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ESTIMATION OF THE COLLATERAL CIRCULATION INDEX (CCI) IN THE LOWER EXTREMITIES USING THE IMPEDANCE RHEOGRAPHY AND ULTRASONIC METHODS

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In this study values of volumetric blood flow in the thigh, measured using the impedance rheography, were compared with values of volumetric flow in the common femoral artery, measured using the ultrasonic method. We examinated 32 healthy and 46 sick people with occlusion of the pelvic limb arteries. More than 120 measurements were made on these subjects. We ascertained diagnostic usefulness of both methods to simultaneous measurement of blood flow in the peripheral vessels. It seems that association of both of the methods – rheographic and ultrasonic – permits the collateral blood flow to be calculated.

1. Introduction

One of the more significant hemodynamic parameters is the volumetric flow which permits quantitative evaluation of blood supply in the area of tissue investigated. Studies concerning quantitative determination of the volumetric flow have not so far been carried out to a large extent in clinical practice because of lack of an appropriate measuring method. Methods known for a long time and applied in physiological investigations are not adequate for routine measurements. Only the introduction of the ultrasonic and impedance methods makes possible quantitative appreciation of this important parameter. Both methods are non-invasive, harmless, painless for patients. Besides that, their common feature is the use of the passive properties of organism: in the case of impedance rheography this is change of impedance for highly alternating current in the area of tissue examined, caused by a pulsating wave of blood [1]. In the case of the ultrasonic technique there is the interaction of the ultrasonic wave with moving blood cells [3]. The purpose of this work is a comparison between the volumetric intensity of a thigh blood flow (determined by the rheographic method) and the volumetric intensity of blood flow in the main vessel supplying the pelvic limb — the femoral common artery (determined by the ultrasonic method).

2. Methods

Rheographic investigation consists in measuring and recording changes of electric impedance of tissue and the rate of these changes i.e. the first derivative. The volumetric blood flow (in relation to the segment investigated) can be qualified using this method on the basis of KUBICEK's formula as follows:

$$Q_R = \varrho \frac{L^2}{(Z_0)^2} \frac{dZ}{dt_{\max}} \times T \times HR \quad [\text{ml/min}], \tag{1}$$

where ϱ — resistance of blood, L — distance between the measuring electrodes, Z — impedance, $dz/dt_{\max}$ — amplitude of the first derivative of impedance changes, T — duration of blood flow, HR — heart rate.

In the pulse Doppler ultrasonic technique used in the hemodynamic investigations both echo and Doppler's phenomena are combined. These phenomena appear in the interaction of ultrasonic wave with moving blood cells [3, 4].

Adoption of the ultrasonic pulse technique and the triangulation head permit the measurement of the diameter of a vessel and a distribution of velocities in the cross-section of the vessel. The volumetric flow in the vessel examined was calculated according to the following formula [8]

$$Q_U = 0.67 \times V_{\text{av}\max} \times \pi \times \frac{d^2}{4} \times 60 \quad [\text{ml/min}], \tag{2}$$

where d — diameter of the vessel, $V_{\text{av}\max}$ — mean flow velocity in the center of the vessel.

Patients were examined in the supine position and then the ECG and rheographic electrodes for limb off take were fixed. Previously the electrodes were moistened or covered with special electrode-paste. For the rheographic investigations the applique and striped receiving electrodes (made of aluminium-foil and equipped with special fixing snaps) were used.

The distance L for the receiving electrodes was on the average 10 cm.

The ultrasonic investigations were carried out using a special ultrasonic triangulation head which was applied on the skin over the common femoral artery. The position of the electrodes and the head is shown in Fig. 1.

Signals from both units were simultaneously recorded on a three-channel recorder: the instantaneous flow velocity in the common femoral artery, ECG and the first derivative – from changes in impedance in the tissue examined.

On the basis of the curves recorded and using the formulae given above (eg. (1), (2)), the parameters Q_R and Q_U were calculated.

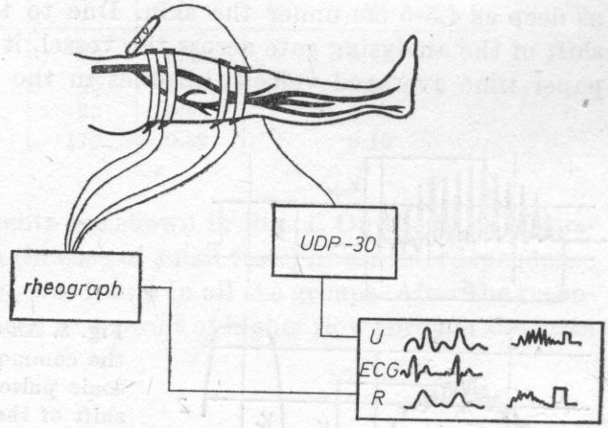

Fig. 1. Means of investigation of blood flow in the thigh using the rheographic and ultrasonic methods. U – velocity of blood flow in the common femoral artery (UDP-30), R – derivative of changes of impedance (rheograph)

3. Materials

In the rheographic investigations a two-channel impedance rheograph RJ – 2k (working in a four-electrode electric system) was used. This rheograph was developed at the Institute of Precision and Biomedical Engineering, Technical University, Warsaw, Poland. The device has a generator of rectangular

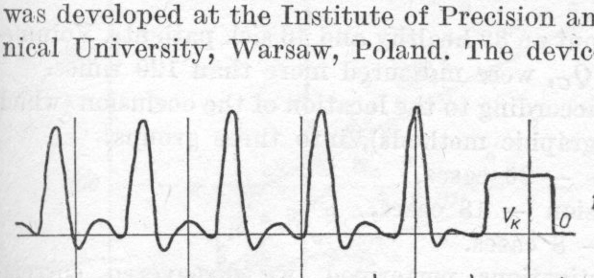

Fig. 2. An example of blood flow recording from the healthy common femoral artery. *1* – instantaneous velocity of the blood flow in the center of the vessel (UDP-30), *2* – ECG, *3* – velocity of changes of impedance in the segment of the thigh, evoked by the pulsating wave of blood (dZ/dt)

wave of 60 kHz and a two-channel detection system, permitting measurements in two ranges of the basic resistance: 30 Ω and 100 Ω. Each channel of the rheograph has an indicator of the basic resistance Z_0 and two outputs: for the variable component of impedance Δ_z and for the first derivative of Δ_z. Sensitivity of the recording system was set on a level of 10 m Ω/cm for Δ_z and 0.1 Ω/s/cm for dz/dt [6, 7].

In the ultrasonic investigations a pulse Doppler ultrasonic flowmeter was used. The flowmeter was built at the Institute of Fundamental Technological Research, Polish Academy of Sciences. This device permits detection of flow as deep as 4.5-5 cm under the skin. Due to the application of an automatic shift of the analysing gate across the vessel, it is possible to record directly on paper time averaged velocity profiles in the vessel under examination.

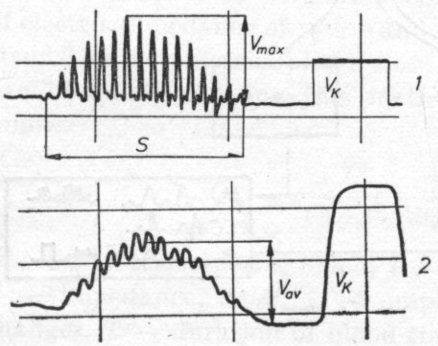

Fig. 3. An example of blood flow recording from the common femoral artery by means of ultrasonic pulse Doppler flow-meter with automatic shift of the analysing gate. *1* — distribution of the instantaneous velocity, *2* — distribution of mean velocity

4. Results

Investigations were carried out on 32 healthy and 46 sick patients. Volumetric intensities of flow, Q_R and Q_U, were measured more than 120 times.

Sick patients were divided, according to the location of the occlusion (which was qualified using the arteriographic methods), into three groups:

the aorto-femoral occlusion — 20 cases,

the femoral-popliteal occlusion — 18 cases,

the multi-level occlusion — 8 cases.

As a result of the investigations performed, we discovered correlation of the volumetric flow in the thigh when measured using the rheographic method with the volumetric flow in the common femoral artery measured using the ultrasonic method, both in the groups of healthy and sick patients. In the group of healthy volunteers there was flow ranging from 120 to 600 ml/min., average 260 ml/min., while flow in the common femoral artery was 110-300 ml/min., average 175 ml/min. In the group of sick patients with the occlusion of the pelvic limb arteries, the values of flow measured using both methods are lower than in the healthy subjects. There are also differences in the level of the occlusion. The mean values of flow intensity in the thigh, Q_R, and in the common femoral artery, Q_U, in the separate groups of patients, along with the index of collateral circulation CCI (ratio of collateral blood flow to the total thigh flow) are shown in Table 1.

Table 1

Occlusion type	Q_R	Q_u	CCI	Standard deviation σ
aorto-femoral	110	50	0.55	0.12
femoral-popliteal	185	55	0.70	0.08
multi-level	60	25	0.58	0.08
normal	260	175	0.33	0.10

The results of the measurements are shown in Fig. 4. On the basis of analysis of regression and correlation (in case of small tests) linear interdependence between the parameters Q_R and Q_U was found in all the groups. After the reconstruction of the artery CCI decreased as a result of higher flow through the main vessel (Figs. 5, 6, 7).

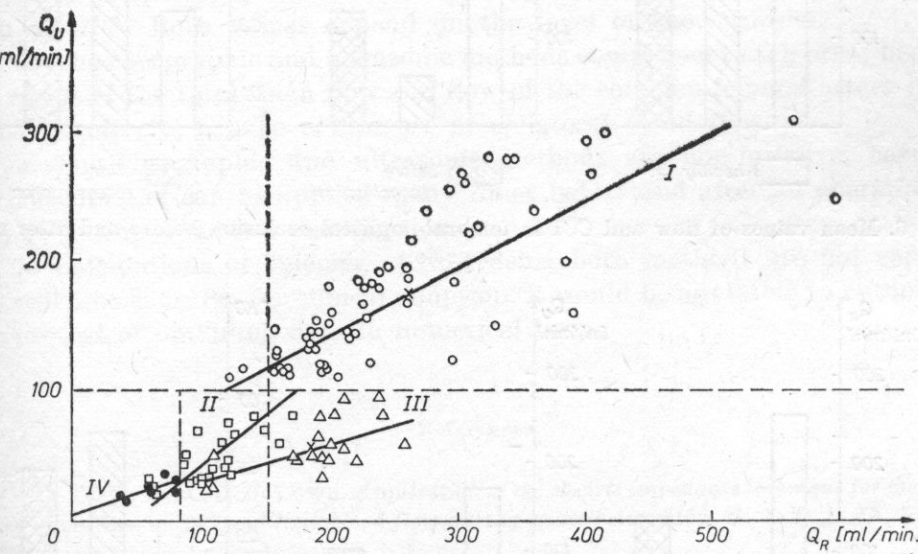

Fig. 4. Interdependence between the measurements of flow in the common femoral artery Q_u(UDP-30) and in the segment of the thigh Q_u (rheograph). ○ – healthy subjects (I) – $Q_u = 0.48\ Q_R + 57$, $r = 0.78$; □ – aorto-femoral occlusion (II) – $Q_u = 0.78\ Q_R - 35$, $r = 0.95$; △ – femoral-popliteal arterial occlusion (III) – $Q_u = 0.79\ Q_R + 1$, $r = 0.62$; ● – multi-level arterial occlusion (IV) – $Q_u = 0.34\ Q_R + 4{,}5$, $r = 0.82$; × – mean values. I (250, 175); II (110, 50); III (180, 55); IV (60, 26)

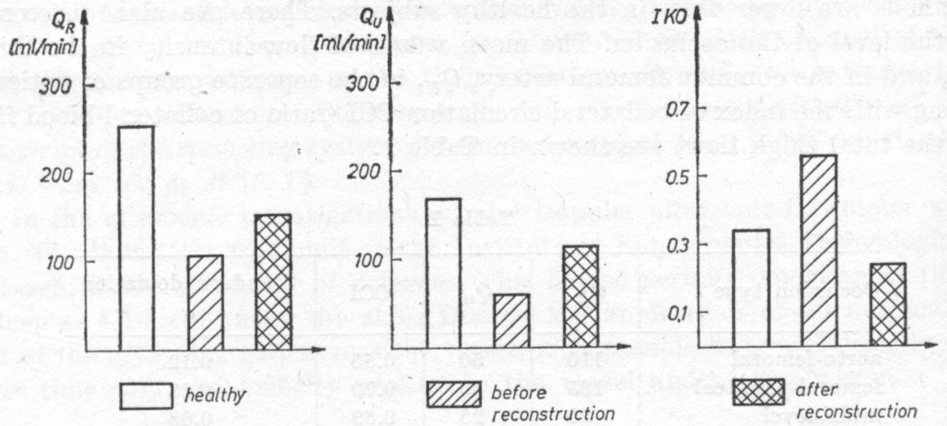

Fig. 5. Mean values of flow and CCI in aorto-femoral occlusion before and after reconstruction

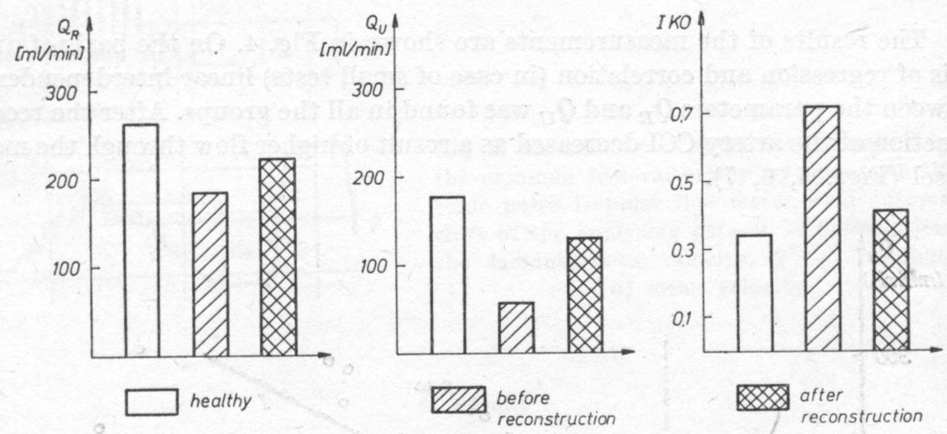

Fig. 6. Mean values of flow and CCI in femoral-popliteal occlusion before and after reconstruction

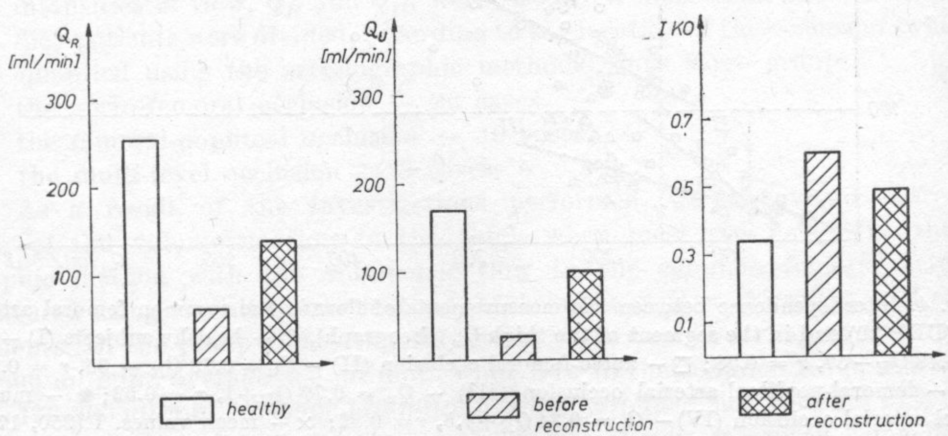

Fig. 7. Mean values of flow and CCI in multi-level occlusion before and after reconstruction

5. Discussion

Taking advantage of the simultaneous measurement of flow in the whole cross-section of the thigh and in the common femoral artery, both values were calculated. In the case of the occlusion of the pelvic limb arteries the value of the entire thigh flow and of flow in the main vessel supplying the pelvic limb with blood permits estimation of collateral circulation. We also noticed that the value of collateral blood flow in proportion to the total thigh flow changes, depending on the level of the occlusion. We call it the "index of collateral circulation". In the group of healthy subjects the mean value of the index of collateral circulation is 0.33. This value increases as flow in the main vessel decreases. The mean values of ICC, depending on the level of the occlusion, are also shown in Table 1.

6. Conclusions

1. The volumetric flow in a segment of the thigh measured using the rheographic method reveals higher values than the volumetric flow in the common femoral artery measured using the ultrasonic method.

2. The values of flow through the thigh and in the common femoral artery are lower in the group of patients suffering from the occlusion of the pelvic limb arteries. Both values depend on the level of the occlusion.

3. The rheographic and ultrasonic methods complement each other because the result of the total thigh flow and flow of the common femoral artery (measured selectively) can be a measure of collateral blood flow.

4. The rheographic and ultrasonic methods are non-invasive, harmless for patients and can be applied many times before and after an operation, as well as during a control examination.

5. Calculations of velocity of flow using both methods are not complex but still laborious. So, for clinical adoption, it would be advisable to automatize the process of obtaining data in numerical form.

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