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Analysis of Correlation Between Heart Rate and Blood Pressure

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***Abstract*—The paper presents an analysis of correlation between heart rate (HR) and blood pressure (BP). The actual data were obtained from three female and one male. The systolic and diastolic blood pressure was measured with the invasive method in the radial artery. The correlation coefficient indicates only linear dependence, so the inverse of HR was also taken into account. Since the measurements can be corrupted by noise the moving average filtering and trend analysis for all data was done. The results of the correlation analysis of this filtered data were similar to results obtained for raw data. The observed correlation coefficient between HR and BP (systolic and diastolic) for whole available data seems a random number. However the short-term correlation is relatively large (about 0.5), but rather unpredictable, since even sign of the correlation coefficient is changing.**

I. Introduction

OUR goal is to monitor value of blood pressure (BP) in elder people at their homes. Such measurements are made using non-invasive technique. However, such measurements are made rarely and a time interval between two successive measurements is relatively large. Thus, some serious events may be overlooked. It would be very useful and desirable to develop a method allowing continuous monitoring of BP. Such method may use information gained non-invasively, e.g. about heart rate (HR) or length of the RR interval. We would like to know if knowledge of one of these parameters allows us to estimate value of BP. We are not interested in cohort correlation between HR (or length of RR interval) and BP, rather we are interested in such correlation for individuals. We are not interesting in the relation between variability of HR and BP also. However, such models have been already proposed [1], [2]. There is a publication [3], which reports that resting HR is associated to clinic BP over the whole range of BP values and has been observed at any age. Moreover, the correlation is positive and is stronger for systolic than diastolic values of BP. The strong positive correlation between BP and HR was also reported in [4]. There is also report that exercise-induced increase in systolic BP was positively correlated with resting systolic BP, whereas the correlation of exercise-induced HR increase with resting HR was negative [5]. The correlation between BP and HR is also reported in [6], for men and women. However, the dependence was much stronger for men than for women. We would like to verify all of these studies for applicability of using HR to predict BP values in our project devoted to home assistance for elders and disabled.

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II. Materials and Methods

The data were obtained from monitoring of four persons: three female at age of 47, 52 and 70 and one male at age 86. Physiological data recordings were performed using the S5 DATEX/OHMEDA system for monitoring critically ill patients. Digital data were transferred by the serial port to Computer Information System developed in Department of Hyperbaric Medicine and Sea Rescue. The measurements included diastolic and systolic values of pressure. The arterial BP (measured invasively in the radial artery), central venous pressure (measured invasively in a close proximity of the right atrium of the heart) and non-invasive BP (measured from pressure oscillations of the cuff placed on the upper arm) where recorded. HR, arterial BP and central venous pressure were measured, on average, each 30 seconds, while the non-invasive BP was measured, also on average, each 30 minutes.

The correlation coefficient for HR and arterial pressure (systolic (SBP) and diastolic (DBP)) measured using invasive method was calculated. Since the correlation coefficient describes only linear dependence the calculations were repeated for inverse of HR and arterial pressure. The relation between HR and 1/HR is nonlinear, thus we can observe correlation in one case and no correlation in another one.

Patients were monitored only for few days. To obtain more reliable results the invasive BP measurements were correlated with HR, since the number of samples was about 60 times larger in comparison to non-invasive BP measurements. Invasive arterial BP measurements were chosen, since theirs values were similar to non-invasive measurements.

Three different approaches were tested. First one was based on correlation between raw data. Since the measurements could be corrupted by noise (for example patient movements or rounding of HR and BP values to the nearest integer by measurement system) the signals were also correlated after performing a filtration procedure. A moving average (MA) with equal weights, thus a very simple low pass filter was used. The filter lengths were 3, 4, and 5 samples and did not introduce too much smoothing. Another approach was based on least squares approximation. The increase and decrease of BP value was considered. As an indicator of such changes the parameter *a* from the linear least square fitting of HR and BP ($y=ax+b$) could be used. It indicated trend of signals. The fitting was done for each signal separately, and the correlation analysis was performed for *a* coefficients. The *a* coefficients were calculated for 3, 4, 5, 6, 8, and 10 successive samples. It prevented from missing short-term changes, since such short-time changes might be interested in many applications. This procedure was repeated for all successive samples similarly as in the case of MA filtration.

The HR and BP were measured regularly each 30 seconds, however in some cases the measurements where done more often, while in some cases less often. Such changes could indicate medical intervention. So the samples where divided into groups of continuous measurements done each 30 seconds. However, each group could have different length (different number of samples). We decided to make analysis taking into account groups, which length was not less than 50 samples. To check if the size of the groups was influencing the correlation coefficient, the second analyze was done for groups, which length was not less than 100 samples. The correlation coefficient *r* and *p*-value (the probability of getting a correlation as large as the observed value by random chance, when the true correlation is zero) were calculated for each group of measurement samples for all patients.

III. RESULTS

All figures show example results of analysis for groups of samples of length not less than 100 samples. Fig. 1 shows SBP dependence on HR. The correlation coefficient was equal to 0.901 ($p<0.001$). Fig. 2 shows results of MA filtration (DBP versus HR). The correlation coefficient was equal to –0.708 ($p<0.001$). Fig. 3 shows coefficients *a* for SBP dependence on coefficients *a* for HR. The correlation coefficient was equal to 0.669 ($p<0.001$). The change of the correlation coefficient with time for SBP dependence on HR after MA filtration is shown in Fig. 4. Corresponding values of *p* for the correlation coefficients presented in Fig 4 have a large distribution (Fig. 5). However, it appears that the lower value of *p* the higher correlation between data (Fig. 6). First 46 correlation coefficients in Fig 6 have $p<0.01$, while first 48 $p<0.05$. However, correlation is both positive and negative.

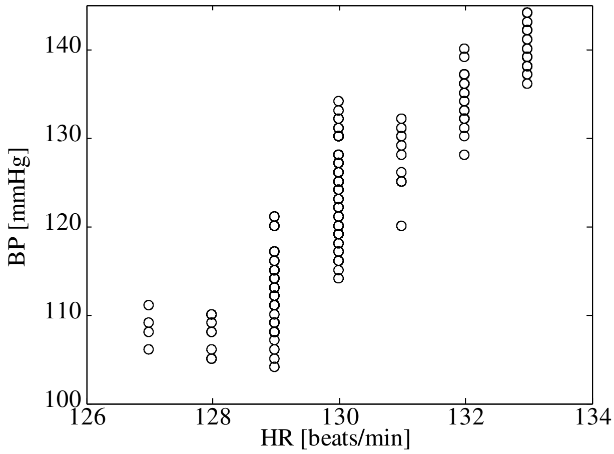

Fig. 1 SBP vs. HR

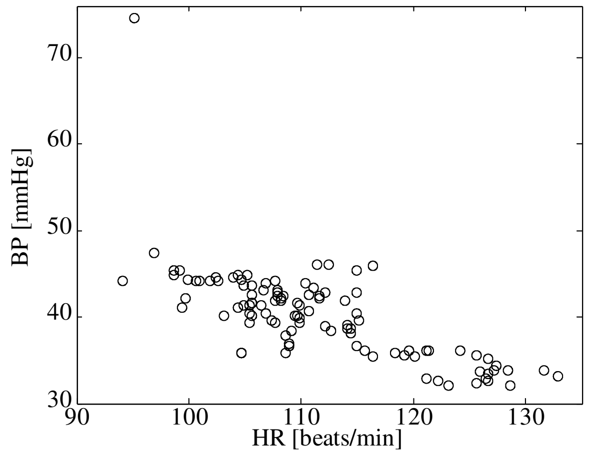

Fig. 2 DBP vs. HR after MA filtering (filter length equal to 4)

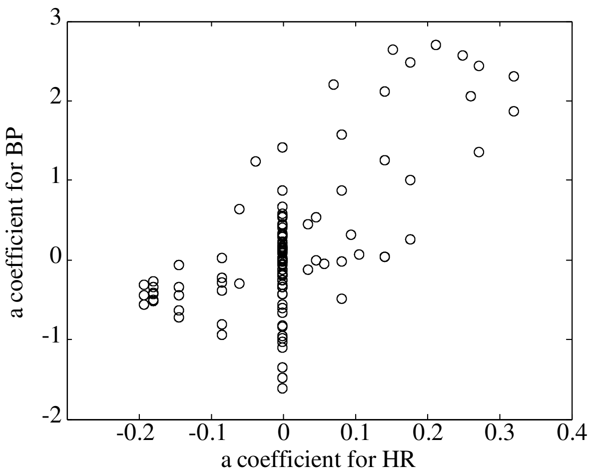

Fig. 3 Results of trend calculation for SBP vs. HR (8 successive samples taken into account)

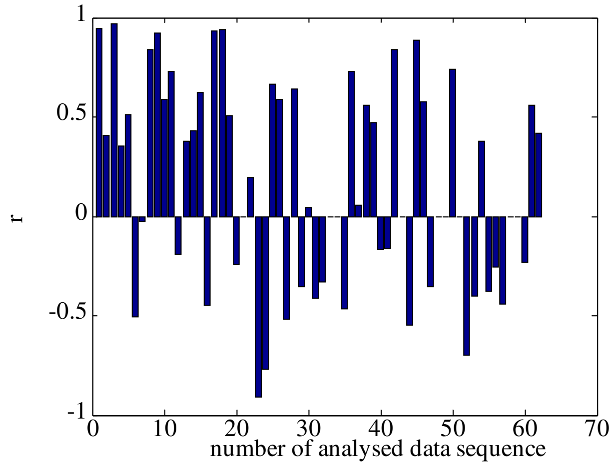

Fig. 4 The correlation coefficient *r* between filtered SBP and filtered HR for successive sequences. HR and SBP are processed using MA filter of length equal to 5

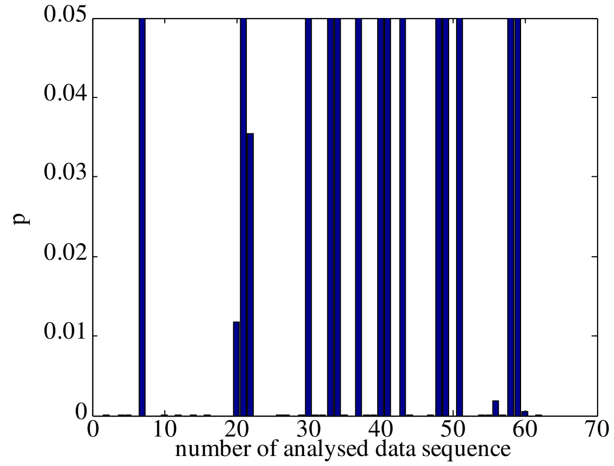

Fig. 5 The *p* values corresponding to the correlation coefficients presented in Fig. 4

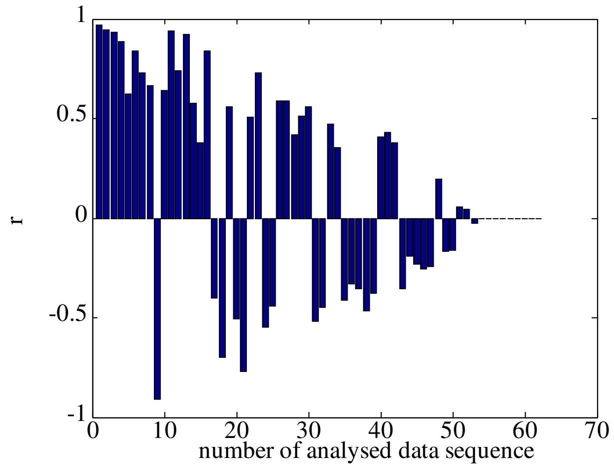

Fig. 6 The correlation coefficient *r* from Fig. 4 sorted from lowest to largest value of *p*

IV. Discussion

Different types of analyses were performed in the study. The properties of raw data, filtered (using MA filter of different length) were analyzed. The trend analysis for different number of samples used in calculation of coefficient "*a*" was also performed. It follows from our study that correlation coefficient is not constant. The value of coefficient is accidental and different for data sequences analyzed. However, it has been found that if there is correlation between HR and BP, then such correlation with opposite sign is between 1/HR and BP. It follows from the fact, that a function $f(x)=1/x$ is nonlinear, but for relatively small interval far from 0 it can be well approximated by straight line. The obtained results show that he correlation coefficient is a good measure of dependence between HR and BP. All observed dependences' were linear or no dependence was observed. No nonlinear dependence was observed.

Assuming that the sequence of data contained at least 100 samples the 20 to 60 correlation coefficients were obtained for each patient and for each type of test performed. This number was larger for shorter sequences (as sequences containing at least 50 samples were also examined). Only the correlation coefficients with $p<0.05$ were considered for further analysis. Because of a relatively large number of coefficients their average value was also calculated. Moreover, average value of the absolute values of the correlation coefficients and theirs variances for each patient and each type of study were calculated. The relative numbers of the significant ($p<0.05$) correlation coefficients were also calculated in each study. The comparison between results for SBP and DBP and for series of at least 50 and 100 samples were conducted.

First, the average of the correlation coefficients and average of theirs absolute values for all patients were calculated. These values were calculated using the average patient's value. The variance between patients has also been considered and the resulting remarks from this examination are presented in the following paragraph.

The average correlation coefficient for HR and BP was about 0.2, but the difference between maximum and minimum value was even about 0.6. As can be seen in Fig. 4 there is very large variation in the correlation coefficients' for each patient. The results for DBP had smaller variation than for SBP. It is interesting that taking into account absolute value of the correlation coefficients the average value is much higher and depends on type of data (correlated parameters). Observe that correlation coefficients having low absolute value have not been significant (Figs. 4 - 6). Absolute values of correlation coefficients were calculated for SBP versus HR and DBP versus HR basing on raw data. Then, the average values were evaluated and they were, respectively, 0.45 and 0.4. This value increased to 0.5 for SBP after applying MA filtration and remained almost constant independently on the filter length. It was in opposition to correlation between HR and DBP where the result was dependent on filter length and changed from 0.45 to 0.48. Trend analysis has shown an increase in the average of the absolute values of the correlation coefficients with number of samples taken into account for the calculation of the *a* coefficient (from 0.30 to 0.40 for SBP and DBP). A little larger variance in the absolute values of the correlation coefficients was observed for SBP.

In the following analysis the variance of the correlation coefficients for each patient is considered. It shows how the correlation was changing with time of data collecting from patients. The variance of the correlation coefficient for SBP and DBP was similar (a little bit lower for DBP). The lowest variance was obtained for trend analysis, while the largest one for MA filtering. The variance was increasing with the length of the filter (for MA) and number of samples taken into account for the calculation of the *a* coefficient.

The ratio of significant ($p<0.05$) to not significant correlation coefficients depended on the type of analysis (raw data, MA filtered, and trend analysis). The values for DBP were about 10% higher than for SBP. The larger number of significant values was obtained for MA analysis and the ratio grew along with the filter length (from 0.66 to 0.71 for SBP and from 0.73 to 0.77 for DBP). A smaller number of significant values was obtained for trend analysis. However, an observed dependence was not monotonic (values from 0.43 to 0.56 for SBP and 0.48 to 0.60 for DBP). Moreover, there was large interpersonal dependence – the ratio changes even from 0.2 to 0.7 for the same method but different persons for SBP. For DBP the variances were smaller.

Influence of the number of samples utilized in the correlation analysis on results obtained is discussed in the following paragraph. Two types of data were compared – containing 50 and more samples to these ones having at least 100 samples. There was no dependence of average value of the correlation coefficient on the length of the data sequence taken into account. In some patients the correlation coefficient was decreasing and in some cases increasing. It was more stable for DBP, while for SBP very large changes for 2 patients were observed. It can be explained if we look at the Fig. 4. It follows from this figure, that one can expect that average value of the correlation coefficient is a random number. However, comparison of the average of the absolute values of the correlation coefficients showed that in most cases this value was decreasing for longer sequences (similarly for SBP and DBP, 10 % on average and it is not dependent on the method of analysis – raw data, MA filtering, trend analysis). Similar results were obtained for variance analysis, but the decrease was even larger – about 20 %. As it can be expected the number of significant correlation coefficients ($p<0.05$) increases in general with increasing sequence length. Similar results for SBP and DBP, like in the previous cases, not dependent on the method of analysis – raw data, MA filtering, trend analysis, were observed. The average increase was 10 %.

Finally, the correlation coefficients between HR and SBP or DBP measured invasively for all data and for each patient were calculated. All the correlation coefficients were significant ($p<0.05$). The correlation coefficients for HR and SBP were equal to 0.30, 0.31, -0.10, and -0.24 for subsequent patients, while for HR and DBP they were respectively -0.02, 0.14, -0.29, and -0.10. The number of measurements for each patient varied from 8451 to 21248 for each parameter. It suggests that a long-term correlation is rather a random number, as can be expected from Fig. 4.

A medicine taken by the patients and interventions of medical doctors could change cardiovascular relationships, thus also our results. Unfortunately, there was no included any information on any medical treatment or interventions in the data. Maybe the low correlation was observed after drug administration, so taking into account such data may allow predicting BP values for HR. However, it should be remembered that elderly people are taking medicines regularly even non-prescribed by physician.

V. Conclusion

The observed correlation coefficient between HR and BP (systolic and diastolic) for whole available data seems a random number. However, the short-term correlation is relatively large (about 0.5), but rather unpredictable, since even sign of the correlation coefficient is changing.

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