Artificial Veins

Suitable tubes had to be identified that could adequately model the collapsing behavior of human veins.

Method

In many existing blood circulation models, artificial veins are made from latex. Therefore, latex tubes were manufactured in different dimensions (see Table 1) by dipping a cylindrical mold in latex milk and drying while rotating.

The bending modulus c can be used to quantify and compare the ability to collapse of tubular structures when mimicking human veins by artificial vein-modeling tubes:

\[ c = \frac{1}{E} \frac{E_A}{h^3} \]

where:

- \( E \) = transversal elastic modulus
- \( h \) = wall thickness

Bending modulus reference values at several transmural pressures were obtained for published elastic modulus and wall thickness measurements of the jugular vein [1]. For the self-made latex tubes and further comparative tubes, the Shore A hardness was measured and the compression elastic modulus derived as proposed by [2].

\[ E = \frac{h^2 \cdot (C_1 + C_2 \cdot Sh_A)}{2 \cdot R \cdot C_3} \left( 2.6 - 0.02 \cdot Sh_A \right) \]

The wall thickness of the tubes was determined from microscopy images.

Results

The results of the bending modulus of the tubes are listed in Table 1. In addition, the bending modulus of a typical arm vein was estimated by extrapolation from its wall thickness and the jugular vein elastic modulus, marked by X in Figure 1.

Discussion

The bending moduli of the artificial tubes are at least 10^3 larger than in the jugular vein at comparably low transmural pressure. However, the estimated bending modulus of an arm vein is higher (1 - 10^3 N/m) and thereby close to the bending modulus of the Penrose drain and the 0.1 mm wall thickness synthetic tube (senior vein, 3 - 10^3 N/m). Based on the mechanical data on human veins that were at hand, these two artificial veins are therefore likely to adequately model arm veins in terms of collapsibility.

Evaluation

Six medical professionals performed venipunctures on the system. The diversity of vein geometries as well as the feeling of the latex tubes during puncture was appreciated.

During 18 punctures, the child vein had collapsed most frequently (9 x) compared to the senior (4 x) and adult vein (1 x). This indicates that the model is suitable to mimic the increased susceptibility to venous collapse that can be observed in children and elderly.

Some participants were able to continue blood draw even during venous collapse which does not yet reflect the challenges in human venipuncture adequately.

Outlook

- Incorporating venous valves and anastomoses (several open vessels in parallel) that are both found in human arm veins might improve the collapsing behavior during venipuncture further.
- The artificial tissue is refined for a wider range of testing to be conducted on the system.
- Retrieving precise values for geometry and elastic modulus of common puncture veins might be the key to further adjusting the mechanical properties of the self-made artificial veins.

Table 1: Dimensions of artificial veins used in the circulatory system

<table>
<thead>
<tr>
<th>Dimensions manufactured</th>
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<tbody>
<tr>
<td>Adult vein</td>
</tr>
<tr>
<td>d = 5.0 mm</td>
</tr>
<tr>
<td>h = 0.3 mm</td>
</tr>
<tr>
<td>Senior vein</td>
</tr>
<tr>
<td>d = 5.0 mm</td>
</tr>
<tr>
<td>h = 0.1 mm</td>
</tr>
<tr>
<td>Child vein</td>
</tr>
<tr>
<td>d = 3.0 mm</td>
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<tr>
<td>h = 0.2 mm</td>
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</tbody>
</table>

Figure 2: Venous circulatory system with puncture site (1), pump (2), sensors (3), interface (4) and fluid container (5)

Figure 1: Bending moduli of artificial tubes at zero transmural pressure and jugular vein at different transmural pressure levels

Literature