CHANGE IN SEVERAL MECHANICAL PROPERTIES
OF HUMAN BLOOD VESSELS WITH AGING

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A method is suggested for the determination of the initial length of a sample of a blood vessel wall at a longitudinal loading. It was found that at loading levels of up to 0.01 kg/mm², the deformation properties of the wall of a large subcutaneous vein and femoral artery differ inappreciably, but on further loading substantial differences were observed between the deformation and strength properties of the walls of vessels.

In recent years, the interest in research on the mechanical properties of blood vessels has increased considerably, and the nature of their changes during the loading process has been established. This is because the elastic and deformation properties of the blood vessels play an important role in the blood circulation processes [1-8]. Moreover, the study of these properties can be most beneficial for the improvement of diagnostic methods, especially with reference to the cardiovascular system diseases [9, 10] so that it is possible to select the best reconstructive operations of the blood vessels [11, 12]. A knowledge of the structure and properties of the biopolymeric material with the optimum internal structure produced by nature makes it possible to prepare reliable substitutes for the blood vessels [13].

In studies on the behavior of the vessels, there are differences both with regard to the experimental results and in their interpretation. These are mostly due to the technical difficulties in carrying out the experiment, the complexity of the material itself, and the absence of a single theory to describe the viscoelastic behavior of blood vessels during loading. Certain fundamental problems on the determination of the characteristics of the mechanical properties of the vessels also remain unsolved. One of these is related to finding the initial no-load length of the sample. Up to now this was determined as the distance between the fixing points before the beginning of tensioning [4, 14], or from the force-displacement diagram, taken by a testing machine [1, 15]. However, the first approach is not above criticism, since between the fixing points before loading, the sample can be present in a bent form, or even in a tensioned state. The second approach is more accurate, but it allows for an error in the measurements, especially at the beginning of loading. If the initial length is taken as the distance between the fixing points at the moment of load application, the subsequent elongation will prove to be larger by a value equal to the length of the part of the samples slipping out of the fixing point. In [4] it was found that the elongation of samples originating from soft tissues, even at the very beginning of the loading, i.e., at very small loads, exceeds the initial length by 108%, determined on freely suspended samples before the beginning of loading.

In the present work a reliable procedure is proposed for determining the initial length of a strip of the wall of human
blood vessels. A correlation has been established between the stresses and deformations at monoaxial loading of the wall strip along its longitudinal axis, and an analysis has been made of the changes in several deformation and strength properties of the large subcutaneous vein and femoral artery walls during aging.

2. The experimental material (a large subcutaneous vein and femoral artery) was taken during an autopsy, not later than 12 hours after the death of 20 people of both sexes, 25 to 59 years old. The causes of death were injuries. The investigations were carried out not later than 2 hours after the autopsy. Before the beginning of the investigation the vessels were stored in a physiological solution, which did not affect their mechanical properties [16]. The complete experiment was carried out at a room temperature of 21 ± 1°C, on moist samples. Cuts of the large subcutaneous vein and femoral artery were thoroughly cleaned from surrounding tissues, and longitudinal strips of the wall, 10 × 55 mm, were cut by a special die. At the same time, the material was subjected to micromorphological investigations. The thickness of the wall shred (δ0) was determined in five places by means of a clockwork tensometer, joined to a micrometric screw. The sample, moistened in the physiological current-conducting solution, was used as a fixed contact, while the micrometric screw was used as a mobile contact, which closed the circuit of a low frequency feeding oscillator. The moment of contact of the screw with the sample was determined by a sound signal. The measurement was accurate to within ± 0.001 mm. Strips of the large subcutaneous vein wall and the femoral artery wall were tensioned in a testing machine WRM-ZM4 at a constant rate of 8 mm/min up to complete rupture, with an automatic registration of the load-elongation dependence. The force and the elongation were measured with an accuracy within ± 1%. The strips of the wall of the vessels were fastened with specially prepared clamps, which prevented slipping out, and with a self-centering system. Before loading, the distance between the clamps of the testing machine (L0) was measured; the initial width (b0) and the changes in the width of the shred during the deformation were measured by means of a commercial television apparatus PTU-27 by using a video-controlling device, accurate to within ± 0.05 mm. After the working conditions have been established (time of heating, 30 min), the amplifier was calibrated. During the change in the input voltage of the circuit of 220 volts \{ +10\textsuperscript{\%} \ -25\textsuperscript{\%} \}, the stabilizer present on the instrument retained the size of scanning. By means of a focusing system of the transmitting television tube, the image was rotated from a vertical to a horizontal position. The image on the screen was magnified 10 times in the vertical direction. To determine the actual initial length (L0\textsuperscript{f}) and the measurements of deformation at the beginning of loading the sample, an electrotensometric device for measuring the deformation was used, with a measurement base of L0 = 10 mm. A 50\% deformation of the measuring device is caused by a load of 2 g. This load is much smaller than that required to attain a similar deformation of the wall strip of the vessel. At loads of up to 50 g, the tensioning force was determined by an electrotensometric dynamometer. The electrotensometric measurements of the deformation and the force were recorded on a loop oscillograph, and from the recordings obtained the deformation was determined at a load of 50 g:

\[
\frac{\Delta L_{50}}{L_0} = \frac{\Delta L_{50} - \Delta L_{50}'}{L_0}
\]

where \( L_0 \) is the measurement base in the middle part of the wall shred; \( \Delta L_{50} \) is the elongation of the measurement base at a load \( P = 50 \text{ g} \). A similar elongation should occur also for the actual initial length:

\[
\frac{\Delta L_{50}}{L_0} = \frac{\Delta L_{50} - \Delta L_{50}'}{L_0}
\]

where \( L_0^f \) is the actual initial length of the sample; \( \Delta L_{50}^f \) is the actual elongation of the sample at a load of 50 g. The actual initial length is

\[
L_0^f = L_0 + \Delta L_{50} - \Delta L_{50}^f.
\]