Calculation of the Pulse Wave Velocity from the Waveform of the Central Aortic Pressure Pulse in Young Adults

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Abstract

Cardiovascular diseases are the most common causes of morbidity and mortality in developed countries. Therefore, the correct determination of the parameters indicating the disease condition is critical in effective treatment of patients [6, 10 - 12].

One of the parameters evaluating arterial stiffness is determining the pulse wave velocity (PWV), but the method of determining faces a number of problems.

In the study was measured 20 healthy patients (15-23). Using applanation tonometry was measured pulse wave from a. radialis and a. carotis. PWV was measured by SphygmoCor and calculated by method of flow tringle using aortic pressure pulse for determination PWV.

Average value of PWV calculated by method of flow triangle was 8.35 ± 0.86 m/ s and average value measured by SphygmoCor 7.2 ± 0.8 m/ s. The variance differences of measured and calculated values PWV was 0.785 ± 0.575 m /s. The average value of the a.radialis-a.carotis distance was 485 ± 43.4 mm.

According to the results it can be assumed that the new method of analysis the forward and backward waves is relatively accurate, but it is very sensitive to standardize measurement. The results are affected by several factors, is necessary to propose further steps to accurate protocol for the more precise results.

1. Introduction

Atherosclerosis affects the arterial system of a person from a young age, the rate disability is individual and depends on many factors. At the moment when is atherosclerosis measurable, status of vessels is already in advanced level of rigidity. This advanced status of atherosclerosis could be caused by many changes, which are in clinical practice difficult to qualify [1].

Although arterial stiffness is a process that occurs mainly on the elastic central arteries, morphologically different from the process of developing atherosclerosis [2].

Measuring of pulse wave velocity (PVW) is a method that is used mainly for obtain data on the elasticity of blood vessels. The elasticity of blood vessels is an important parameter of the circulatory system. It induces a state of arteries and their level of arteriosclerotic changes. Risk factors of cardiovascular diseases are the major cause of arteriosclerosis and indicators formation of myocardial ischaemia, cerebral ischaemia and increased central pulse pressure, which leads to heart failure. When is found a reduced elasticity of the arteries, it is necessary to think over the other symptoms in connection with cardiovascular diseases and metabolit syndrome. These conditions reduce the quality of life of the patients and in the final stage can result in death. PVW can also be used for clinical studies ascertaining the cause, for example, some types of hypertension [3].

Pulse wave is mostly measured on major arteries (a. carotis and a. femoralis), but also on a. radialis, the place depends on using method. In our case, we use applanation tonometry for measuring intravascular heartbeat on a. radialis and a. carotis [6].

One of the methods for the calculation of PWV is a mathematical analysis of the pulse wave distribution. The method determines carotid-radial pulse transport time (PTT) of radial pressure waves, which is transformed to obtain waveform central pressure of certified transfer function. Central aortic pressure wave is spread over forward and backward waves using uncalibrated triangle of aortic flow [4].

2. Materials and methods.

Pulse wave velocity measurement is used for classifying arterial stiffness and auxiliary indicator of cardiovascular risk for cardiovascular disease.

Aortic PWV is determined noninvasively by measuring the pulse transit time (PTT) over a known distance of the aortic trunk. [2]. There are several methods for detecting arterial pulse. Sometimes it is used Doppler ultrasound probe placed at the aortic arch and subclavian artery and femoral artery, it is also possible to use mechanical transducers. Carotid and femoral pulses are recorded simultaneously (Complior device, Artech Medical), or are recorded sequentially using one probe, and carotid-femoral PTT provided together with the ECG recording (it is necessary to capture the R wave, in order to obtain PTT) [2].

This principle use device SphygmoCor, which we use as a comparative method for our measurement. The aim of this study was obtained from the measured central aortic pressure waveform and PTT without using ECG.

2.1. Mathematical ground

The measured time-varying pressure wave, $P_m(t)$, can be expressed as a sum of forward [$P_f(t)$] and backward [$P_b(t)$] waves [4-5] :

$$P_m(t)= P_f(t)+ P_b(t) \quad (1)$$

Because reflected waves increase pressure but decrease flow, similarly, measured flow [$Q_m(t)$] is the algebraic sum of forward [$Q_f(t)$] and backward [$Q_b(t)$] flow [4-5]:

$$Q_m(t)= Q_f(t)-Q_b(t) \quad (2)$$

From transmission line analysis, $P_f(t)$ and $P_b(t)$ can be obtained from $P_m(t)$ and $Q_m(t)$ and characteristic impedance, Z_c [4-5] as follows:

$$P_f(t)=0.5(P_m(t)+Z_c\, Q_m(t)) \quad (3)$$

$$P_b(t)=0.5(P_m(t)-Z_c\, Q_m(t)) \quad (4)$$

P_m (t) may be obtained from the transfer function of the pressure wave of the radial artery using the transfer function of the radial artery.

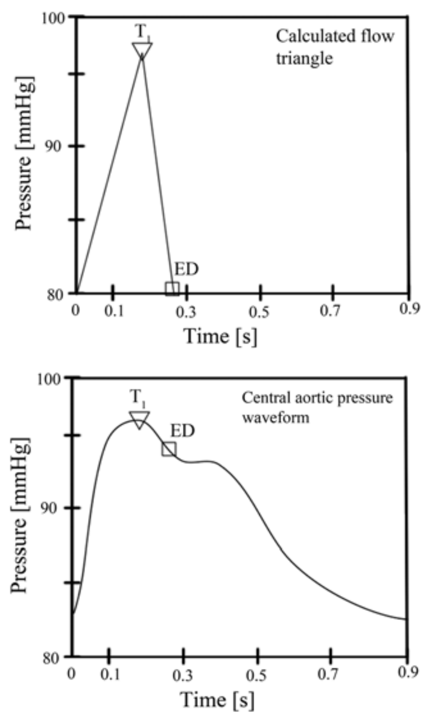

Figure 1. Central aortic pressure waveform. T_1 presents the time of the first systolic peak and ED presents ejection duration. Those points are essentials for construction the top and the base of the flow triangle.

$Q_m(t)$ is construct as a triangle wave flow with the maximum value in the first systolic peak T1 and the base has length of the ejection duration (ED) (Figure1) [7].

T1 and ED are obtained as a derivation of the aortic pressure wave. T_1 is obtained from the time index of the digital values of the vector containing the derivatives of the ascending aortic pressure wave. It is calculated from the first negative 0 crossing (in the direction from positive to negative) in the first derivative. If 0 is crossing and is not currently before the peak pressure waves, T1 is calculated from the positive (in the direction of negative to positive) 0 crossing of the second derivative [4].

In all the analyzed data, this algorithm was able to determine (identify) T1 value of all the waves.

The input impedance Z_{in} (which is need for calculation of Z_c) is calculated as a function of frequency of Fourier decomposition.

PTT is obtained from the value of the maximum lag (TR2) determined from the cross-correlation of the modified waves $P'_b(t)$ and $P_f'(t)$ normalized to the same amplitude (Figure 2). [10]

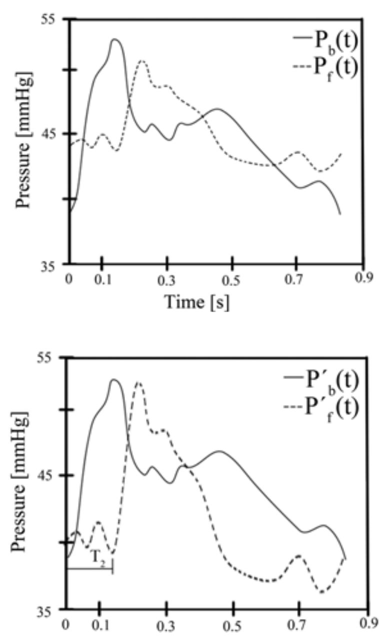

Figure 2. Constructed $P_b(t)$ and $P_f(t)$ must by normalized to the same amplitude (lower graph). T_2 is a delay between the estimates of forward and backward waves.

TR2/2 was compared with the measured carotid-radial transit time. The normalization process was made so as to avoid inconsistencies because of different magnitudes of relative scales of the forward and backward waves. This procedure ensured that all of the pairs of waves were analyzed in an identical manner. Because of the algebraic relationship between flow and pressure components following 1 and 4, and because flow is 0 during diastole, the values of forward and backward waves during diastole are identical. [4]

3. Results

From the results of the cross-correlation od $P'_b(t)$ and $P_f'(t)$ can be determined PTT as half of relative displacement where is the maximum correlation value, and according to equation (5) can be calculated PVW (Figure 3):

$$CR\_PWV = \frac{CR\ dist}{TR2/2} \quad (5)$$

CR_PWV stands between pulse wave velocity and a.carotid and a.radialis. CRdist is the distance between the suprasternal a.radialis hole and the distance between the suprasternal hole and carotid artery TR2/ 2 is actually worth PTT.

Average value of PWV calculated by method of flow triangle was 8.35 ± 0.86 m / s and average value measured by SphygmoCor 7.2 ± 0.8 m / s. The variance differences of measured and calculated values PWV was 0.785 ± 0.575 m / s. The average value of the a.radialis-a.carotis distance was 485 ± 43.4 mm.

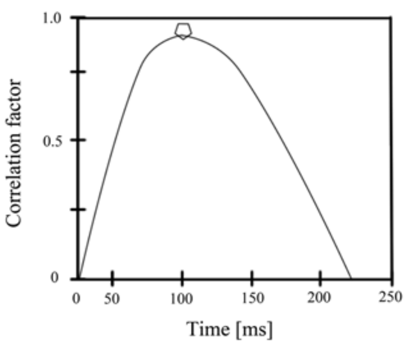

Figure 3. The cross correlation of od $P'_b(t)$ and $P_f'(t)$. The time lag is obtained from the maximum correlation.

4. Discussion

Although there are already many methods for measuring the pulse wave velocity, it is very important to constantly refine measurement because it is still not achieved a satisfactory estimation accuracy PWV. One possibility is deleting parameters entering measurements such as ECG.

The study have shown that decomposition of the central aortic pressure wave can be used for aortic PWV estimates. As has been shown derived central aortic pressure, can be applicable to other measures of aortic pressure, such as direct measurement, or indirect measurement, such as the use of the carotid pressure or diameter waveform as a surrogate measure of the aortic pressure pulse.

5. Conclusions

A new noninvasive method to determine the aortic PTT has been proposed and validated with independent noninvasive measurements of CR-PTT. The method can be used as an examination for aortic PWV.

6. Perspectives

According to the results it can be assumed that the new method of analysis forward and backward waves is relatively accurate, rapid, non-invasive and patient-friendly. But the method is very sensitive to standardize measurement and require precise distance measurements that show up as a parameter which most affects a false result.

Acknowledgements

We cordially thank to Professor Natasa Honzikova, Physiology department MU, Brno for allowing us to use devices and laboratories.

This publication was written at Masaryk university as part of the project „ KASBUCPAC (Kardiovaskulární systém od buňky k lůžku pacienta)", MUNI/A/1326/2014. with the support of the Specific University Research Grant, as provided by the Ministry of Education,

Youth and Sports of the Czech Republic in the year

"Supported by European Regional Development Fund – Project FNUSA-ICRC (No.CZ.1.05/1.1.00/02.1023)"

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