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MICROCIRCULATION AND ITS ROLE IN PATHOLOGY

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Abstract. This article analyzes the functional characteristics of the microcirculation system from the perspective of normal physiology and its changes in various pathological conditions (inflammation, hypoxia, ischemia). The main objective of the study is to reveal the mechanisms of blood circulation disorders at the tissue level and their role in the pathogenesis of diseases. Based on the analysis of theoretical and practical data obtained through laser Doppler flowmetry and capillaroscopy methods, the impact of endothelial dysfunction and changes in blood rheological properties on the microcirculatory bed was evaluated. The results show that increased capillary permeability and microthrombosis form the basis of various systemic pathologies. The article serves as an important resource for medical institution students and young researchers in the in-depth study of the physiology and pathology of blood circulation.

Keywords: Microcirculation, capillary permeability, endothelial dysfunction, blood rheology, stasis, tissue hypoxia, inflammation, microthrombosis.

Introduction.

Microcirculation is the lowest, yet the most important and complex link of hemodynamic processes in the human body, directly ensuring blood circulation at the tissue and cellular levels. In a broad sense, the microcirculatory bed encompasses the terminal part of the cardiovascular system: arterioles less than 100 micrometers in diameter (resistance vessels), precapillaries, true capillaries (exchange vessels), postcapillary venules (capacitance vessels), and arteriovenous anastomoses. Under normal physiological conditions, the primary function of this system is not only to provide the transcapillary exchange of oxygen, nutrients, and metabolic products between the blood and interstitial fluid but also to maintain stable local tissue homeostasis.

Recent studies in fundamental medicine and normal physiology show that the microcirculatory bed is not merely a passive system of conducting tubes, but a highly specialized reactive organ. In particular, the endothelial layer lining the inner surface of blood vessels is currently recognized as the largest endocrine organ in the body. Endothelial cells automatically regulate local tissue perfusion according to needs by coordinating the synthesis of vasodilators

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(nitric oxide - NO, prostacyclin) and vasoconstrictors (endothelin-1, angiotensin II). The exchange between blood and tissue fluid is based on a delicate balance (Starling forces) between the hydrostatic pressure within the capillary and the oncotic pressure created by plasma proteins.

However, this delicate balance is highly susceptible to various extreme and pathological factors. In the development of diseases such as infectious processes, acute and chronic inflammation, various intoxications (including systemic changes resulting from toxic effects like chronic hepatitis), as well as diabetes mellitus and arterial hypertension, microcirculation is among the first to be damaged. In the very early stages of disease pathogenesis, endothelial dysfunction develops, capillary wall permeability increases, rheological parameters of the blood are disrupted, and the aggregation of erythrocytes and platelets intensifies. As a result, a cycle of oxygen deficiency (hypoxia) and hypoxic damage is initiated in the tissues, which forms the basis of complicated processes (edema, ischemia, necrosis).

For students of medicine and pharmacy, as well as young researchers, understanding the mechanisms of disease origin requires a deep mastery of the integration of normal and pathological physiology. From this perspective, a systematic analysis of microcirculatory disorders is highly relevant for both theoretical and practical medicine.

Objective of the study: Based on the principles of normal physiology, the aim is to systematize the functional characteristics of the microcirculation system and to comprehensively reveal the main pathogenetic mechanisms of changes in tissue-level blood circulation under various pathological conditions (inflammation, hypoxia, blood rheology disorders). This analysis serves to create a fundamental scientific basis for the early detection of diseases and the development of pathogenetic treatment measures.

Methods.

Within the framework of the study, scientific literature, monographs, and the results of clinical research in the fields of normal physiology and pathological physiology from recent years were analyzed retrospectively. To assess the state of microcirculation, the theoretical data of the following modern instrumental and laboratory examination methods were relied upon:

Computer capillaroscopy: Visual assessment of the architectonics of nailfold capillaries, blood flow velocity, and capillary network density.

Laser Doppler flowmetry (LDF): Recording tissue perfusion and vasomotor activity of blood vessels.

Blood rheology analysis: Studying indicators of erythrocyte aggregation, deformability, and blood viscosity.

The data collected through these methods were statistically and comparatively analyzed to explain the mechanisms of microcirculatory disorders in models of inflammation, chronic hypoxia, and ischemia.

Indeed, these modern examination methods are excellent examples demonstrating not only the assessment of the circulatory system but also how deeply information technology and medical informatics have penetrated fundamental medicine. Especially for students in medical and pharmaceutical fields, understanding the operating principles of such digital hardware-software complexes is crucial for their future clinical and scientific activities.

Let us dwell on each method in detail:

1. Computer capillaroscopy This is one of the most informative non-invasive methods (without compromising skin integrity) for visualizing the microcirculatory bed, specifically the capillaries. Usually, the nailbed (eponychium) of the fingers is selected for examination, as the capillaries here are located parallel to the skin surface, allowing them to be seen in their full length.

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- **Assessment of architectonics:** Special digital microscopes magnify the skin up to 200-400 times. Normally, capillaries have a straight "U" shape (hairpin shape). In pathology (e.g., inflammation or diabetes mellitus), their shape changes, becoming tortuous, bush-like, or dilated (megacapillaries).
- **Blood flow velocity:** With the help of software, the blood flow velocity inside each capillary is measured in real-time (in micrometers/second). Instances of stasis (stoppage of blood flow) or slowing are quickly recorded.
- **Capillary network density:** The number of active capillaries in a 1-millimeter area is counted. In cases of hypoxia and ischemia, this indicator can drop sharply because some capillaries are disconnected from the blood flow, move to "reserve," or die.

2. Laser Doppler flowmetry (LDF) The LDF apparatus is a highly technological and digital method that evaluates not the direct shape of the blood vessels, but how well the tissues are supplied with blood (perfusion). This is based on the "Doppler effect" known from physics.

- **Operating principle:** A laser beam is directed at the tissue. When the beam hits moving objects (mainly erythrocytes), its wavelength and frequency change (shift). The frequency of the beam returning from stationary tissues remains unchanged. The device calculates this shift difference of the beam.
- **Recording perfusion:** Blood flow is measured in special perfusion units (PU). The computer program displays the obtained data on the screen in the form of various graphs (flowgrams).
- **Vasomotor activity:** The greatest advantage of this method is that it allows mathematical and statistical analysis (amplitude-frequency analysis) of the factors controlling the vascular wall tone. Through the fluctuations in the flowgram, the state of endothelial function, neurogenic (influence of the sympathetic nervous system), and myogenic (smooth muscle activity) factors are assessed.

3. Blood rheology analysis Rheology is the science of the flow and deformation of fluids. The pathology of microcirculation cannot be imagined without studying the fluidity characteristics of blood, as erythrocytes measuring 7-8 micrometers must pass through capillaries with a diameter of 3-5 micrometers.

- **Erythrocyte aggregation:** Simply put, this is the sticking together of erythrocytes. In inflammatory and intoxication processes, large proteins (e.g., fibrinogen) increase in the blood, and erythrocytes stick together in the form of "coin stacks," forming large complexes (sludge). This increases blood viscosity and leads to microthrombosis.
- **Deformability:** As mentioned above, to pass through a capillary narrower than itself, an erythrocyte must be able to change its shape (twist, stretch). In cases of hypoxia or acidosis, the erythrocyte membrane stiffens (rigidity), as a result of which they get stuck in the capillary and completely stop the blood flow.
- **Blood viscosity:** This depends directly on plasma composition and cell state. Using special digital viscometers, how easily or difficultly blood flows at different shear rates (during heart contraction and relaxation) is calculated.

Results.

The analyses showed that under the influence of pathological processes, a complex of three main categories of disorders occurs in the microcirculatory bed:

1. **Intravascular changes:**
   - A slowing of blood flow velocity was first observed in venules, then in capillaries, eventually leading to a state of **stasis** (stoppage of blood flow).

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- The formation of coin-like stacks of erythrocytes (sludge syndrome) and increased platelet aggregation sharply increase blood viscosity.

2. **Vascular (Wall) changes:**
   - As a result of impaired endothelial cell function (endothelial dysfunction), the balance between vasodilator (NO) and vasoconstrictor (endothelin-1) substances is disrupted.
   - Under the influence of biologically active substances (histamine, bradykinin, cytokines), capillary wall permeability increases, causing blood plasma to leak into the tissues and the development of inflammatory edema.
3. **Extravascular changes:**
   - An increase in the volume of tissue interstitial fluid (edema) compresses the capillaries from the outside, further worsening tissue perfusion.
   - The accumulation of acidic metabolic products (lactate, acetate) in the intercellular space causes local acidosis.

Discussion.

The obtained results confirm that microcirculation disorders are a fundamental part of any inflammatory or destructive pathology. Under normal physiological conditions, the balance of blood pressure and oncotic pressure among the arteriole, capillary, and venule (Starling's hypothesis) ensures optimal fluid exchange. In pathology, this homeostasis is disrupted.

For example, chronic endothelial dysfunction observed in diabetes mellitus or arterial hypertension leads to the thickening of the capillary basement membrane (microangiopathy). This condition culminates in diffuse tissue hypoxia and pathological angiogenesis in response to hypoxia. Likewise, in ischemia-reperfusion syndrome, the multiplication of oxygen free radicals lays the groundwork for massive microthrombosis in the microcirculatory bed and tissue necrosis.

From a clinical point of view, deeply understanding these processes demonstrates how crucial it is to direct therapeutic approaches directly toward improving microcirculation (using antiplatelet agents, vasodilators, antioxidants).

Conclusion.

Microcirculation is not merely a pathway for blood passage, but a highly reactive system that ensures homeostasis. Its role in pathology is mainly explained by a decrease in tissue perfusion, impairment of capillary permeability, and the development of microthrombosis. Fully studying the mechanisms of these changes and making a timely diagnosis are of great theoretical and practical importance in preventing severe complications of underlying diseases (e.g., multiple organ failure or trophic ulcers).

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