An evaluation of Arterial Stiffness Index in Relation to the State of the Cardiovascular System

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Abstract— **The study deals with an evaluation of correlation between an Arterial Stiffness Index and a state of the cardiovascular system. The main goal of the research is to show whether the ASI is an appropriate parameter for CVS state classification. The statistical evaluation of the dependency of the ASI on the CVS state and other parameters has been done using the linear regression analysis and the t-test of mean values. The ASI has been correlated with the age of the patient, the blood pressure (low/normal/high), the mean arterial pressure and the presence both of the cardiovascular diseases and diabetes mellitus. For the evaluation the signal database which consists of signals from more than 90 persons in wide age range (from 20 to 94 years) has been used. It has been proved that the ASI depends on the age of the patient, on the MAP and on the presence both of the cardiovascular diseases and diabetes mellitus in the study. Only the correlation between the ASI and blood pressure (low/normal/high) has not been directly proved. Although the results are statistically significant, the study shows the limitations of ASI as a CVS status marker. The ASI is a suitable parameter for primary screening, but it should be complemented by additional parameters for increased reliability.**

Keywords— **arterial stiffness index (ASI), hemodynamic parameters, oscillometry pulsations, cardiovascular system, atherosclerosis**

I. INTRODUCTION

It is widely known that diseases of the cardiovascular system (CVS) are among the most common causes of death in the developed countries. Many of these diseases are age-related and closely connected with suboptimal regimen. The typical implication of the bad regimen is arteriosclerosis, the deposition of the fat on vessel walls which results in the loss of vessel walls elasticity. The final outcome of the arteriosclerosis could be a life threatening situation such as thrombosis, stroke injury or heart attack. Unfortunately, it is very difficult to diagnose the arteriosclerosis early and to begin an appropriate treatment. In this context it is shown as a key to find suitable and easy assessable markers which will have a provable correlation with the arteriosclerosis. [1]

There are a many studies which deal with a description of CVS biomechanics and with a classification of the state of CVS, for example [2–6]. One of the interesting parameter which could closely correlates with the state of the CVS is arterial stiffness.

In clinical practice, there are several different methods for assessment of the arterial stiffness. Unfortunately, most of them are not sufficient for daily clinical practice due to a need of specialized or expensive medical devices such as ultrasound or MRI. There are only a few parameters which could be determined without specialized devices. From this point of view, it is important to look for parameters which could be assessed for example during the common investigation of the blood pressure. Typically, in case of oscillometry measurement of blood pressure, the oscillometric pulsations are measured and could be stored for a subsequent processing. Based on these pulsations – typically from a change of the amplitude of the pulsations or from an envelope of the signal – some hemodynamic parameters could be assessed, for example Pulse Wave Velocity (PWV), Augmentation Index (AI) and Arterial Stiffness Index (ASI). [7] This paper deals with the ASI and with the investigation whether it is possible to use ASI as a marker of CVS state.

In popular literature, for example in [8], the ASI is explained as a measure of the loss of elasticity in the arteries that occurs with onset of vascular disease and advancing age. In the theory, the ASI is a number that correlates with arteriosclerosis, which is a condition in which fatty material collects along the walls of arteries.

In fact, the ASI is as a simple measure which could be determined non-invasively without a specialized measuring device. [9] For the ASI assessment it is only necessary to store the signal of oscillometric pulsations during the blood pressure measurement [10–14] and to investigate the signal envelope.

II. Methods

The main goal of the research is to study the dependency of the ASI on the CVS state and other parameters and to identify whether the ASI is an appropriate parameter for CVS state classification.

A. Assessment of Arterial Stiffness Index

The ASI is defined as a rate of oscillometric pulsations increase during the decreasing of the pressure in the cuff. The increase of the pulsations is represented as a steepness of the pulsations envelope.

For the research, the signal of oscillometric pulsations has been cleaned up from a noise and artefacts and the drift of isoline has been eliminated firstly. A typical behaviour of the signal and the signal after filtration are shown on the Fig. 1.

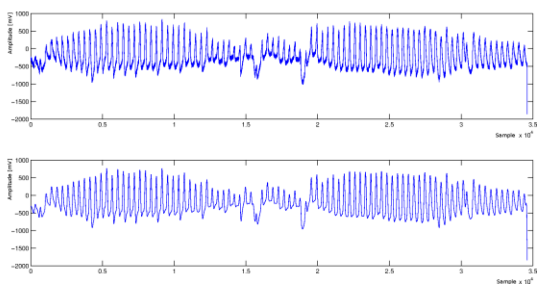

Fig. 1 A typical record of oscillometric pulsations during inflating and deflating of the cuff; a raw signal (above) and the filtered signal (below)

In the second step, the envelope of the signal has been determined. The amplitude of the signal has been computed as a difference between each subsequent maximum and minimum of the signal (see black crosses on the Fig. 2) and the envelope has been computed using the polynomial fit (blue curve).

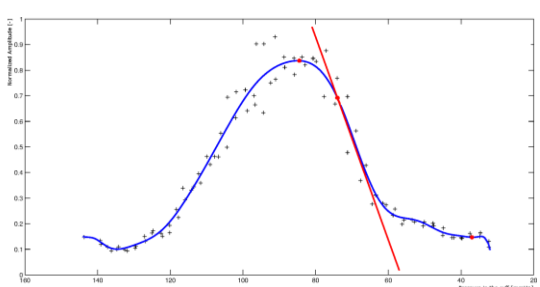

Fig. 2 An assessment of the ASI: the amplitude of the signal derived from the maximums and minimums of the signal (black crosses), a typical pulsations envelope (blue curve), points of inflexion (red points) and a steepness of the pulsations (red line)

Finally, the ASI is determined as a steepness of the oscillometric pulsations. The inflexion points have been determined (Fig. 2, red points) and the slope of the tangent has been computed (red line). On the vertical axis of the Fig. 2 there is a normalized voltage (or the pressure, it is the same in this meaning). As the slope of the straight line, the physical unit of the ASI is $mmHg^{-1}$.

B. Statistical Evaluation

The relationship between the ASI and other CVS and patient parameters the statistical evaluation has been used. Each correlation has been proved or disproved based on the linear regression analysis and/or the t-test of mean values. The null hypothesis for linear regression was H_0: ASI is independent on the compared parameter, the null hypothesis for t–test was H_0: mean values of ASI in two different groups are the same. The level of significance was 5 % for both tests.

III. Signal Database

The study of the ASI was performed on the oscillometric signals database. The database has been collecting in the author's workplace and consists of oscillometric, electrocardiography (ECG) and photoplethysmography (PPG) signals from different persons. All signals from one person were measured synchronously. The signal database actually includes signals from more than 90 persons in wide age range. The signals were measured on two main groups of persons, in young healthy people aged from 20 to 26 years (average age 23.1 ± 1,7 years; mean ± SD; university students) and in elderly people aged between 53 and 94 years (average age 83.9 ± 7.9 years; seniors in one of the Prague's senior houses).

Each record in the database is supplemented with a set of patient data obtained from a personal questionnaire. Thus the database consists also the information about the age, gender, height and weight of the patient, the information about the presence of cardiovascular diseases and presence of diabetes, the information about the blood pressure, smoking, drugs and other important facts which could be associated with the state of the CVS.

The database offers sufficient width of various signals which represents all types and behaviours of oscillometric signals. [15]

IV. Results

The correlation of ASI was analyzed for a couple of papaparameters.

The first one was an age of the patient. The age of the patient is a natural image of the CVS age, and closely correlates with the state of the CVS. The dependency between ASI and age was performed both using regression analysis and t–test. The equation obtained from the regression analysis is

$$\mathrm{ASI} = 0{,}025 \cdot \mathrm{age} + 1{,}16 \cdot 10^{-4} \quad (1)$$

and the p–value is $3{,}89 \cdot 10^{-10}$. It follows that ASI and the age are statistically dependent. The box–plots of the ASI for young and elderly people are shown on the Fig. 3. The mean values of the ASI are 0,014 for youngs and 0,023 for the elderly, the p–value from the t–test is $1{,}03 \cdot 10^{-7}$. It follows that the mean value of ASI in young and elderly are statistically not the same.

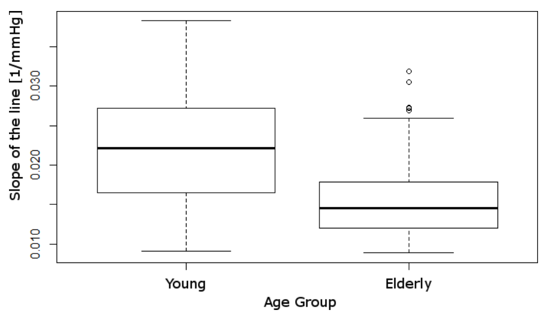

Fig. 3 ASI v. age for young and elderly people

The second parameter in which the correlation with the ASI was performed was the blood pressure. The ASI was examined for the people with the low, normal and high blood pressure, the box–plots are shown on the Fig. 4. The ASI is independent on the blood pressure. Although the mean values are different, the variances are too large.

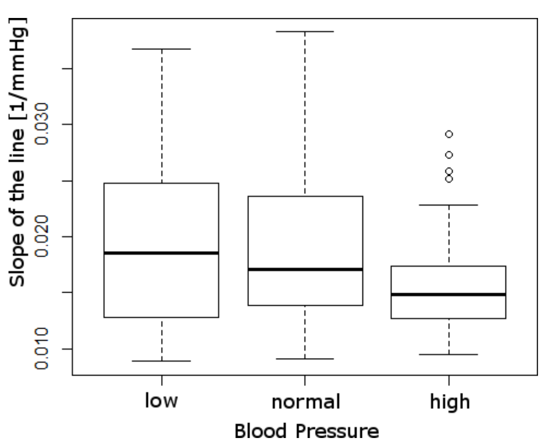

Fig. 4 ASI v. blood pressure for low, normal and high blood pressure

The correlation with the mean arterial pressure (MAP) [16, 17] was investigated for each person separately. The equation resulting from the regression analysis is

$$\mathrm{ASI} = 0{,}039 \cdot \mathrm{MAP} + 2{,}2 \cdot 10^{-4} \quad (2)$$

and the p–value is $5{,}96 \cdot 10^{-9}$. It means that the ASI depends on the MAP, even though the correlation between the ASI and the blood pressure obtained from the questionnaires has not been proved.

Finally, the dependency between the ASI and the presence of a cardiovascular disease or diabetes was studied. The box–plots are shown on the Fig. 5 (cardiovascular diseases) and 6 (diabetes mellitus). In both case, the ASI is statistically dependent on the presence of the disease, for cardiovascular diseases the p–value is 0,011 and for the diabetes the p–value is 10^{-4}.

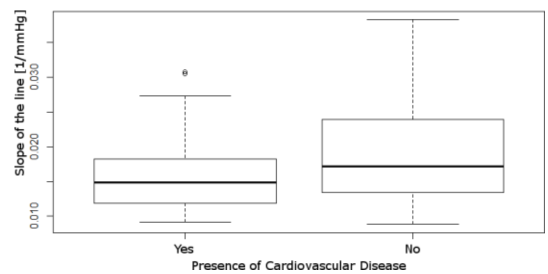

Fig. 5 ASI v. presence of cardiovascular diseases

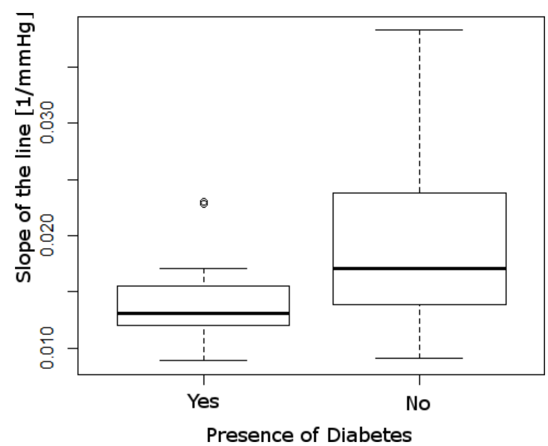

Fig. 6 ASI v. presence of diabetes

V. CONCLUSION

The study of the correlation between the ASI and several parameters describing the health state of the patient has been done. It has been proved that the ASI depends on the age of the patient, on the MAP and on the presence both of the cardiovascular diseases and diabetes mellitus in the study. Only the correlation between the ASI and blood pressure (low/normal/high) has not been directly proved. It could be stated that the older and the more sick patient seems the smaller ASI. It shows that the ASI could be used as a marker for primary screening of CVS state especially for the primary screening of the atherosclerosis.

Although the results were statistically significant, measured variances were quite large. This indicates a possible lack of precision measurement and evaluation, and may limit the interpretation of results.

The study shows the limitations of ASI as a CVS status marker. The ASI is a suitable parameter for primary screening, but it should be complemented by additional parameters for increased reliability.

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