Atheroma regression with intermittent pneumatic compression

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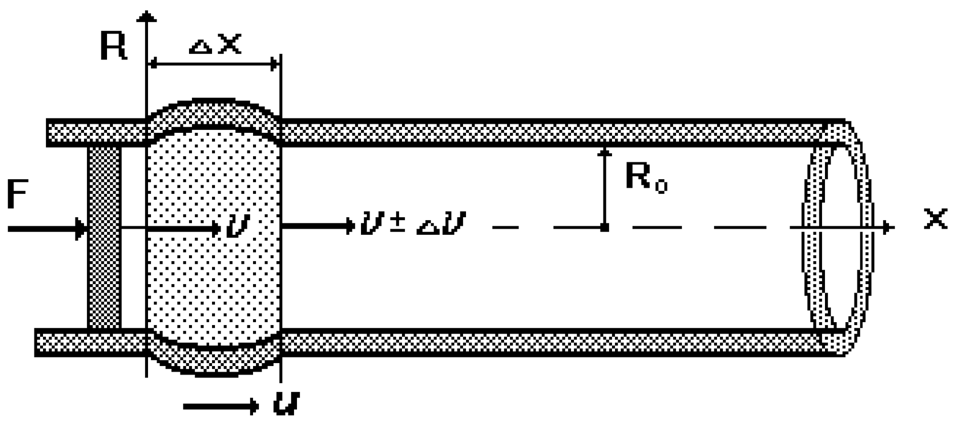

Fig. 1. Model of area of elastic vessel ([6]).

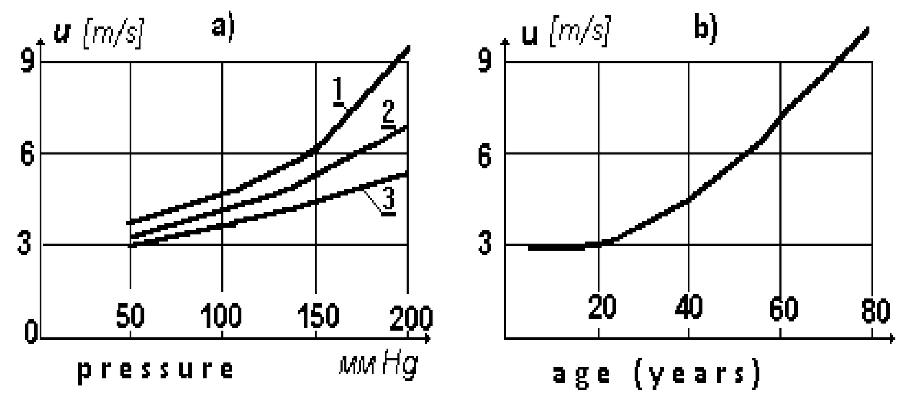

Fig. 2. a) change of blood velocity with increasing pressure (1, 2, 3 - accordingly for senior, middle and young age), b) change of blood velocity with age.

Introduction

Intermittent pneumatic compression (*IPC*) is used in patients with peripheral arterial disease, claudication[1], sometimes as an alternative to reconstructive intervention in critical ischemia[2]. It is known for its ability to increase arterial blood flow and oxygen blood rate, terminate ischemia, and support collateral vessel growth. In one study, *IPC* was shown to have a positive effect on plasma lipids[3]. Based on data of renewal of cholesterol molecules in atheromas[4], we have predicted that, while maintaining a compensated ratio of lipids in plasma, local acceleration of hemodynamic processes can promote the resorption of cholesterol deposits within 1.5 – 3 years[5].

Case Presentation

A 54-year-old woman was admitted with complaints of hearing loss and frequent episodes of dizziness. There were no factors aggravating the course of arteriosclerosis (overweight, high blood pressure, smoking, diabetes). The patient followed a diet, took preparations of omega-3 acids and had a regularly aerobic physical activity as the choreography teacher. An ultrasound examination of the brachiocephalic vessels was performed, which revealed atherosclerotic deposits in the arteria carotis bifurcation, which occupied 10% on the right, and 30% of the arterial lumen on the left.

So *IPC* procedures were prescribed. Each procedure lasted 72 – 78 minutes and included alternating compression along and across the back, across the abdomen, and on the arms, legs, and head. Each stage took 6 – 12 minutes. A cuff with 10 chambers was used. Each chamber was inflated for 1 s, the maximum pressure reached 50 mm Hg. The direction of air compression wave was variable, with two alternate cycles, from the 10th chamber to the 1st and vice versa. The procedures were carried out once a week for two years.

No additional treatment were prescribed. Simultaneously with long-term compression therapy, the patient maintained the regimen as described at the beginning. Two years later, an ultrasound scan of the brachiocephalic arteries was performed again (the same apparatus and the same doctor). A decrease in the size of atherosclerotic deposits on the right up to 5%, on the left up to 25% of the lumen was found.

Discussion

Consider a simplified model of pulse waves in an elastic vessel. It is clear that their origin is related to the activity of the heart. If the blood flow at the outlet of the heart was constant, there would be no pulsations. On the other hand, if the walls of the vessels were very rigid, then even with pulsating blood flow, the movement of the walls would be almost imperceptible. Thus, the origin of pulse waves is related to the reaction of the elastic walls of the vessel to the pulsating flow of blood, which occurs during the periodic work of the heart.

Select a small area of elastic vessel (**Fig. 1**), at one end of which is the piston. The force *F* acts on the piston for a short time due to its inertia. As the wall tension in this area will be greater than in the neighboring ones, the fluid will move further along the vessel. Motion of the fluid will reduce the pressure in this area, the vessel will begin to restore its original volume while the volume of the adjacent area will increase. The process is repeated after a new push of the piston. A pulse wave will propagate along the elastic wall.

To write the equation of the pulse wave, consider the motion of an ideal fluid through an elastic tube under the action of pressure forces alone. Select a section of length Δx and volume *V*. Denote the change in the radius of the section of the tube when expanding through ε, then the current value of the radius will be equal to

$$R(x,t) = R_0 + \varepsilon(x,t). \quad (1)$$

The equation of the pulse wave, which characterizes the process of propagation of the change in the radius of the vessel ε along its axis, has the following form:

$$\frac{\partial^2 \varepsilon}{\partial t^2} = u^2 \frac{\partial^2 \varepsilon}{\partial x^2} \quad (2)$$

Where $u = \sqrt{\frac{\chi}{\rho}}$ is the speed of propagation of the pulse wave.

In the absence of longitudinal tension (so that the tube will shrink during expansion), the modulus of volume elasticity χ for a thin cylindrical vessel with radius *R* and wall thickness *h* is determined by formula (3) without a factor of $1 - \mu^2$. After substitution we have the Moyens-Korteweg formula for speed:

$$u = \sqrt{\frac{hE}{2\rho R}} \quad (3)$$

Thus, the speed of propagation of a pulse wave depends both on geometrical parameters of a vessel (radius and thickness), and on elastic properties of a vascular wall.

The Poisson's ratio for the vessel is a constant value and is approximately 0.5. The Young's modulus, as shown above, does not remain a constant value for the vessel, so the speed of propagation of pulse waves considerably varies. Some examples of changes in the velocities of pulse waves are shown in **Fig. 2**. The speed of the pulse wave varies significantly in various vascular diseases, in this regard, its clinical definition allows to obtain additional information to assess the functional state of the vessel walls.

The blood motion through the cardiovascular system is quite a complex phenomenon. The bloodstream has a complex structure, which is a branched system of elastic vessels of various types. The liquid itself – blood – Is a complex suspension, the rheological characteristics of which depend on the conditions of its flow. The circulatory system has active sources of energy (ventricles and atria of the heart). Various active physiological processes (mechanisms of reflex change of vascular tone and heart productivity) change the physiological properties of the circulatory system, and hence the conditions of blood movement. Any description of hemodynamic processes (from simple cases of blood flow mechanics to complex processes of reflex blood circulation control) is based on experimental data accumulated over many years of research. **Table 1** shows some indicators of the circulatory system at rest and during exercise.

Table 1. Indicators of the human circulatory system in normal and underload case ([7])

Circulatory system parameters	Value
The average linear velocity	
- in aorta	0.3–0.4 m/s
- in capillaries	0.002–0.01 m/s
- in veins	0.2–0.4 m/s
Average blood pressure	
- calm	90–100 mm Hg
- maximum load	> 200 mm Hg.
The average pressure in the capillaries	25-30 mm Hg
Minute blood volume	
- calm	5-6 l/min.
- maximum load	> 20 l/min.
Pulse wave velocity (artery)	4–6 m/s
Reynolds number	
- in aorta	3000 – 4000
- in veins	500 – 700
- in capillaries	0.001
Section area	
- aorta	≈ 3 cm^2
- capillaries	≈ 1200 cm^2

Conclusion

Analytical researches show, that value — changes insignificant at different d people and practically does not depend on type of an artery. Therefore, it is possible to count that speed of pulse wave changes only from elasticity of walls of vessel and its module of elasticity. With age and also at the diseases accompanying with increase of E (hypertension, atherosclerosis) speed 9 can be increased almost in 2-4 times in comparison with norm.

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