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Possibilities of estimating the velocity of capillary blood circulation according to optical capillaroscopy

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ABSTRACT

The article is devoted to the problem of studying microcirculation, because one of the reasons for the development of microcirculation disorders is hypoxia, which is associated with a violation of the normal anatomy of the capillary wall, changes in the properties of blood rheologies, acceleration or deceleration of microflow. Capillaries are the first to react to long-term disturbance of nasal breathing by changing the functional state and morphological restructuring of micro vessels in the bloodstream. Based on the results of the research work, software was developed that was tested on patients with pathology of intranasal structures and impaired respiratory function. The advanced method of optical capillaroscopy allows not only to perform a visual assessment of the condition of microvessels, but also to determine such an important parameter as blood flow velocity and actually replace the laser Doppler study.

Keywords: biomedical imaging, blood velocity, capillary, video capillaroscopy

1. INTRODUCTION

The study of the vascular microcirculation system is important for diagnosis, assessment of the severity and nature of pathological processes in the human body, monitoring the effectiveness of treatment. Thus, changes in the capillary chain are closely correlated with changes in central hemodynamics, which allows the use of microcirculation parameters as prognostic and diagnostic criteria for assessing the body as a whole[1]. In the authors' research, it is noted that microcirculation disorders are the earliest, persistent and often the only signs of the disease, which responds most quickly to the influence of various pathological factors[2]. However, the insufficient number of studies in this area and the low prevalence of techniques in the assessment of systemic microcirculation does not allow to establish clear quantitative criteria for various chronic diseases of the nose[3,4]. And the complexity of the etiopathogenesis of microcirculatory disorders once again proves the feasibility of using highly sensitive methods for the diagnosis of capillary blood flow and associated changes in the microvessels of the arteriolar and venular units[5,6].

Therefore, the problem of studying microcirculation is of particular interest, because one of the reasons for the development of its disorders is hypoxia associated with a violation of the normal anatomy of the capillary wall, changes in the properties of blood rheologies, acceleration or deceleration of microflow. Due to the introduction into clinical practice of functional computer capillaroscopy[8,16] it is possible to observe in real time blood flow parameters, assess the level of hypoxia, characterize the metabolism and at the same time to correct pathological conditions. Observation of the state of microcirculation in violation of the respiratory function of the nose will study the subtle mechanisms of regulation of vascular-tissue relations[9,10]. To do this, use biomicroscopic methods to study capillary blood flow. One of the most relevant and promising methods is optical capillaroscopy of the nail bed[11].

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This method allows to identify at the evidentiary level the peculiarities of the functioning of the peripheral circulatory system by the state of the capillary system[7,15,17] and to evaluate the effectiveness of treatment by the rheological properties of blood in hematological practice. It is a common fact that the states of the microcirculatory system are similar throughout the body. Also known classification of microcirculation disorders to form a medical opinion about the degree of severity of hemodynamic disorders. It is created on the basis of quantitative characteristics. However, modern methods of optical capillaroscopy are difficult to fully automate due to the complexity of perception of the picture of the microvascular network, which has a high degree of individual variability. Qualitative assessment, or routine calculations in the analysis of the capillaroscopic picture have a significant share of subjectivity. So the movement of blood in the capillaries has its own characteristics. It occurs due to the pressure drop created by the work of the heart. The pressure at the arterial end of the module is about 30 mm Hg. and 10 mm Hg on venous. Pulse pressure fluctuations with a period of 5 - 40 s are also recorded[12-14,18,19].

Blood is a tissue in the form of a suspension consisting of cellular and plasma fractions. The properties of the corpuscular fluid are manifested in vessels less than 200 μm in diameter. When moving in the capillary, erythrocytes combine into kinematic groups ("trains") of 3 to 15 cells. The movement of blood also depends on the ability of erythrocytes to plastic deformation, to pass through microvessels with a diameter smaller than the diameter of the erythrocyte. The limiting limit of human erythrocyte deformation is about 2.6 μm[11,15]. Thus, the present work is aimed at studying the rate of capillary circulation of patients with pathology of intranasal structures and disorders of nasal breathing.

2. EXPERIMENTAL

The state of blood microcirculation and structural changes in capillaries were assessed by the results of computerized capillaroscopy of the nail bed of the 4th finger of the hand (Biobase Group WXH-8 1004C video capillaroscope, JOYMED TECH co., ltd)[8,10]. This modification of the device using the method of computerized capillaroscopy (visual magnification 550 times) allows non-invasive assessment of cutaneous microcirculatory blood flow, which is considered as a universal marker of systemic microcirculation.

The choice of the recording digital camera was carried out according to the following characteristics:

– video stream speed, which must be at least 30 frames per second;
– spatial resolution, which is determined by the number of elements on the matrix of the camera, based on the linear dimensions of the field of view L of the capillaroscope and the minimum displayed object *d* by the following formula) $F(k,i,j)$

$$R = 2\frac{L}{d}. \tag{1}$$

Thus, based on the fact that the diameter of the capillary is about 10 μm, and the field of view is about 1 mm, then, when displaying the diameter of the capillary 10 - ma pixels with a size of 1 μm according to formula (1) we obtain 2000 image elements on the matrix, which characterizes the camera by about 4 Mega pixels[3-5,14]. Further significant increase in resolution is not useful, as the size of individual pixels decreases, the dynamic range of the image begins to decrease.

The process of blood circulation in the capillaries was observed based on the movement of erythrocytes, the size of which even exceeds the average diameter of the capillaries. Schematically, this is shown in Fig. 1). Figure 2a shows the original image of the capillary grid fragment. Based on the actual discrete movement of erythrocytes along the capillaries, it is possible to calculate the speed of their movement. To do this, you need to know information about the frequency f_{fr} (or duration T_{fr}) of frames and the linear dimensions of the studied area of the capillary. Thus, image sequences were used $F\left(k,i,j\right)$ (where *k, i, j* is the frame number and spatial coordinates on the *k*-th frame, respectively).

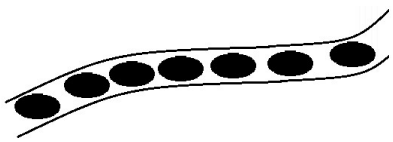
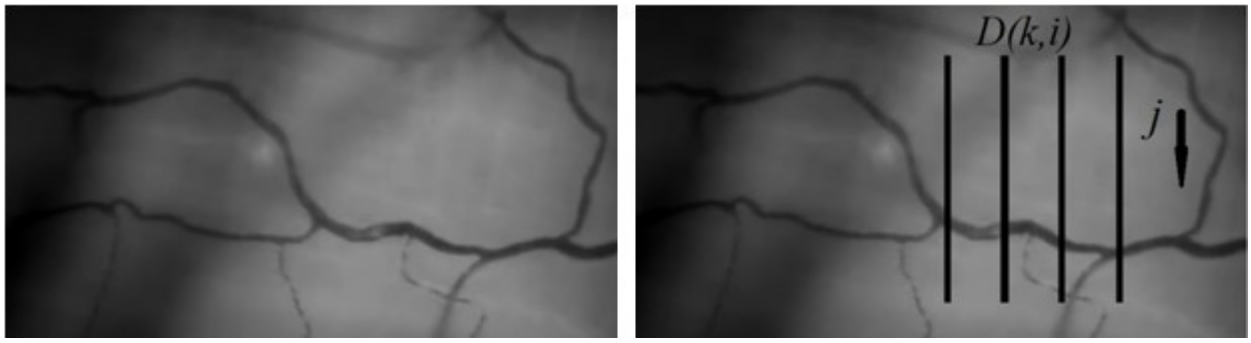


Figure 1. Schematic illustration of the movement of erythrocytes in the capillary.

Then we need for each k personnel to perform the construction of integrated intensity profiles $D(k,i)$ along the direction of the coordinate j (with the accumulation of intensity values $F(k,i,j)$:

$$D(k,i) = D(k,i) + F(k,i,j) \tag{2}$$

Intensity profiles were observed in a direction perpendicular to the location of the studied capillary (Fig. 2b).



a b

Figure 2. Capillaroscopic images: a) the original image; b) the original image with the marks of the integral intensity profile $D(k,i)$ and the direction of its construction j.

The process of storyboard capillary imaging is illustrated in Figure 3.

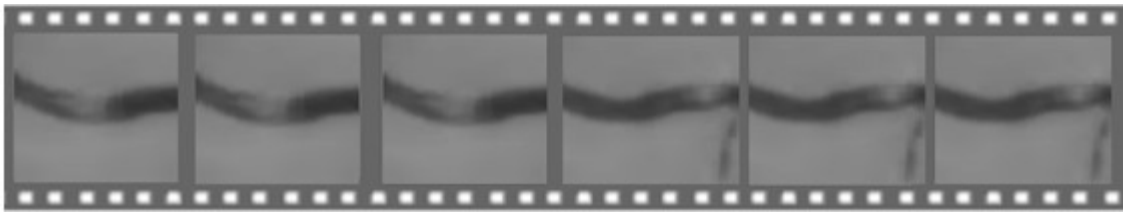


Figure 3. The process of storyboarding the capillary image.

Next, to eliminate the high-frequency measurement error, the averaging of the obtained intensity profiles by the formula:

$$\bar{D}(k,i) = \frac{1}{2N+1}\sum_{n=0}^{N} D(k,i+n) \tag{3}$$

where N is an averaging parameter, which in our own experience for the tangible result is about 7.

3. RESULTS AND DISCUSSION

An illustration of the construction of integrated profiles of intensity D is shown in Fig. 4, respectively. From these studies it can be seen that when finding an erythrocyte there is a defect in optical density – intensity in the field of view, which can be determined using an integrated intensity profile, the graphs of which clearly visualize the minimum integral density.

Next, the extremes $G(k,i)$ (minima) of discrete averaged integral intensity profiles $\bar{D}(k,i)$ are determined:

$$G(k,i) = \min(\bar{D}(k,i)) \tag{4}$$

and determining their jth coordinates and entering them into the array $H(k,i)$:

$$H(k,i) = j(\min(\bar{D}(k,i))). \tag{5}$$

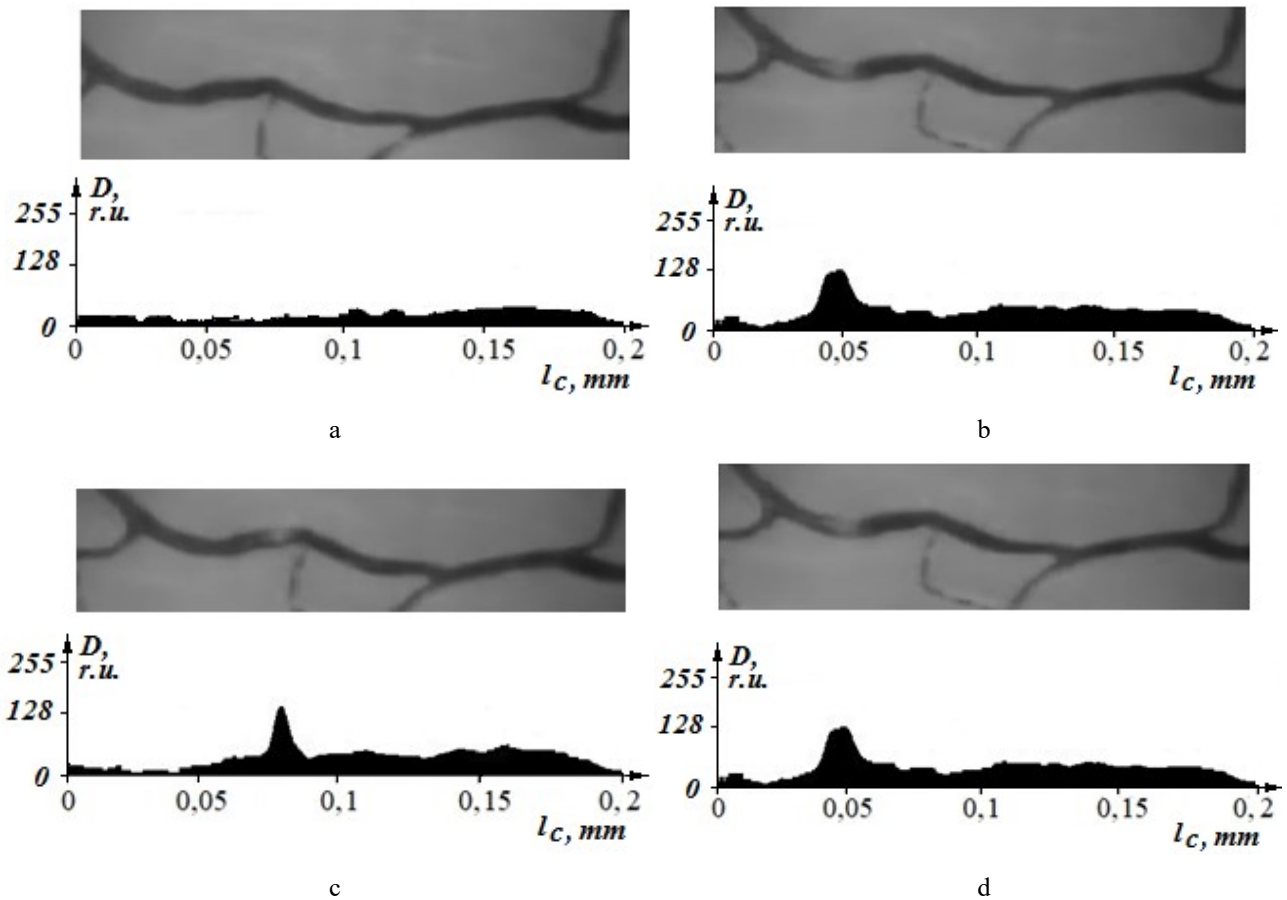


Figure 4. The process of constructing a vertical integral profile of intensity *D* (in relative units of intensity encoded by 8-bit characteristic) along the length of the capillary in frames where there is movement of erythrocytes in the field of view from left to right a) no erythrocyte is traced; b) on the 5th; c) on the 8th, d) on the 11th frames corresponding to the distance *lc* (top – optical image, bottom – vertical integrated intensity profile).

The velocity V_c of blood circulation in the capillary is determined by the formula[10]

$$\mathrm{V}_c = \frac{l_c \cdot f_{fr}}{N_{fr}} = \frac{l_c}{T_{fr} N_{fr}}, \tag{6}$$

where: l_c – the length of the studied area of the capillary, which moved the erythrocyte; T_{fr} – frame duration; f_{fr} – frame rate; N_{fr} – the number of studied staff.

According to formula (6), the blood flow velocity V_c in the capillary according to the integrated intensity profiles will be determined by the formula:

$$V_C = \frac{(H(l) - H(m)) \cdot \Delta x}{T_{fr} \cdot (m - l)} = \frac{(H(l) - H(m)) \cdot \Delta x \cdot f_{fr}}{(m - l)} \tag{7}$$

where: Δx is a spatial distinction along the axis *i* (horizontal coordinate *x*); l, m – numbers of final and starting frames, respectively; T_{fr} – frame duration; f_{fr} – frame rate; N_{fr} – the number of studied staff.

Taking into account the fact that the coordinates on the graphs of the integrated optical density correspond to the frame numbers *k* of the video sequence, then based on the schematic representation in Fig. 3.

At a frame rate of 30 frames per second and the length of the capillary path (0.12 mm - 0.05 mm = 0.7 mm) and the difference between the frame numbers between the positions of the minimums of the integrated intensity profiles of 7 frames, we obtain the blood circulation:

$$V_C = \frac{0,07mm \cdot 30k / c}{7k} = 0,3mm / s \quad (8)$$

which generally corresponds to the data of other authors[3-5,10,11].

Considering that microcirculation disorders are generalized for the whole organism, it is possible by capillaroscopy of the finger nail bed to indirectly determine about changes in blood flow, for example, in the mucous membrane of the nasal cavity. Based on the results, software was developed, which was tested on patients with pathology of intranasal structures and impaired respiratory function[7,11]. The first group (main) included 53 (36.6%) patients with changes in the intranasal structures and varying degrees of dysfunction of nasal breathing (aerodynamic resistance in the range of 2.6 ÷ 3.5 kPa s / l), in whom the duration of the disease was intranasal structures and varying degrees of dysfunction of nasal breathing was 3 ÷ 5 years; the rate of capillary blood circulation in the first group was 0.32 ± 0.11 mm / s; the second group consisted of 48 (33.1%) patients with altered intranasal structures, partial obstruction of the nasal cavity (aerodynamic resistance within 1.8 ÷ 2.7 kPa · s / l), the duration of the disease was up to 0.5 years; The fluidity of capillary blood circulation in another group was 0.46 ± 0.15 mm / s; the third group consisted of 44 (30.3%) patients with changes in the intranasal structures and varying degrees of dysfunction of nasal breathing and smell (aerodynamic resistance in the range of 3.1 ÷ 3.9 kPa s / l), in whom the duration of the disease was up to 1 month. The fluidity of capillary blood circulation in the third group was 0.38 ± 0.14 mm / s.

The change in blood circulation is tied in the form of capillaries. Changes in blood circulation are associated with the presence of pathological tortuosity, a change in the caliber of arterioles and venules. Pronounced disorganization of the capillary network, intravascular aggregation of erythrocytes, isolated areas of stopping blood flow in the capillaries can be traced.

4. CONCLUSIONS

The study of microcirculation using capillaroscopy made it possible to study the smallest vessels – capillaries, which are the first to respond to long-term disturbance of nasal breathing by changing the functional state and morphological restructuring of microvessels in the bloodstream. At optical capillaroscopy it is expedient to use two-dimensional procedure of interframe measurements for search of lateral shift of the next images in the field of blood circulation with movement of erythrocytes and for direct measurement of speed of blood circulation along a capillary. The developed method opens new possibilities for diagnostics of microcirculation process, thanks to the possibility of constant monitoring of erythrocyte velocity in capillaries. The spatio-temporal representation of capillary circulation is considered. Experimental results of direct measurement of blood circulation velocity in individual capillaries of the microvascular network are presented and analyzed. The result of the circulatory velocity was about 0.3 mm / s, which generally corresponds to the data of circulatory physiology.

Changes and decreases in blood circulation in patients with pathology of the intranasal structures and impaired respiratory function are associated with the presence of pathological tortuosity, a change in the caliber of arterioles and venules, pronounced disorganization of the capillary network, intravascular aggregation of erythrocytes, and isolated areas of blood flow arrest in the capillaries are traced. Thus, the improved method of optical capillaroscopy allows not only to perform a visual assessment of the condition of microvessels, but also to determine such an important parameter as blood flow velocity and actually replace the study of laser Doppler.

The results of the work after passing the previous clinical trial can be used in medical centers and clinical institutions as an additional method of diagnosis. In the future, it is advisable to identify the correlation between capillaroscopic parameters and colorimetric characteristics of the mucous membrane, as well as the parameters of the boundary layer of air flow that affects the surface of the nasal cavity. Such data will be important in the diagnosis of respiratory and olfactory disorders and the formation of adequate tactics for their treatment.

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