NONINVASIVE QUANTITATIVE EVALUATION OF THE CHARACTERISTIC IMPEDANCE MODULUS OF HUMAN LIMB ARTERIES

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UDC 616.134.1/.4+616.137.8/9]-073.731

KEY WORDS: Large artery; characteristic impedance modulus; postural effects; physical exertion; vasoconstriction.

In large arteries, with sufficiently high extensibility and a marked pulsating blood flow, relations between blood flow and pressure can be adequately described by hydraulic impedance [1, 8, 14]. To determine the input hydraulic impedance, which reflects total resistance of the lower (relative to blood flow) blood vessels, it is necessary to know momentary values of blood pressure and blood flow throughout the cardiac cycle recorded simultaneously at the input to the system of vessels under examination, which at present is possible by the use of invasive methods of measurement [10, 15]. As model experiments [2] have shown, using dependence of this parameter on the following frequency of the disturbing stimulus (pulsations of pressure), it is possible to judge the functional state of different parts of the vascular system. For instance, the impedance modulus at zero frequency, i.e., the first component in the Fourier expansion, is the resistance (Poiseuille) of blood vessels (R) of mainly small caliber, whereas the impedance modulus at high harmonics corresponds to the so-called characteristic impedance, which reflects the functional state mainly of large vessels.

This paper describes the quantitative evaluation of the characteristic impedance modulus of human limb arteries, and changes in this parameter during postural reactions and physical exertion are demonstrated.

EXPERIMENTAL METHOD

The characteristic impedance (Z_c) can be determined by invasive methods with averaging of harmonics of the input impedance within the frequency range from 2 to 15 Hz [12]. Another way of determining it is derived from the theory of spread of pulse waves, from which an expression can be obtained for the value of the characteristic impedance [1]:

$$Z_c = \frac{1}{A} \cdot \left(\frac{\rho}{D}\right)^{1/2}, \qquad (1)$$

where D denotes distensibility of the blood vessel studied, A the area of a cross section of the vessel, and ρ the density of blood. Since noninvasive determination of D and A also is beset by great technical difficulties, hitherto the study of characteristic impedance (Z_c) has not yet been widely adopted in man [6, 13]. If, however, in equation (1) Z_c of a blood vessel beneath a cuff, regarded as a cylindrical tube of constant length (L), is expressed through the value of the initial volume of the vessel (V_0), its pulse increase (ΔV_{in}) and the pulse increase of pressure (PP), we obtain an appropriate expression for the characteristic impedance modulus:

$$Z_0 = i\left(\frac{\rho \cdot PP}{V_0 \cdot \Delta V_{in}}\right)^{1/2}. \qquad (2)$$

The values indicated in equation (2) can be determined by a noninvasive method and by the apparatus described in detail previously [15]. For graphic recording, the "Mingograf-82" automatic jet writer was used. The results were subjected to statistical analysis by the

Laboratory of Physiology of the Circulation, Institute of Physiology, Siberian Branch, Academy of Medical Sciences of the USSR, Novosibirsk. (Presented by Academician of Academy of Medical Sciences of the USSR Yu. I. Borodin.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 100, No. 10, pp. 390-392, October, 1985. Original article submitted February 15, 1985.

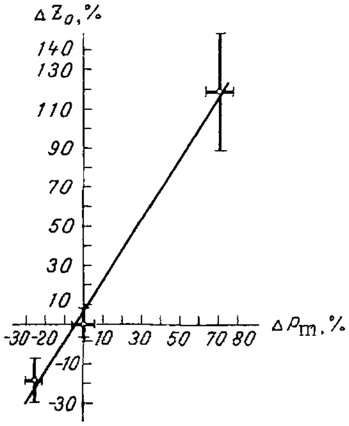

Fig. 1. Dependence of characteristic impedance modulus of arteries of lower third of leg (Z_0) on mean blood pressure (P_m) during changes of posture. ΔZ_0) Relative change in impedance modulus (in % of original value, in horizontal position); ΔP_m) relative change of pressure (in % of initial value, in horizontal position).

difference method, using Student's t test. The result was considered significant at the $P < 0.05$ level. A group of 40 clinically healthy male volunteers was studied. The average age of the subjects was 34.3 ± 1.3 years, their body weight 73.1 ± 1.3 kg, and height 175.1 1.4 cm. In series I (17 subjects) the tests were conducted on a special tilting chair: in the horizontal (0°), passive antiorthostatic (–20°) and passive orthostatic (+70°) positions. In the observations of series II, the subjects (23), who also were in the horizontal position (lying on their backs), were tested before and immediately after work on a bicycle ergometer of average heaviness (about 0.5 PWC_{170}), which was done with the upper or lower limbs (sitting) for 5 min.

EXPERIMENTAL RESULTS

In the horizontal position at rest the characteristic impedance modulus (Z_c; equation 2) of the arteries of the lower third of the leg, on average for the group, was $(6.62 \pm 0.28) \cdot 10^5$ $kg \cdot sec^{-1} \cdot m^{-4}$, and of the arteries of the arm $(5.53 \pm 0.24) \cdot 10^5$ $kg \cdot sec^{-1} \cdot m^{-4}$ ($P < 0.01$). The value of the characteristic impedance modulus calculated by this method was approximately the same as that calculated on the basis of invasive measurements of pressure and blood flow [13]. Incidentally, no differences likewise were found in the values of the characteristic impedance modulus determined by equation (1) and by the method of averaging harmonics of input impedance.

During any change in the position of the body the blood pressure in the arteries of the upper limbs did not change significantly [5] and the characteristic impedance modulus (Z_0) likewise did not change significantly in the antiorthostatic position, but it increased in the orthostatic position — on average by 40.3 ± 17.3% ($P < 0.05$).

The pressure in the lower limb arteries increased in the passive orthostatic and decreased in the passive antiorthostatic positions [5]. Changes in the impedance modulus were similar in direction to changes in blood pressure (Fig. 1) and were due both to a change in the mechanical properties of the material of the vessel wall and a change in the diameter and thickness of the wall of these vessels. Similar dependence, linear within the range from 60 to 80 mm Hg, of the impedance modulus on the value of the transmural pressure (P_{trans}) also was obtained in experiments *in vitro* [11].

The data in the literature on changes in blood flow through the lower limbs during a change in the orthostatic position are very contradictory [3]. Most investigators, however, have observed a decrease in the blood flow, and they associate this fact with an increase in the regional hydraulic resistance [9], on account of reflex vasoconstriction which arises during the change into the orthostatic position [4]. Since this vasoconstriction also extends to the large arteries [5], it is also manifested as an increase in their characteristic impedance modulus. According to data in the literature [11], the vasoconstriction arising during activation of the vascular smooth muscle leads to a shift of the beginning of rise of the characteristic impedance on the graph of $Z_c = F(P_{trans})$ toward higher values of P_{trans}, and for this reasons, the increase in Z_c shown in Fig. 1 in the region of physiological pres-

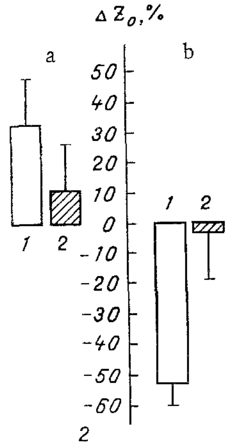

Fig. 2. Change in characteristic impedance modulus (Z_0) of arteries of arm (1) and arteries of lower third of leg (2) after performance of physical work by lower (a) and upper (b) limbs on bicycle ergometer.

sures could be even greater in the case of an inactivated arterial wall. Since the ratio Z_c/R for the limb arteries is usually about 0.1-0.15 [16], an increase in Z_0 may appreciably increase the input impedance modulus and lead to restriction of the blood flow through the lower limbs in the orthostatic position. Analysis of previous results [7, 9] suggests that the ratio Z_0/R ought not to change significantly in this position. We also know that Z_c/R remains virtually unchanged during reactive hyperemia [10]. Incidently the difference indicated previously [6] between values of Z_0 in arteries of the arm and leg in the initial state can evidently be explained by higher tone of the lower limb arteries.

With the general rise of blood pressure after physical exercise, Z_0 of the upper limb arteries was significantly reduced ($P < 0.001$) in response to work with the upper limbs, and significantly increased ($P < 0.001$) in response to work with the lower limbs (Fig. 2). Changes in Z_c, according to data in the literature [11], are associated with a change in energy losses (pulsatile power components) during movement of the blood in these vessels. The data given above may be evidence of a decrease in energy losses during movement of a unit volume of blood in the upper limb arteries in the case when work was done with the upper limbs, and an increase in these losses in the same blood vessels during work with the lower limbs. As was shown in [17], the response of Z_c to physical work may differ in magnitude and, in particular, it depends on age changes in the vessel wall and other causes.

The characteristic impedance modulus of the lower limb arteries was not significantly changed (mean increase ΔZ_0, in %, was less than the corresponding confidence interval) during work with either the lower limbs or the upper limbs. If, however, it is recalled that physical exertion led to an increase in P_m in the lower limb arteries on average by 10%, this state of affairs, according to the data in Fig. 1, ought to have led to a twice greater increase in ΔZ_0. The absence of such an increase in these arteries is evidently connected with differences in vasoconstriction during postural reactions and physical exertion. The lower limb vessels are constantly subjected during life to higher (hydrostatic) loads than the upper limb vessels, and for that reason they may have different reponses. We know that occulusion of the lower limb arteries is a frequent and serious disease, whereas occlusive diseases of the upper limb arteries do not present a clinically important problem [4].

The fact that the characteristic impedance modulus of arteries of the lower third of the leg was virtually unchanged after physical work done with the lower and upper limbs (despite an increase in the intravascular pressure) is evidence of differences in the intimate mechanisms of vasoconstriction, leading to dissimilar behavior of the characteristic impedance modulus of arteries in the upper and lower limbs after physical exertion, and evidence of corresponding activation of the smooth muscle of the blood vessels of the lower limbs in the original state.

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PARAMETERS OF HORMONAL REGULATION OF FLUID-ELECTROLYTE EXCHANGE AND cAMP RECEPTION IN THE RAT RENAL PAPILLA DURING ADAPTATION TO COLD

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UDC 612.014.461.3-06:612.46.018-06: 612.592.014.49

KEY WORDS: cold adaptation; fluid-electrolyte exchange; hormones; cAMP reception.

Under the influence of moderately low temperatures the diuresis and excretion of chlorides with the urine increase in man [3]. In experiments on animals exposed for several days to cold, changes in diuresis and sodium excretion also have been observed [9], and the antidiuretic activity of the blood is reduced [8]. A state of adaptation is known to arise in rats 30-40 days after the begining of exposure to cold [12] and it is characterized by a persistently raised level of metabolism [2]. Accordingly it is important to study the coordinated changes in parameters of fluid-electrolyte exchange and of its regulators, such as antidiuretic hormone (ADH) and aldosterone, in rats adapted to cold.

Since the effectiveness of action of hormones depends not only on their concentration in the plasma, but also evidently on the state of the intracellular systems which mediate their action [1], it was decided to study the intracellular reaction of cAMP, which is an important functional component of the action of ADH in target tissues, in the renal papilla.

EXPERIMENTAL METHOD

Experiments were carried out on mature male Wistar rats weighing 200-250 g. Animals of the experimental group were kept at a temperature of 4-5°C, rats of the control group at 19-21°C. The 24-hourly urine was collected from the animals 7 days after the beginning of the

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 0007-4888/85/0010-1308$09.50