Holzapfel-Gasser-Ogden material, was used with the parameters derived as explained in the previous paragraph.

Two different clamp designs were used, a simple flat surface, and a corrugated surface, similar to a typical mosquito clamp,
both approximated by analytical rigid surfaces. Three steps were modeled. First, the cylinder was longitudinally stretched with a factor of 1.5. Second, the segment was pressurized with an internal pressure of 13 kPa. In the final step, the internal pressure pulsed between the physiological level of 13 kPa and 10 kPa at a rate of 1 Hz, and both clamps were moved towards each other until they exerted a clamping force of 0.2 N per mm² of clamped surface.

Contact, enforced with the penalty method, was defined between all contacting surfaces, nonlinearity due to large displacements was taken into account and the analysis was run in double precision.

RESULTS AND DISCUSSION

Table 1: Holzapfel parameters for rat abdominal artery. Average values and standard deviation (SD) for 9 specimens.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average (kPa)</th>
<th>SD (kPa)</th>
<th>c (kPa)</th>
<th>κ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_1$</td>
<td>32.51</td>
<td>6.13</td>
<td>3.05</td>
<td>0.16</td>
</tr>
<tr>
<td>$k_2$</td>
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<td>1.32</td>
<td>23.63</td>
<td>4.13</td>
</tr>
<tr>
<td>$c$</td>
<td>23.63</td>
<td>4.13</td>
<td>0.16</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 1 shows the results of the parameter fitting. Figure 1 shows a section of the artery subjected to a clamping force of 0.2 N/mm², for the smooth clamp and for the mosquito clamp, respectively. The color overlay in the different plots shows the distribution of the Von Mises stress and the three principal stresses.

Figure 2 shows the numerically calculated clamping force as a function of time during the closing of a smooth clamp. This clamping force is also compared to the clamping force measured during the *in vivo* clamping of a rat coronary artery, as described in [3].

Figure 2: Force pattern during arterial clamping in an *in vivo* clamping experiment and in an FE simulation with a smooth clamp.

CONCLUSIONS

A finite element model for the clamping of a rat abdominal artery was built and experimentally validated. Future work will include the effect of damage to the mechanical properties.

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REFERENCES