Statistical Estimate on Indices Associated to Atherosclerosis Risk

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Abstract— **A statistical analysis based on the estimate of the linear correlation between two significant health indices is performed here, in support of a noninvasive method suited for circulatory disease prognosis and diagnosis. The pulse wave velocity, evaluated by signal acquisition and processing, and several personal data, easily collected from the subject, enter the statistical analysis. The study was performed on a sample of 52 randomly chosen persons and was extended to sub-groups identified by specific characteristics. The results confirm an already known public health trend: wrong habits and lifestyle reflected by the increased incidence of obesity in young generations will contribute in the near future to the expansion of circulatory disease.**

Keywords— **biomedical signals, statistical analysis, circulatory assessment, noninvasive investigation.**

I. Introduction

Circulatory disease is an important concern in nowadays preventive medicine, because it is highly sustained by wrong cultural and lifestyle habits. It has disastrous health and social consequences for individuals and their entourage while forcing the health care system to significant financial effort. Civilized populations suffer, more and more, and even from early ages, of Arteriosclerotic Vascular Disease (ASDV) syndrome, more frequently called *atherosclerosis*, caused by the accumulation and integration into the arterial wall of atheroma (cells and residue with high lipid content). They originate in fats received from food, and start to accumulate from the first years of life. However, the magnitude of the phenomenon varies widely from a person to another, depending on several particularities of the lifestyle, which set a personal mark on quantifiable physiologic and somatic parameters.

Noninvasive medical investigations (electrocardiographic and pulse signals) correlated with the relevance of several personal characteristics (age, sex, body size, health status) and habits (selection of food, smoking, exercising) could give a proper forecast toward the development and perspective of circulatory disease for an individual. Our research work originated in a statistical study aimed to find and sustain quantitative relations among personal indices associated to health.

Electrical activity of heart is quantitatively represented by electrocardiographic (ECG) recordings; the wave of electrical depolarization and repolarization of cardiac excitable cells propagates through electroconductive heart tissue and triggers the mechanical activity of the myocardium. The ventricular systole (R-S-T sequence on the ECG signal recording) corresponds to the contraction of the heart ventricular muscle, as Fig. 1 illustrates. Myocytes contraction pushes a volume of blood through arteries; from the left ventricle, the blood spreads into the whole body, through aorta and subsequent arteries, in the systemic circulation. It is considered that the R peak represents the beginning of blood pumping out from the heart.

The pumping action determines a pressure wave on the arterial walls, which is propagated to the periphery of the circulatory system. The blood pressure increases on the systolic period and decreases on the diastolic period (the period of ventricle muscle relaxation). In this way every systole determines a propagating pulse of increased pressure on arterial walls.

Pulse Transit Time (PTT) is the time it takes the pulse pressure waveform to propagate through the length of the arterial tree; it is directly conditioned by the traveling speed of blood pulse. PTT is affected by various factors, like heart contraction strength, blood pressure, elasticity and cross-section dimension of arteries, pathological conditions, drugs administration, etc. On the other hand, PTT is proportional to the length of the traveled pathway and its value is considered a physical measure of the circulatory system state. It has the advantage to be identified during a relative simple and noninvasive investigation, which is easily accepted by the patient and suitable for clinical purpose [2, 3].

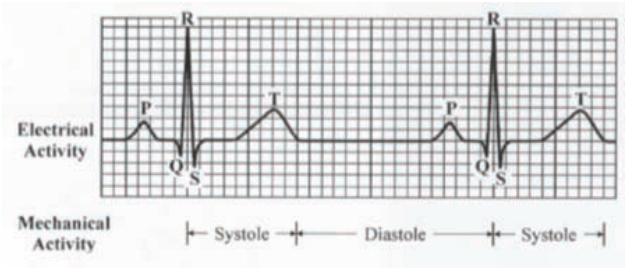

Fig. 1. Correlation between symbolic ECG signal and mechanical activity of the heart [1]

Besides a proper heart activity or an arterial good state, the length of the arterial circuit is a primary factor that affects PTT value, when estimated on a certain anatomical branch of the circulatory tree. The arterial length is thus seen as a somatic feature, irrelevant as a quantitative index related to the health and functionality of the circulatory system. A better quantification and more realistic information may come from the Pulse Wave Velocity (PWV). PWV is computed by rating the distance traveled by the pulse wave between two well determined positions on the arterial tree, to the time interval between two registered biosignals (marked by the pulse at each location).

As a general physiology law, based on fluid biodynamics, the PWV value is inversely related on the arterial wall elasticity. It could be assumed that PWV increases with the cholesterol concentration in blood (atherosclerosis) and possibly with the arterial stiffness (caused by medial calcification and loss of elasticity); this is usually related to subject's age and senile arterial degeneration. The evolution of the aortic injury could be followed by hypertension and increased risk of heart failure. Aortic PWV is frequently considered as a marker of cardiovascular risk independently of blood pressure level, but in conjunction with heart rate.

There are opinions expressed in scientific literature, that PWV generally increases with the age [4]. This simplistic statement was invalidated by a previous study conducted by our team [5] and is further discussed here.

The investigation algorithm followed by our study may give, in the same time, information on the heart rhythm variability and average pulse.

II. Material and Methods

The study presented here follows an acquisition and analysis protocol applied to each of the 52 subjects that enrolled voluntarily in the program. The total number of participants exceeds the minimal dimension of the relevant sample, determined through statistical tests (single mean and single proportion) [6, 7].

The subjects (23 females and 29 males), with ages between 10 and 80, are considered to have a normal health status (particularly free of any diagnosed circulatory disease). More than half of the participants were students, randomly chosen to be integrated in that study. Before the acquisition of the biosignals, during the accommodation period, participants were asked to provide some personal data (age, body weight and height, current medication if any, emotional state, the habitude of smoking and physical exercising); their arterial blood pressure and pulse were also measured at the beginning of the test with a digital monitor. The measurements were performed in a laboratory, in a quiet environment, while the subjects had a relaxed sitting position. Further measurements were performed only after pulse and blood pressure were stable at each subject's regular values.

As previously described, PWV estimate needs a PTT evaluation; ECG signal and peripheral pulse photoplethysmography (PPG) recordings are necessary. We used a portable MP30/35 BIOPAC acquisition system [1], set to simultaneously record ECG Lead I and PPG signals, as shown by the image in Fig. 2.

The two recording locations are: (1) the heart – where the pulse is associated to the R peak on the ECG signal, and (2) an endpoint of the arterial circuit, i.e. one fingertip – where the pulse is effectively captured through a photoplethysmography transducer [1, 3]. The arterial circuit length (AL) is defined here as the metric distance from the heart to the endpoint of the arterial circuit. AL is an individual somatic index that was measured and recorded with the other previously mentioned personal data.

During the RR period, one maximal value occurs on the pulse waveform. PTT is determined by the measurement of the time interval between the peak of the QRS complex and the following peak, which occurs on the pulse waveform, as the signals recording illustrates in Fig. 3. The acquisition is set to 2 kHz sampling rate, for the best identification and localization of peaks. The recordings were made for intervals of approx. 100s, but the analysis was performed on a 30 s interval of stationarity, usually chosen from the last part of the acquisition. The instantaneous heart rate (BPM) and its mean value were automatically computed from the ECG waveform.

Several processing techniques were applied for the automatic detection of the instants when the peaks occur. The signals were processed in order to enhance the peaks, comparative to the other amplitudes of the signals and the "find all peaks" command of the BSL Pro software [1] was applied to both ECG and PPG derived signals.

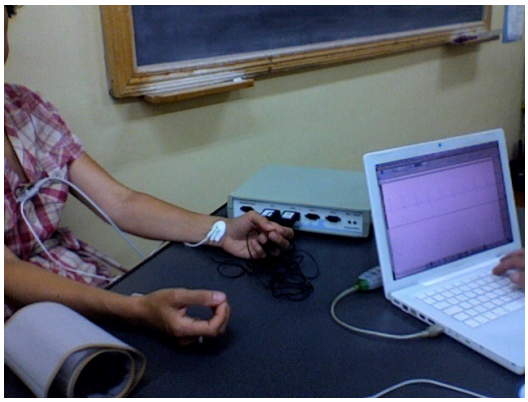

Fig. 2. ECG and PPG portable recording system (BIOPAC MP30/35)

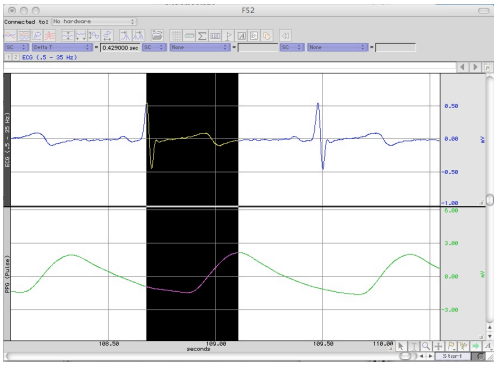

Fig. 3. ECG and PPG recordings (Biopac Student Lab Pro software window) [1]

The identified instant values were transferred in an arithmetic worksheet and the PTT-time series was determined as a succession of delays measured between the pairs of peaks. PTT over the 30 seconds sequence was averaged and PWV for each subject was computed and recorded in the database. A manual identification of peaks and measurement of delay intervals, combined with the morphologic analysis provided by BSL Pro was also applied, as a supplementary checking, for several samples randomly selected from the recordings. In that way, the automatic processing was satisfactorily validated.

The PWV-time series was easily computed afterwards, by dividing each PTT value to the subject's own AL.

III. Results

An arithmetic worksheet is primarily filled with each subject's personal data: sex, age, body mass index (BMI = body weight / height^2) and the determined value of the PWV as described earlier (as an example, see Table 1 with two randomly selected samples).

Table 1. Arithmetic worksheet with personal and health related data

sex	age	BMI [kg/m^2]	PWV [m/s]
f	24	16.8	2.314
m	38	35.1	2.983
…	..	…	…

The groups that were individually analyzed are: (1) all 52 investigated cases, (2) the young people category (31 persons with ages between 20 and 25 years), (3) the 23 female subjects and (4) the 29 male subjects.

Data were primarily analyzed for compliance with the normal distribution; the performed Kolmogorov-Smirnov test shows indices higher than 0.9 [6] for each sample, that reveals very good adequacy of all defined groups to the Gaussian distribution. For each sample we computed statistical parameters like: lowest / highest / median value, arithmetic mean, standard deviation, relative standard deviation, standard error for the mean; 95% confidence interval for mean and median were also estimated.

Several statistical tests were afterwards performed for the assessment of correlation of the PWV indices with other physiologic characteristics.

Our analysis was first oriented to find if any positive correlation exists between the PWV and the age, as claimed in [4]. Linear correlation coefficient r was computed [7, 8] for the first sample of subjects (52 persons, different as age and sex) and the results show, paradoxically in appearence, that *PWV and age are negatively correlated* ($r = -0.412$) (Fig. 4). This result is influenced by the large weight of young people, having a wide dispersion in the PVW values. Our previous study [5], performed on a smaller sample, only 37 subjects, with ages more uniformly spread in the range 10 to 80 years found *no significant correlation* between PWV and age. Apparently contradictory results reveal, in fact, a lack of significant conditioning of the age on the PWV and suggest that other individual indices may explain the increase of PVW values as a signal for the ASDV diagnosys.

The linear correlation was applied to evaluate another relationship between personal indices. PWV and BMI, applied to the same group of 52 subjects, were chosen for this test. We observed that the higher PWV values are related to higher BMIs; Fig. 5 displays the distribution of data. The linear correlation coefficient $r = 0.293$ (with the null hypothesys probability $0.01 < p < 0.05$) was this time found to indicate that *PWV and BMI are positively correlated* for the whole sample of 52 subjects.

More interesting results are revealed by the analysis of the second group, the young persons (31 subjects), with ages in the range 20-25 years. The linear positive correlation between PWV and BMI is stronger at this time ($r = 0.605$, with $p < 0.001$), as Fig. 6 shows.

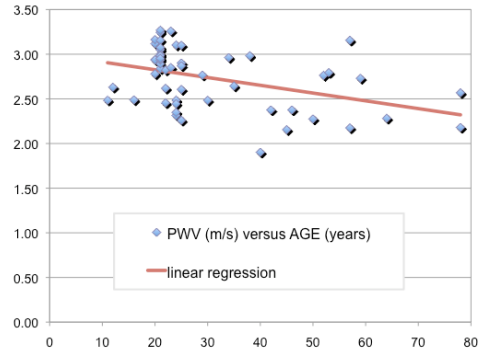

Fig. 4. Correlation analysis between PWV and AGE, for the population under investigation (52 persons, with ages between 11 and 78 years)

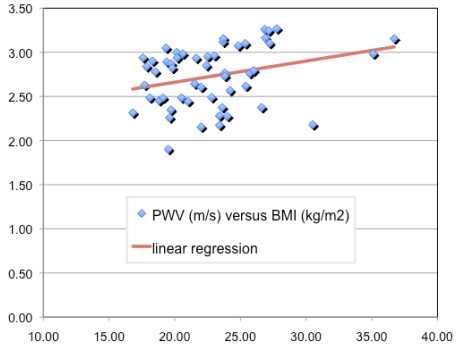

Fig. 5. Correlation analysis between PWV and BMI, for the whole population under investigation (52 persons)

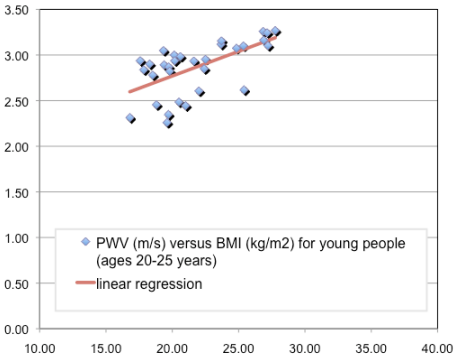

Fig. 6. Correlation analysis between PWV and BMI, for the young people (31 persons, with ages between 20 and 25 years)

Similar analysis performed on the two groups identified by gender does not reveal any significant novelty; the male group, however, displays a higher linear correlation coefficient between PVW and BMI, than the female group.

IV. Conclusions

The study presented here investigates statistical correlations among health related indices, as a quantitative evaluation of the arterial wall integrity. The Pulse Wave Velocity through the arterial tree is the measured physiological quantity. PWV was determined by processing two physiologic signals, simultaneously acquired: the ECG (Lead I on the Einthoven triangle) and the pulse captured with a photoplethysmography sensor at the left-hand ring finger. A statistical estimate was conducted on a sample randomly composed by 52 persons, both male and female, with ages in the range 10 - 80 years.

The correlation between PWV and age was found irrelevant in our research, but the positive correlation between PVW and the Body and Mass Index is confirmed and supported by our results on the whole group of persons under test, but especially on the sub-group of young people (students), ages between 20 and 25 years.

Despite the conservative opinion, supported also by studies presented in scientific literature, that the PWV is directly related to the age, we found a more complex relation. The PWV becomes higher as a natural mechanical effect of the wall stiffness rise, generally known as atherosclerosis, which is not necessarily age conditioned. Atherogenesis, the main cause of PWV rise involves accumulation of fatty substances into the arterial wall. Ageing is not the dominant cause of plaque accumulation in the arterial wall, but this process is more dependent on modern unhealthy lifestyle - bad habits in nutrition and sedentarism, which especially affects young generations.

The further development of the research will take into consideration the extension of that analysis methodology, both by the enlargement of the database, and by exploring other adequate mutual relations among health indices.

Acknowledgment

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References

1. Biopac Student Lab (BSL) Pro –Reference Manual Version 3.7.2 for Biopac Student Lab PRO Software and MP30/35 Hardware - © BIOPAC Systems, Inc. 2005
2. Payne R. A., Symeonides C. N., Webb D. J., Maxwell S. R. J., (2006) "Pulse transit time measured from the ECG: an unreliable marker of beat-to-beat blood pressure", Journal of Applied Physiology, 100(1):136-41
3. C.H. Tang, G.S. Chan, P.M. Middleton, A.V. Savkin, N.H. Lovell, (2009) "Spectral analysis of heart period and pulse transit time derived from electrocardiogram and photoplethysmogram in sepsis patients", Conf Proc IEEE Eng Med Biol Soc.1:1781-4.
4. Byeong C. C., et a., (2004) "Evaluation of Arterial Compliance on Pulse Transit Time using Photoplethysmography", The 30th Annual Conf. of the IEEE Ind. Electron. Soc., Busan, Korea
5. Machedon A., Ipate M.C., Morega M., (2009) "Noninvasive Evaluation of the Arterial Wall Elasticity", 2nd Intl. Conf. on e-Health and Bioengineering - EHB 2009, Iasi-Constanta, Romania
6. MedCalc - V 10.4.8 - © 1993-2009 MedCalc Software bvba
7. Wayne W. D., (1996) *Biostatistics*, *A Foundation for Analysis in the Health Sciences*, 6th Edition, John Wiley
8. Dragomirescu L., (1998) *Biostatistics* (in Romanian), Constelatii Publishing House, Bucharest

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