The Role of the Composition and Gas-Transporting Function of the Blood in the Fluctuations of the Electrical Properties of the Epidermis and Subepidermal Tissues

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Changes in the composition and gas-transporting function of the blood contribute to the formation of the total electrical impedance of the epidermis, subepidermal connective tissue, and muscles. It is concluded that time fluctuations of the impedance result from the summated influence of the factors characterizing the modulations of the tissue oxygen consumption.

Key Words: *electrical impedance; oxygen transport; minute circulation volume; number of erythrocytes*

Recent years have witnessed an upsurge in the number of studies dealing with electrical parameters of biological tissues. However, the results of these studies are ambiguous [1,5,8]. For example, when the response to a dosed physical load was analyzed, the expected changes in electrical impedance [4] are 2- to 3-fold lower than the recorded value [5]. This discrepancy probably results from the fact that the model employed for physiological interpretation of the data reflected only blood filling [4] of tissues, ignoring the influence of other factors, such as variations of blood composition and of the natural dynamics of tissue resistance to electrical current, which determine many aspects of metabolic processes and structural transformations in tissues.

Our aim was to analyze the fluctuations of the electrical properties of biological tissues and the relationship between these fluctuations and changes in the oxygen consumption and gas-transporting function of the blood.

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MATERIALS AND METHODS

Thirty-two healthy volunteers of both sexes aged 18-55 years were enrolled in the study. High-frequency (HFI) and low-frequency (LFI) impedance of the palm, including the epidermis, connective tissue of the dermis, and muscle [7], heart rate, blood pressure, oxygen consumption, and blood formula were recorded. The minute circulation volume (MCV) was calculated as the ratio between oxygen consumption and heart rate ("oxygen pulse"). Measurements were performed in different seasons five times a day starting from eight o'clock in the morning.

RESULTS

Fluctuations of HFI and LFI with periods of several hours to several days were recorded. There were no significant age- or sex-related differences in impedance and its dynamics; however, the impedance tended to decrease with age. For example, in 30-year-old individuals (n=8) HFI and LFI were 856±65 and 3641±175 Ω, respectively, while in persons over 40 they were 739±54 and 3474±161 Ω, respectively. This is consistent with published data [5,6]. At the mean annual values of MCV and erythrocyte count of 2900±115 ml/min and 4250±210 cells/mm^3, respectively, in winter MCV decreased 5-10%, while the erythrocyte count increased 12-15% (p<0.001). The mean HFI and LFI varied from 700 to 1150 Ω and from 3600 to 4500 Ω, respectively.

Generally, the maximum HFI and LFI values coincided with the extreme values of the physiological parameters, and their dynamics were synchronous (p<0.005). The circadian rhythm of HFI and LFI corresponded to the dynamics of oxygen consumption, showing a decrease at noon and an increase in the evening (p<0.001), which agrees with the results of others [2,3]. The coefficient (r) for the impedance and MCV correlation was -0.85.

However, no relationship was found between the mean diurnal amplitudes of the electrical and physiological parameters of interest, although their dynamics was similar to the rhythmic variations of the "oxygen pulse" in the 3.2-5.9 range.

Averaging of the values over more than one month revealed the variations of HFI and LFI as a function of physiological parameters. The correlation between LFI and MCV (r=-0.87) allowed us to establish an empirical relationship between these indexes (Fig. 1). The correlation between HFI and MCV values was much weaker (r=-062), since the relationship disappeared at MCV values higher than 2800 ml/min.

There was no correlation between the impedance variations and the erythrocyte count over 24 h. However, analysis of the mean diurnal and monthly values revealed a clear nonlinear relationship between LFI and the erythrocyte count (Fig. 1). The variations of HFI were statistically significant only at an erythrocyte count of 4200 cells/mm^3.

Variations of blood HFI and LFI as a function of the erythrocyte count did not exceed 4-5% of the mean physiological norm. There were no differences in the dynamics and values of blood HFI and LFI, although the total change in the tissue impedance exceeded 10-15%.

Thus, the peculiarities of the fluctuations of tissue HFI and LFI over time cannot be attributed solely to changes in the volume of circulating blood or to variation of the blood composition, although the latter does affect the electrical properties of the blood [8].

We believe that the following aspects should be taken into account for a correct interpretation of our findings: the oxygen-transporting function of the blood and the factors modulating the oxygen demand of tissues, such as changes in MCV, erythrocyte count and volume, and oxygen delivery from the lungs.

These factors may affect impedance both simultaneously and individually at different times. Therefore, the total effect is variable, being determined by

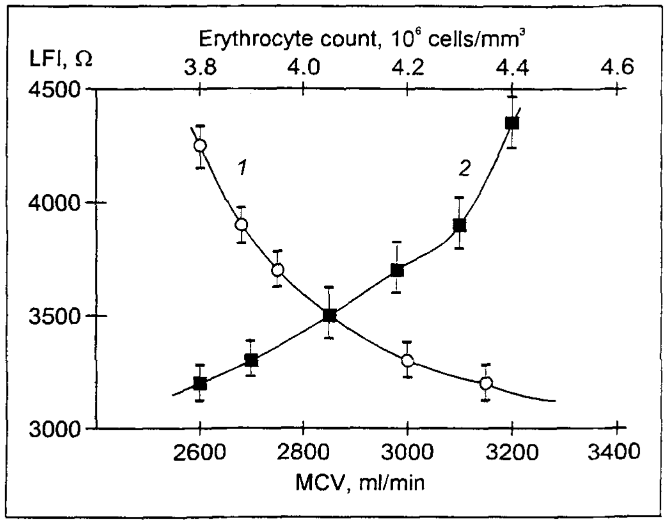

Fig. 1. Dynamics of LFI of the palm as a function of MCV (*1*) and erythrocyte count (*2*).

the lability of a factor, the time of measurement, and the period of data averaging [2].

Among the factors studied MCV is the most labile determinant of the daily oxygen demand. This accounts for the strong correlation between the impedance and MCV and the absence of a correlation between the impedance and erythrocyte count. The dynamics of the erythrocyte count should be considered in long-term studies, otherwise there will be a discrepancy between the amplitude fluctuations of the impedance and the physiological parameters in question, since they produce opposite effects on the impedance.

When the period of data averaging was increased, the contributions of the individual factors became smoothed, being determined by the dynamics of the tissue oxygen demand, which depended on the season. This agrees with the findings of others [3]. From this standpoint, the age-related changes in the tissue oxygen demand may explain the tendency for the impedance to decrease with age [2,3].

The differences in the HFI and LFI dynamics depending on the variation of MCV and erythrocyte count may stem from the fact that when the volume of circulating blood and the blood composition vary, the contribution of physical changes in the impedance is greater to LFI than to HFI [7]. Modulations of the blood gas-transporting function responsible for the supply and utilization of oxygen in tissues are associated with significant alterations of the mitochondrial structure, enzyme systems, biochemical processes, and electrolyte balance [2,3,6-8], all of which affect HFI to a greater extent than LFI. The greater the changes in MCV and the erythrocyte count, the stronger should be the impairment in the relationship between the volume of circulating blood and HFI. This was indeed observed in our study. The fact that the rhythms of variation of "oxygen pulse" and impedance are similar testifies to a significant role of metabolic processes in the fluctuations of impedance.

Thus, it can be assumed that the fluctuations of the studied physiological and electrical parameters are based on common factors that reflect changes in oxygen supply and utilization in tissues via modifications in the state of the cardiovascular system and in tissue metabolism.

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