EXPERIMENTAL MEASUREMENT OF ARTERIAL MECHANICAL PROPERTIES

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Abstract. Any simulation requires adequate and correct information about mechanical properties of a given structure. To ensure the optimal way of arterial surgery requires the knowledge of arterial mechanical properties. Therefore this contribution is dealing with the methodology of measuring mechanical properties of arteries namely Young’s modulus and Poisson’s ratio assuming an isotropic behaviour. These parameters have been found experimentally by means of specially developed device. To verify our methodology the specimens have been taken from pork arterial system and subsequently fixed in a measuring device firstly. The supports of both ends allowed us to apply theory of thin walled-pressure vessels for determining mechanical parameters. Then the longitudinal and transversal deformations were measured due to the increase of inner pressure of physiological dilution where both specimen and measuring device have been placed. Finally to get both mechanical parameters we have applied the above mentioned theory of thin-walled pressure vessels. Thus obtained experimental data we have used for the simulation of blood flow in the artery using ANSYS WORKBENCH Version 11. The results obtained seem to be realistic.

Keywords: Experimental measuring, Mechanical properties, Artery, Simulation

1. INTRODUCTION

An understanding of blood vessels mechanical properties is important in the selection of vascular stents or design of artificial vessels. The mechanical properties also contribute to understand the normal and pathological physiology of blood vessels, to help the development of new surgical techniques.

The biomechanical experimental methods can be divided into two groups: in vivo and in vitro. Both are important to ensure the progress in our knowledge. In vivo experiments we can apply non-invasive approaches only to save the patient life or not to damage biological tissue. In vitro we must ensure the same properties as during the tissue life. But on the other hand we can apply destructive approaches.

The review of both methods can be found for example (Zhang et al 2002) and others. All mentioned method are contact ones or they can measure the strains in one axis only. Non-contact approaches such as optical methods are one of possible ways to over come these problems. But we need to take into account the natural properties of blood vessels. The blood vessels are hydrated, smooth and without any natural markers. For applying non-contact method we need to build a system of markers those are distinguishable and to be placed very easily.

In the current study the simple optical imaging in combination with longitudinal markers has been adopted to determine strains in a pork aorta subjected to internal pressure. The size of pork aorta is comparable with a human one. Using inverse approach in the sense of theory for thin-walled pressured members we determined mechanical properties of artery namely Young’s modulus and Poisson’s ratio assuming an isotropic behaviour. Then we have applied experimental data in a numerical simulation using ANSYS Work bench Version 11. We have modelled the response of a straight artery due to the pressure impulse of blood.

2. THEORETICAL BACKGROUND

Our approach for determining mechanical quantities is based on theory of thin-walled pressured vessels. Therefore we adopt the following assumptions that the stress over the wall thickness is constant. We neglect the effect of wall bending. The principle of a constant wall stress is one of in the development and the adaptation in arteries. Therefore we need to reflect and to accept it.

Applying this theory to thin-walled cylinder we can get two principal stresses: longitudinal $\sigma_L$ and circumferential $\sigma_C$ in the well-known following form

$$\sigma_C = \frac{P \cdot R}{t} \quad \text{and} \quad \sigma_L = \frac{P \cdot R}{2t}$$

where $P$ is the internal pressure, $t$ is the wall thickness and $R$ is the inner radius of artery. The magnitude of wall stress in the artery depends on the ratio of $R/t$ see Eq. (1). The arteries maintain this ratio to be constant or nearly constant between 8-10, see Table 1. These experimental data have been obtained for a normal body pressure.
Table 1. R/t ratio for the arteries

<table>
<thead>
<tr>
<th>Artery</th>
<th>(Bergel 1961)</th>
<th>(Gow a Taylor 1968)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoracic aorta</td>
<td>9.52</td>
<td>7.14</td>
</tr>
<tr>
<td>Abdominal aorta</td>
<td>9.52</td>
<td>8.33</td>
</tr>
<tr>
<td>Femoral artery</td>
<td>8.93</td>
<td>7.69</td>
</tr>
<tr>
<td>Carotid artery</td>
<td>7.58</td>
<td>--</td>
</tr>
<tr>
<td>Comments</td>
<td>at 100 mmHg of blood pressure</td>
<td>mean pressure 105 – 124 mmHg of blood pressure</td>
</tr>
</tbody>
</table>

Then we can apply theory of elasticity for plane problems for determining longitudinal $\varepsilon_L$ and circumferential $\varepsilon_C$ strains as follows

$$\varepsilon_L = \frac{\sigma_L}{E} - \frac{\nu \sigma_C}{E} \quad \text{and} \quad \varepsilon_C = \frac{\sigma_C}{E} - \frac{\nu \sigma_L}{E}$$

(2)

where $E$ is the Young modulus and $\nu$ is the Poisson ratio. If the strains are obtained experimentally then subsequently both Young modulus and Poisson ratio will be determined.

3. EXPERIMENTS AND SIMULATIONS

3.1. Experimental measurements

The measurement assembly has been designed, see Fig. 1. The sample of blood vessel is fixed in the measuring device. The sample is subjected to the internal pressure of physiological dilution. The pressure increase is ensured by the compression of injection pump. This pressure increase is measured by the manometer. The sample has two visible and distinguishable marks in a longitudinal direction.

![Figure 1. Measurement assembly](image1)

The changes of longitudinal distance between two marks and the changes of outer diameter are measured by digital camera at the same time, see Fig.1 and Fig.2.

![Figure 2. Measurement of outer diameter](image2)
Then we can calculate both strains as follows

$$
\varepsilon_k = \frac{L - L_0}{L_0}
$$

and

$$
\varepsilon_c = \frac{D - D_0}{D_0}
$$

(3)

Then we can substitute Eq. (3) into Eq. (2) and thus we can get the Young modulus and the Poisson ratio. The sample tested have the outer diameter of 14.6 mm and the distance between marks of 46.3 mm. After loading of 0.14185 MPa we observed the outer diameter of 16.8 mm and the marks distance of 47.5 mm. After applying the above mentioned approach we got the Young modulus $E = 4.23$ MPa and the Poisson ratio $\nu = 0.38$.

3.2. Numerical simulations

Experimentally obtained mechanical properties have been used in numerical simulation using ANSYS Workbench. This code allows us to model the solid-fluid interaction (FSI). The FSI contains two-way simulation, i.e. it is possible to model impulse loading of blood contained in artery. For our simulation we built the model of straight artery with the length of 150 mm and the outer diameter of 20 mm, see Fig. 3.

The additional mechanical parameters have used in simulation:

- density of arterial wall 1200 kg/m$^3$
- blood density 1035 kg/m$^3$
- dynamic blood viscosity 10 e-3 Pa.s

This artery has been subjected to the blood impulse, see Fig. 4. This moving impulse represents the blood pressure change from 80 mmHg to 160 mmHg recalculated in Pascals. The duration of impulse is 0.01 s. The total time of our simulation or observation of impulse moving is 0.5 s. The peak value of this impulse is less than 5.5 kPa, see Fig. 4.
The results are clear from graphical representation on Fig. 5 and Fig. 6. The FSI simulation contains both parts: fluid and solid. Therefore presented figures contain results for both parts at the same time. Figure 5 represents results of blood pressure distribution and deformation of arterial wall. Figure 6 represents results of blood pressure distribution and von Mises stresses in the arterial wall.

Figure 5. The deformation of artery and the pressure distribution in blood

Figure 6. Von Misses stresses and the pressure distribution in blood
4. CONCLUSIONS

In this work we proposed the simple experimental determination of mechanical arterial properties. We have found out the Young modulus $E = 4.23$ MPa and the Poisson ratio $\nu = 0.38$ for a given pork arterial specimen. Then we have tested the straight artery with obtained mechanical parameter using two-way simulation of FSI. The artery was subjected the blood impulse from 80 mmHg to 160 mmHg. The response of artery on the blood pressure impulse is realistic. The peak value of blood impulse caused the maximum von Mises equivalent stress of 0.052 MPa. The presented approach allows us to simulate and to analyze more precisely the process of stent implementation and the interaction between stent and the arterial wall, see (Walke et al 2005) and (Hučko et al 2007).

5. ACKNOWLEDGEMENTS

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6. REFERENCES


7. RESPONSIBILITY NOTICE

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