Mechanical properties of tissues-vascular system

Heart

The heart is the source of mechanical energy for the vascular system. It is a hollow muscular organ that has 4 compartments: 2 ventricles and 2 atria. The ventricles ensure their own expulsion of blood from the heart, the atria are only reservoirs from which it is filled. One-way blood flow is ensured by heart valves.

Work of the heart

With **each contraction**, the heart does mechanical work by expelling a certain amount of blood into the circulation **(stroke volume**). The total work of the heart consists of mechanical and kinetic work:

$$W = W_p + W_k$$

For simplification, the volumetric work of the heart can be replaced by the work of the piston, which pushes out the blood volume V with a certain pressure p, the total mechanical work will be expressed by the formula :

$$W_p = p \cdot V$$

The kinetic energy of the systolic cardiac output is equal to:

$$E_k = \frac{1}{2} \cdot \rho \cdot v^2 \cdot V$$

To calculate the total heart work in every systole, the following quantities must be known: **mean blood pressure** (p = 13.3 kPa), **blood density** (ρ = 1.06·103 kg·m-3), **speed** of blood ejection from the heart (in = 0.3 m·s-1) and pulsatile **cardiac output (V = 70 ml). The *work of the left ventricle* will therefore be equal to:**

$$W = 0,93J$$

During **one systole**, the *right ventricle* performs 20% of the work of the left ventricle, i.e.: 0.19J. **In total, the heart does 1.12J of work during one systole.**

The **mechanical power** of the heart is 13W, which is approximately 13% of the total power of the organism at rest. Most of this performance has the task of maintaining a constant tension of the heart muscle. Only 1/10 is used for the mechanical work itself.

Mechanical properties of Blood

Blood is a very complex system. It is a solution of organic and inorganic substances, then also a colloidal dispersion system and finally a suspension of blood cells. This composition causes a **number of interactions** between the individual blood components. In addition to mechanical forces, these interactions include, for example, electrical double layers.

Viscosity generally depends on temperature, and blood is no different. The relative viscosity of blood to that of water is 4.5. The absolute viscosity of blood at a temperature of 37°C ranges between 3-3.6·10-3 Pa·s.

Mechanical properties of Blood Vessels

Blood vessels are specific in their ability to passively or actively **change their volume**(i.e. increase the lumen size= vasodilation, or decrease the lumen size= vasoconstriction). **Arteries primarily have this ability**, therefore their walls must contain collagen, elastin and smooth muscle. Collagen and elastin fibers ensure the elastic tension of the blood vessels and thereby balance the pulsation of the blood. These vessels are called elastic vessels.

Muscular vessels, on the other hand, have a high proportion of smooth muscle fibers in their walls. They are not very flexible, but they can actively change their cross-section and thereby regulate blood flow (vasodilation, vasoconstriction).

[There are 2 kinds of arteries based on their wall composition (histology)- Elastic arteries and Muscular arteries. The big arteries in the body like aorta, pulmonary artery, common carotids, subclavian artery, common iliacs for example are elastic arteries and can accomodate higher pressure of blood. Muscular arteries are the smaller branches and the blood pressure in them is reduced plus they cant take so much pressure as the elastic arteries.]

Electrical resistance can be used analogously to explain the resistance that a river bed offers to blood flow. The mechanical resistance R (like resistance to flow of current) of a certain section of the vessel is calculated from the ratio of the pressure difference Δp (like voltage) and the flow rate Q.(like current)

$$R = \frac{\Delta p}{Q}$$

By substituting the Hagen-Poiseuille law, we get the formula:

$$R = \frac{8\eta \Delta l}{\pi r^4}$$

Blood flow

Physical laws of flow

Bernoulli's law applies to blood flow:

$$\frac{1}{2}\rho v^2 + h\rho g + P = Constant$$

The application of this law is only approximate - **it only approximates the real state**. Bernoulli's law presupposes the use of an ideal liquid and also the fact that the molecules of the liquid move at the same speed throughout the cross-section of the tube. However, in the blood vessels, the speed of blood flow is different, it is lower near the wall of the vessel than in its center. However, even this model is not accurate, since such a parabolic velocity profile is only in small arteries. As the cross-section of the artery increases, the velocity profile flattens to the extent that in the thoracic aorta, blood flows at almost the same speed throughout the cross-section.

The amount of liquid flowing through a tube of a certain volume per unit time - the flow volume - is represented by the Hagen-Poiseuille law:

$$Q = \frac{\Delta P \pi r^4}{8L\eta}$$

The **fourth power of the radius of the tube** in this law explains **why the narrowing of the cross-section of the vessels is so dangerous** in some diseases (atherosclerosis). Even a minimal narrowing of a vessel will cause a significant reduction in blood flow through this vessel.

Based on the properties of the *vessel*, the flow rate and physical properties of *blood*, the blood in this vessel can flow either laminarly or turbulently. **Laminar flow** is characterized by the fact that individual layers of liquid move parallel to the longitudinal axis of the vessel. In laminar flow, the flow volume increases linearly until it reaches a critical value, eddies begin to appear, and thus the flow becomes turbulent. **This critical value** (Reynolds number) depends on the radius of the tube, the velocity and the physical properties of the flowing liquid. A value of 1000 is generally given as critical.

$$Re = \frac{v \cdot \rho \cdot r}{\eta}$$

Blood flow in Caplillaries

Capillaries represent the most important part of the vascular system, because **it is here that the exchange of respiratory gases between the blood and the interstitial space takes place**. Gas exchange through the capillary wall takes place on the basis of different pressures at the arterial and venous end of the capillary. At the arterial end the pressure is 4.6 kPa, at the venous end the pressure is 2.2 kPa.

Water and substances dissolved in it pass through the capillary wall based on diffusion mechanisms: filtration and resorption.

Osmotic pressure of blood proteins (=Oncotic pressure) works against hydrostatic pressure and affects filtration in the venous part of the capillary.

Starling law of caplillaries- for understanding the exchnage of material through capillaries (will be taught in Physiology.)

Links

Související články

- Mechanical properties of tissues - introduction
- Mechanical properties of tissues - Support and movement system
- Mechanical properties of tissues - Digestive system
- Mechanical properties of tissues - Excretory system
- Mechanical properties of tissues - Human voice and human voice production

References

- HRAZDIRA, Ivo – MORNSTEIN, Vojtěch. *Lékařská biofyzika a přístrojová technika.* 1. edition. Brno : Neptun, 2001. 396 pp. ISBN 80-902896-1-4.