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Investigation on Measuring Total Peripheral Resistance of Human Body by Means of Reconstructed Impedance Cardiogram

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Abstract. Objective The purpose in this article is to investigate the measurement method and normal values of the total peripheral resistance (TPR) and total peripheral resistance index (TPRI) measured by the reconstructed impedance cardiogram (RICG). **Methods** The cardiac output and cardiac index of 180 normal adults is measured by means of the RICG. The computed formula of the TPR and TPRI are deduced, and the TPR and TPRI are calculated. The subjects are divided to the different groups according to the sex and age. The TPR and TPRI are calculated statistically. **Results** The TPR and TPRI are increased with the increase of the age, and there is significant difference between the young and elder groups (P<0.05). In the same age group, the TPR of the female group is higher than that of the male group (P<0.05), but the TPRI of the male and female groups is basically the same (P> 0.05). The normal value of the TPR is less than 1650 dyn.s.cm^{-5}, and that of the TPRI is less than 2650 dyn.s.cm^{-5}.m^2. **Conclusion** The TPR and TPRI measured by the RICG can reflect the hemodynamic changes of the normal or abnormal body.

1 Introduction

The total peripheral resistance (TPR) of the human body is the total flow resistance of the blood in the systemic circulation system. The TPR is a parameter which reflects the effect of the blood flow obstruction in the blood vessels, and it is an important hemodynamic data to study the diseases such as hypertension and heart failure. Now the TPR is usually measured by the Kubicek' method (or Sramek' method) in the measurement of the cardiac function of Impedance cardiogram (ICG)[1,2]. But many studies have confirmed that the ICG measured by the above methods is a kind of the mixed impedance signal, which mainly evokes from the volume changes of the aorta, blood vessels in lung and ventricles[3,6]. Thus the measurement results obtained with this mixed signal include not only the left heart effects, but also include the right heart effects. This method lacks the uniqueness for evaluating the cardiac function. Many scholars raised disagreement on its theoretical rationality. In order to avoid the above difficulties, the TPR is measured by the reconstructed impedance cardiogram (RICG) and are analyzed statistically for 180 normal adults in this paper.

2 Methods and Materials

2. 1 Calculated method

It is known from the medical physics that the flow rate Q of the fluid is proportional to the pressure difference ΔP at both ends of the pipe and is inversely proportional to the flow resistance R[7], i.e.

$$Q = \frac{\Delta P}{R} \tag{1}$$

If the above formula is used to the circulation system of the human body, the Q should be replaced by the cardiac output, the ΔP is approximately replaced by the mean blood pressure P_m, the R is the total peripheral resistance, so Equation (1) can be rewritten as

$$TPR = \frac{P_m}{CO} \tag{2}$$

It is known from the physics that

$$1\text{mmHg} = \frac{1}{10}\text{cm} \times 13.6\text{g}\cdot\text{cm}^{-3} \times 980\text{cm}\cdot\text{s}^{-2}$$
$$= 1332.8\text{g}\cdot\text{cm}\cdot\text{s}^{-2} = 1332.8\text{dyn}\cdot\text{cm}^{-2}$$
$$1\text{L}\cdot\text{min}^{-1} = \frac{1000\text{cm}^3}{60\text{s}} \approx 16.67\text{cm}^{-3}\cdot\text{s}^{-1}$$

Substituting the above unit conversion relationship into Equation (2) obtaining

$$TPR \approx 80\frac{P_m}{CO} \tag{3}$$

This is the practical formula used to calculating the total peripheral resistance of the systemic circulation of the human body. The coefficient 80 is introduced in the unit conversion. The total peripheral resistance index (TPRI) is also commonly used in clinical practice, and it is equal to the radio of the mean blood pressure P_m to the cardiac index (CI), i.e.

$$TPRI = 80\frac{P_m}{CI} = TPR \cdot BSA \tag{4}$$

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In which the CI= CO/BSA, the BSA is the body surface area, and its unit is m^2.

The average blood pressure P_m in the above equations (2), (3) and (4) can be computed by the followed formula, approximately

$$P_m = \frac{1}{3} \cdot P_s + \frac{1}{3} \cdot P_d \quad (5)$$

In which the P_s is the systolic pressure, and the P_d is the diastolic pressure. The cardiac output CO is the blood volume which is fed to the aorta by left ventricle in one minute, and it is equaled to the product of the stroke volume (SV) and heart rate (HR),

$$CO = SV \times HR \quad (6)$$

2.2 Subjects

The subjects are 180 normal adults aged between 18 and 69 years, and they are divided into three age groups: the youth group (18 to 35 years); middle group (36 to 49 years) and Elder group (50 to 69 years). There are 30 males and 30 females in each age group. All the subjects by asking the medical history, as well as the ECG, blood pressure, heart rate and other tests are normal. The blood pressure requirements: the diastolic pressure, ≤ 85mmHg for the youth group, ≤ 90mmHg for the middle and elder groups; the systolic pressure, ≤ 130mmHg for the youth group, ≤ 140mmHg for the middle and elder groups. In addition, the diastolic pressure is not less than 65mmHg, the systolic pressure is not less than 95mmHg.

2.3 Measurement methods

The impedance signal on the chest surface is detected by means of six leads consisting of 15 electrodes [8], as shown in Fig.1. In which there are 3 cureent electrodes and 12 voltage electrodes.

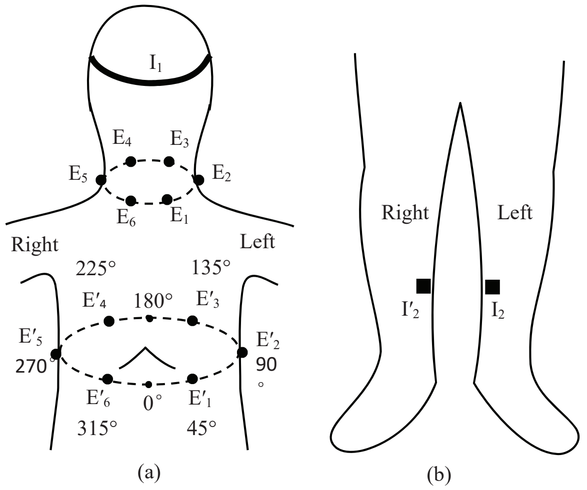

Fig. 1 Placement method of the sening electrodes

The weak high frequency current I_0, with a constant root-mean-square (rms) current, is fed into the human body by means of the current electrodes I_1, I_2 and I_2'. In which the I_1 is located on the forehead, the I_2 and I_2' are located on the left and right lower leg, and the I_2 and I_2' are connected by wires. The voltage sensing electrodes are used for detecting the impedance signals on the chest surface, and all they are the disposable Ag/AgCl electrodes. In which the E_1, E_2, E_3, E_4, E_5 and E_6 are applied to the neck root, and the E_1', E_2', E_3', E_4', E_5' and $E_6'$are applied to the chest surface at the xiphoid level. In addition, the electrodes for sensing the electrocardiogram (ECG) are attached to the right upper arm and to left and the right lower legs. The transducer for sensing the phonocardiogram (PCG) is placed at the position of the cardiac apex on the chest surface.

The instrumentation used in this study was developed by the research group. As shown in Fig. 2, its main parts consist of: an alternating current source, six impedance detection circuits with same structure, an amplifier for the ECG, an amplifier for the PCG, an A/D transform circuit, an isolated source, a computer, each electrodes, as well as the measurement software.

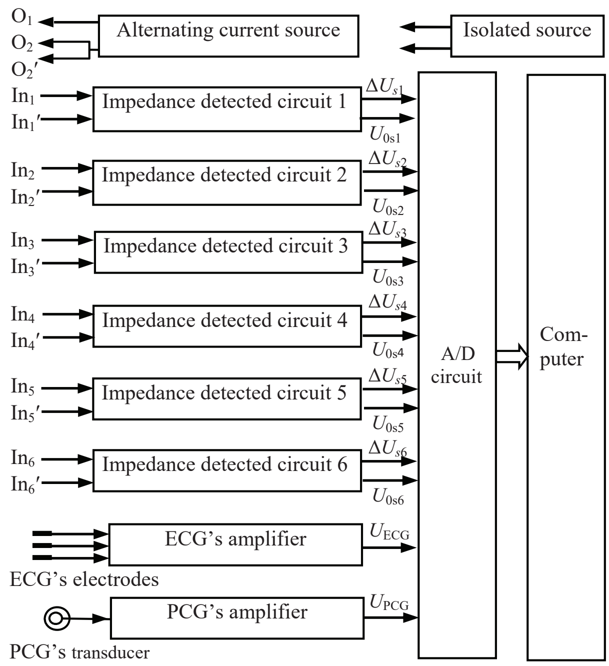

Fig. 2 Block diagram of instrumentation

The subject' body height, body weight, neck circumference, chest circumference, blood pressure and other parameters are measured before the measurement, then they are entered into the computer. The supine position of human body is adopted for the measurement. The subject is asked to hold his/her breath for the duration of the measurement. Then the thoracic impedance changes and base impedances of six leads, as well as the ECG and PCG are collected and displayed simultaneously by the computer. After the waveform collection is ended, the Q wave starting point of four continuous heart beat cycles in the ECG and the corresponding second heart sound S2 of the PCG are selected by means of the artificial operation. The waveform reconstruction of the impedance cardiogram is automatically completed through simplifying and solving the thoracic impedance equations. The waveform parameters of the impedance change components are measured. The TPR and TPRI, as well as other cardiac function data are computed.

3 Results

The TPR and TPRI measured by the above method are computed statistically according to the sex and age groups. The results are shown in Table 1 (In order to analyze expediently, the measured results of the CO, CI and P_m are also listed). It can be seen from Table 1 that:

(1) The TPR and TPRI of the normal adults are increased along with the age augmentation, and there is the significant difference between the young and elder groups (*P*<0.05).

(2) In the same age group, the TPR of the female group is higher than that of the male group (*P*<0.05), but the TPRI of the male and female groups is basically the same (*P*> 0.05).

Table 1 The measurement results of the total peripheral resistance for 180 normal adults ($\bar{x} \pm s$)

Groups	Sex	number	TPR (dyn .s.cm^{-5})	TPRI (dyn .s.cm^{-5}.m^2)	CO (L.min^{-1})	CI (L.min^{-1}.m^{-2})	P_m (mmHg)
Youth	Male	30	1135 ± 130	1882 ± 204	6.17 ± 0.54	3.72 ± 0.34	86.8 ± 5.4
	Female	30	1253 ± 169	1823 ± 248	5.42 ± 0.66	3.72 ± 0.40	83.8 ± 5.5
Middle	Male	30	1183 ± 131	2105 ± 232	6.00 ± 0.61	3.37 ± 0.28	88.0 ± 6.1
	Female	30	1349 ± 163	2044 ± 249	5.15 ± 0.63	3.40 ± 0.39	85.9 ± 5.7
Elder	Male	30	1313 ± 165	2280 ± 249	5.72 ± 0.63	3.29 ± 0.25	93.1 ± 8.4
	Female	30	1457 ± 203	2241 ± 278	5.08 ± 0.50	3.30 ± 0.29	91.6 ± 6.7
Total	/	180	1282 ± 194	2060 ± 301	5.59 ± 0.72	3.47 ± 0.38	88.2 ± 7.1

4 Discussion

The blood is an uneven viscous fluid, and the blood vessels show a certain degree of the resistance when the blood is flowed. This resistance effect is denoted by the flow resistance. The flow resistance R of the vessels are mainly generated from two aspects[9]: First is the friction between the blood and wall of the vessel, and second is the friction caused from the inner relative movement of blood.

According to Poiseuille's law, the flow resistance of the pipe is proportional to the length L of the pipe and the viscosity η of fluid, while is inversely proportional to the fourth power of the pipe radius r. If Poiseuille's Law is used in the systemic circulation of the human body, the flow resistance is the total peripheral resistance TPR (note that it is not an interaction force in the physics and does not have also a force dimension). For a particular individual, the change of the vessel length is very little, so the TPR is mainly determined by the viscosity η of the blood and the radius of the vessel. The physiology shows that the peripheral arteries are the main part of the blood blockage[9], because the flow resistance of the vessel is inversely proportional to fourth power of the pipe radius, and a small change of the inner diameter of the small arterials can make a large peripheral resistance. Therefore, the size of the inner diameter of the small arterials is the main factor affecting the total peripheral resistance. However, the total peripheral resistance cannot be measured directly by means of the vessel length, inner diameter and blood viscosity, and it is usually calculated using the mean blood pressure P_m and the cardiac output CO according to Equation (3).

From the above equations (2) and (3), we know that the TPR is calculated using the mean blood pressure P_m and the cardiac output CO, but the effect of the individual size on the CO is large; hence the total peripheral resistance is also affected by the size of the individual. Generally large the size of an individual is, the lower the TPR is, while the smaller the size of an individual is, the higher the TPR. Thus it is appeared that the TPR of the female group is higher than that of the male group for the normal adults in Table 1. In order to facilitate the comparison between the different individuals, this paper uses Equation (4) to calculate the total peripheral resistance index TPRI. It can be seen from Table 1 that in the same age group, the difference between the TPRI of the male and female groups is small, and the difference of the TPR is large. Thus it can be concluded that using the TPRI is more reasonable than using only the TPR to compare the blood flow resistance in the systemic circulation between the different individuals.

It can be seen from Table 1 that the CO and CI of the population decrease along with the increase in the age, and the average blood pressure P_m increases along with the increase in age, so the TPR and TPRI calculated by Equations (3) and (4) are increased along with increase in the age. These results is consistent with the change laws of the human physiology. In the same age group, there is not the significantly difference between the mean blood pressures of the male and the female groups, but the CO of the female group is significantly lower than that of the male group. Therefore, in the condition that the TPR is

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calculated by means of the equation (3), the TPR of the female group is higher than that of the male group.

According to the measurement results of the TPR and TPRI in Table 1 and the calculation method of the normal value in the medical statistics, it can be obtained that the normal value of the TPR is less than 1650 dyn.s.cm^{-5}, and that of the TPRI is less than 2650 dyn.s.cm^{-5}.m^2.

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