VERIFICATION OF PHONOCARDIOGRAPHIC METHOD USING STETHOSCOPES TO DETERMINE PULSE WAVE VELOCITY

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Abstract: In this primary study the sensitivity of the proposed PCG measuring method of pulse wave velocity estimation is verified. As a reference method the commercial measuring system of the pulse wave velocity SphygmoCor® (SPH) was used. Both methods are noninvasive. Electronic stethoscopes were used as phonocardiographic signal transducers in the PCG method. The SPH method is intended to measure arterial pressure pulse from the human body surface. Four volunteers were examined in this study, divided in groups of healthy objects and objects with hypertensive disease.

Introduction

Pulse wave velocity (PWV) in the systemic arterial tree is an indicator closely connected to the condition of the cardiovascular system [1]. Non-invasive measuring techniques offer an efficient and simple way to obtain the indicator – PWV. The PWV measurement is not a standard cardiovascular examinational method. Commercial systems of the PWV measurement are mainly based on the evaluation of each one of the pulse wave (PW) periods of pressure curves [2] recorded non-invasively on palpable arteries on human body. This way of PW sensing requires special transducers. These systems are relatively expensive, which is an obstacle of their expansion to the general practitioners' offices. Therefore it can not be widely used as an early diagnostic method. Another possible way how the PWV can be estimated is sensing the manifestations of pulsating arteries on human body surface. For this purpose standard medical equipment – stethoscopes can be used with advantage (so-called PCG method), for more details see [3].

Materials and Methods

The proposed PCG method [3] which is based on the non-invasive phonocardiographic (PCG) signal measurement is verified using a reference method – commercially available device SphygmoCor® [4] (let us mark this method as SPH). The PCG signals were sensed using two electronic stethoscopes. Another of information sensed in this study was ECG signal, see Fig. 1. SPH method is based on non-invasive pulse pressure measurement used for the pulse wave velocity (PWV) estimation. The *PWV* is calculated in the same manner in both cases as

$$PWV = \frac{d_D - d_P}{t_{PD}}, \qquad (1)$$

where d_D – distal distance is a true distance between the jugular pit (fossa jugularis) and the distal sensing point – right femoral artery (at a groin), d_P – proximal distance is the true distance between the jugular pit and the proximal sensing point on the right common carotid artery (a. carotis communis dex.), and t_{PD} is the time the pulse wave needs to get from the proximal to the distal sensing point.

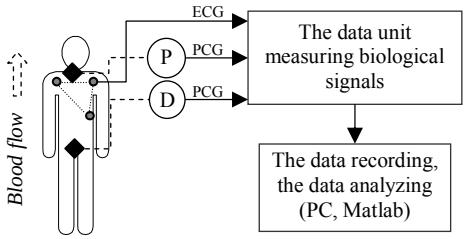

Figure 1: The block diagram of the PWV experimental measurement. P – proximal, D – distal PCG transducers (electronic stethoscopes) complemented by the three-lead ECG.

The distance is determined using this method because the position of jugular pit is clearly and exactly localized on human body. On the contrary, the more precise length, i.e. the exact length of arterial path between sensing points, can not be non-invasively and easily measured. The resulting time t_{PD}, see Tab. 1, was determined as a mean value of argument of maximum of cross-correlation functions of the measured PCG signals, envelopes of these PCG signals, see Eq. 3, and average realizations of PCGs – from the right carotid and right femoral arteries, see Fig. 2 and Eq. 4, in the PCG method. In the reference pressure pulse measurement the t_{PD} was determined by an argument of 10% height of the pressure pulse curve (in each heart beat), more details elsewhere [4].

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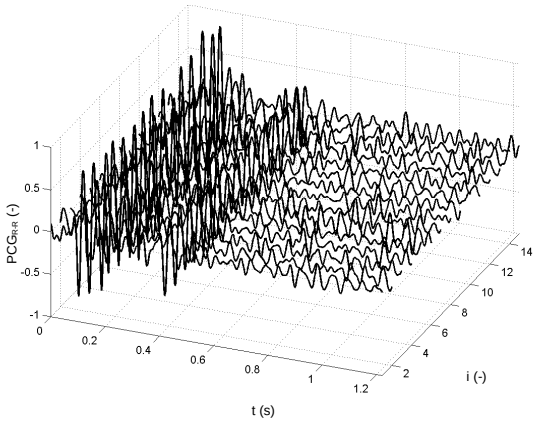

Figure 2: Demonstration of several realizations of normalized proximal PCG signal

The cross-correlation function of measured PCG signals was calculated as [5]

$$R_{P_P-P_D}(\tau)=\frac{1}{2T}\sum_{t=-T}^{T} PCG_P(t)\cdot PCG_D(t+\tau), \qquad (2)$$

where t and τ are discrete time variables, T is the length of the PCG signals, i.e. PCG_P – the proximal and also PCG_D – the distal PCG signal. The cross-correlation function of the signal envelopes is calculated by Eq. (2) using the PCG signal envelope, which is designated for each PCG signal by relation [5]

$$V_P(t)=\sqrt{PCG^2(t)+\hat{PCG}^2(t)}, \qquad (3)$$

where $\hat{PCG}$ is a Hilbert transform of the PCG signal and t is the discrete time.

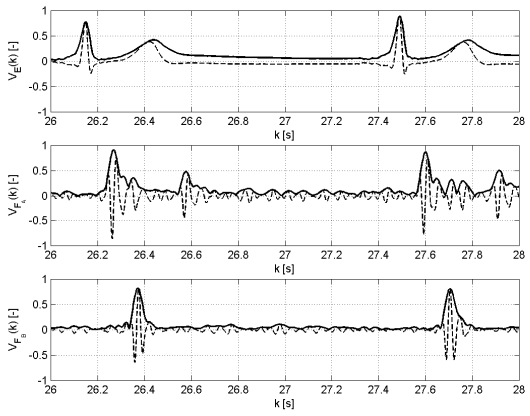

Figure 3: Demonstration of the envelopes of the measured signals, from the top: envelope of the ECG signal, envelope of the proximal PCG and distal PCG signal.

The cross-correlation function of average R-R intervals (an average R-R realization, see Fig. 4) of PCGs is also calculated by Eq. (2), however, using the mean PCG interval, which is designated by relation

$$\overline{PCG}_{R-R}(t)=\frac{1}{L}\sum_{i=1}^{L} PCG^{i}_{R-R}(t), \quad 0\le t\le T_{\min}, \qquad (4)$$

where $T_{\min}$ is the length of the shortest R-R interval which were found in the ECG signal. All the others R-R realizations of PCGs were shortened in the value $T_{\min}$.

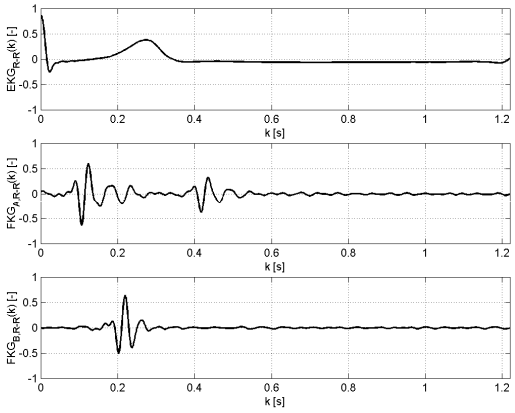

Figure 4: Demonstration of the average R-R realizations of the measured signals, from the top: R-R interval of the ECG signal, R-R interval of the proximal PCG and distal PCG signal.

The time t_{PD} can be subsequently found from the calculated cross-correlation function by

$$t_{PD}=\arg\max R(\tau). \qquad (5)$$

Pulse wave velocities PWV mentioned in Tab. 1 obtained by the PCG method were computed as average values of the data obtained using the three correlation methods mentioned above. PWV_m are average values of all given velocities PWV in both methods, i.e. verified method – PCG and the reference one – SPH, see Tab. 1.

$$PWV_m=\frac{1}{N_{obj}}\sum_{i=1}^{N_{obj}} PWV_i, \qquad (6)$$

where an index i denotes the number of the object and N_{obj} denotes the number of objects in the whole examined group ($N_{obj}=4$), i.e. healthy objects together with hypertensive one. The standard deviations $Std\ PWV_m$ where calculated as [6]

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$$Std\ PWV_m = \sqrt{\frac{1}{N_{obj}-1}\left(\sum_{i=1}^{N_{obj}} PWV_i - N_{obj}\cdot PWV_m{}^2\right)}. \quad (7)$$

An average value PWV_S of PWV obtained by different methods (PCG and SPH) in each examinational group (healthy and hypertensive) was determined by Eq. (8) and listed in Tab. 2.

$$PWV_S = \frac{1}{N_g}\sum_{j=1}^{N_g} PWV_j, \quad (8)$$

in which an index j denotes the number of object in the selected examined group and N_g is the number of objects in the group (for both groups $N_g = 2$). Standard deviation $Std\ PWV_S$ was then calculated as [6]

$$Std\ PWV_S = \sqrt{\frac{1}{N_g-1}\left(\sum_{j=1}^{N_g} PWV_j - N_g\cdot PWV_S{}^2\right)}. \quad (9)$$

This study was accomplished on four male volunteers of mean age 41.8 ± 10.4 years. All of examinants were divided into two experimental groups: the first one contained two healthy objects and the second one contained examinants with diagnosed hypertensive disease. Increased value of the pulse wave velocity is typical for hypertensive disease.

Results

The values of the pulse wave velocities PWV of each of the examinants measured by two methods – PCG and SPH (referential method) are listed in Tab. 1. There is also the mean value PWV_m calculated, see Eq. (6) and its standard deviations, Eq. (7), for both methods across the examinational groups.

Table 1: Values of PWV [m·s^{-1}], i.e. mean values across the methods in each of the object

Met.	Object *i*				PWV_m [m·s^{-1}]
	1	2	3	4	
	healthy		diseased		
PCG	5.9±0.4	4.8±0.2	10.5±0.2	10.2±0.2	7.9±2.9
SPH	6.4±0.2	4.8±0.2	8.0±0.5	10.4±2.5	7.4±2.4

The discrepancy between the values of PWV_m of both methods is 0.5 m/s.

The average values of PWV_S of each experimental group (healthy and hypertensive) for each of the measuring methods are listed in Tab. 2. The PWV_S was determined by Eq. (8) and standard deviation by Eq. (9). The final values PWV_S show that the difference of these values for the PCG method is 5.1 m/s and for the SPH method is 3.6 m/s.

Table 2: The values of PWV_S [m·s^{-1}], i.e. mean values for each group of objects (healthy, diseased)

Method	Object *i*			
	1	2	3	4
	healthy		diseased	
PCG	5.3±0.8		10.4±0.2	
SPH	5.6±1.1		9.2±1.7	

Discussion

The difference of the values of PWV_m of both methods, i.e. PCG and SPH, is 0.5 m/s. From this result it can be concluded that both methods used in this study give analogous results, i.e. that the difference between the results of measurements using the two methods is not significant. The difference of PWV_S values for the PCG method is 5.1 m/s and for the SPH method is 3.6 m/s. From these results it can be demonstrated that the measuring method PCG can be considered sensitive to changes in a cardiovascular system associated with the hypertensive disease.

These preliminary findings of this primary study were expressed on the basis of the results calculated from a small data set. For more accurate results the analysis should be carried out on larger data set.

Conclusion

The sensitivity of the proposed PCG measuring method of the pulse wave velocity [3] was verified in this primary study. Two electronic stethoscopes were used as phonocardiographic signal transducers in the PCG method. Four male volunteers of 41.8 ± 10.4 years of age were examined in this study. The objects were divided into groups of healthy and hypertensive ones with two objects in each experimental group. Commercial measuring system of the pulse wave velocity SphygmoCor® (SPH) was used as a reference method [4]. The SPH method is intended to measure the arterial pressure pulse from the human body surface. Both measuring methods are noninvasive.

The values of the pulse wave velocity PWV of each of the objects obtained by these two methods are listed in Tab. 1 together with the mean value PWV_m. The difference of the PWV_m values was 0.5 m/s. It means that the difference is not significant. The average values of PWV_S of each examinational group for each measuring method are listed in Tab. 2. The resulting PWV_S values show that the differences 5.1 m/s for the PCG method and 3.6 m/s for the SPH method are significant. Thus, measuring method PCG can be considered sensitive to changes in the cardiovascular system associated with the hypertensive disease. These preliminary results were calculated from a small data set in this primary study so they cannot be generalized.

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