Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Can the Timing-Characteristics of Phonocardiographic Signal be Used for Cuffless Systolic Blood Pressure Estimation?

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Abstract—**Continuous and non-invasive measurement of blood pressure (BP) is always important to critically ill patients. To achieve continuous and cuffless BP monitoring, pulse transit time (PTT) has been reported as a potential parameter. Recently a novel parameter RS_2 (defined as the time interval measured from the R wave of electrocardiographic (ECG) signal to the peak of second heart sound of phonocardiographic (PCG) signal) is proposed for the same purpose.**

In this study, the relationship between systolic BP (SBP) and PTT as well as the relationship between SBP and RS_2 on 25 healthy subjects, aged 24±3 years, were compared after exercise. The results in current study showed that SBP is correlated with both PTT and RS_2, where the mean individual correlations are r=-0.95 and r=-0.85 respectively. The mean standard deviation of the differences between the measured SBP and the SBP predicted from the regression lines in scatter plots of SBP~PTT and SBP~RS_2 are 4.1 mmHg and 7.2 mmHg respectively. In summary, the results showed that RS_2 is possible to be used for continuous and non-invasive monitoring of SBP after exercise. In the future, it is important to investigate more robust techniques for locating characteristic points on the PCG signals.

I. INTRODUCTION

CONTINUOUS monitoring of blood pressure (BP) is always important to critically ill patients. Existing tools are usually limited to provide continuous but invasive monitoring of BP. Previous literatures reported that pulse transit time (PTT) was a potential parameter to provide continuous and non-invasive BP monitoring. Several researchers revealed that PTT was inversely correlated with systolic BP (SBP) individually [1]-[3].

PTT is usually recorded as the time delay from the R wave of electrocardiographic (ECG) signal to the upstroke of a peripheral pulse wave signal [4], wherein photoplethysmographic (PPG) signal is a popular choice of the pulse wave signal. Recently, a novel parameter RS_2 was proposed as an alternative to PTT for BP measurement and the results showed that BP was correlated with RS_2 [5].

In order to compare the capabilities of PTT and RS_2 on SBP estimation, the relationship between SBP and PTT as well as the relationship between SBP and RS_2 are studied after exercise. Fig. 1 illustrates the definitions of the PTT and RS_2. Namely, PTT and RS_2 are the time intervals measured from the R wave of ECG signal to the foot of PPG signal and to the peak of second heart sound of phonocardiographic (PCG) signal respectively.

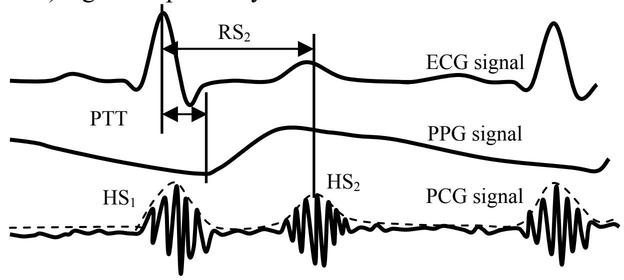

Fig. 1. An illustration shows the definitions of PTT and RS_2 (HS_1 and HS_2 refer to the first and second heart sound respectively).

II. MATERIALS AND METHODS

Experiment was conducted on 25 healthy subjects, aged 24±3 years. All subjects were not diagnosed with any chronic diseases. An in-house-designed circuitry with sensors was used to detect ECG and PPG signals while an electronic stethoscope (Model 5079-400, Welch Allyn, USA) was used to detect PCG signal. The signals were sampled at 1 kHz and recorded simultaneously for 45 seconds. SBP was measured by an automatic BP machine (Model HEM-907, OMRON, Japan) while exercise was carried out on a treadmill (Model C956, Precor, USA).

Fig. 2 shows the procedure of the experiment. At the beginning of the experiment, subjects were asked to sit down and rest for 3 minutes. BP measurements were conducted on the subject before and after recording the first set of signals (T1). Subjects were then directed to run on the treadmill at 10km/h for 3 minutes. Immediately after running, BP measurements and the signal recording (T2) were carried out. After resting for 3 minutes, subjects ran on the treadmill at a lower speed, 8km/h, for 3 minutes. BP measurements and signal recordings were carried out immediately (T3), 18 minutes (T4) and 43 minutes (T5) after the second running.

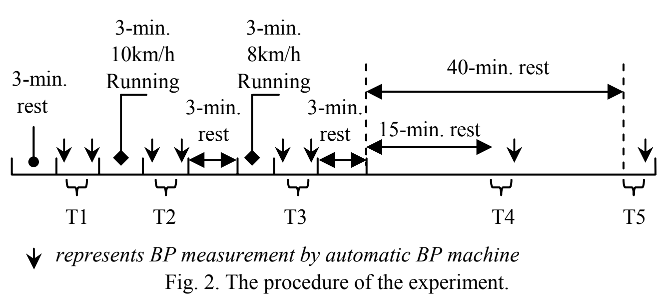

Fig. 2. The procedure of the experiment.

This work is supported by the Hong Kong Innovation and Technology Fund. The authors would like to acknowledge Jetfly Technology Ltd., Golden Meditech Company Ltd., Bird International Ltd. and Bright Steps Corporation for their supports to the study.

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III. RESULTS

Fig. 3 shows the variations of the mean PTT, RS_2 and SBP. Both PTT and RS_2 vary inversely with respect to the mean values of SBP. The coefficient of variation (CV) of PTT is always smaller than that of RS_2, where the CV of RS_2 becomes larger after exercises. The means of RS_2 almost double the means of PTT.

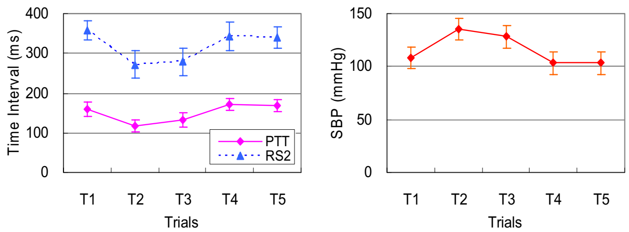

Fig. 3. The variations of the mean PTT, RS_2 and SBP.

Fig. 4 depicts the scatter plots of SBP~PTT and SBP~RS_2. Regression lines are fitted to individuals. SBP is inversely correlated with PTT and RS_2, where the mean individual correlations are r=-0.95 and r=-0.85 respectively.

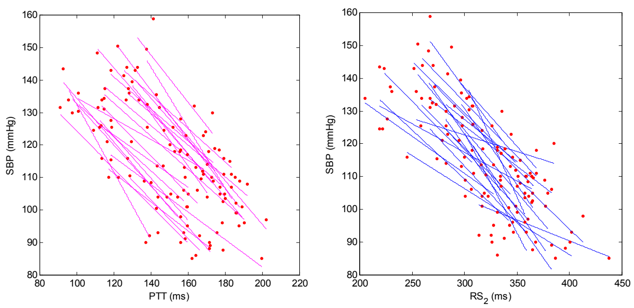

Fig. 4. The scatter plots of SBP against PTT (left) and RS_2 (right).

Fig. 5 reveals the standard deviations of the differences between the measured SBP and the SBP predicted from the linear regression lines in the scatter plots of SBP~PTT and SBP~RS_2. When SBP is predicted from PTT and RS_2, the mean standard deviations of the differences between the measured and predicted SBP are 4.1 mmHg and 7.2 mmHg respectively. The standard deviations of the differences are usually larger if SBP is predicted from RS_2.

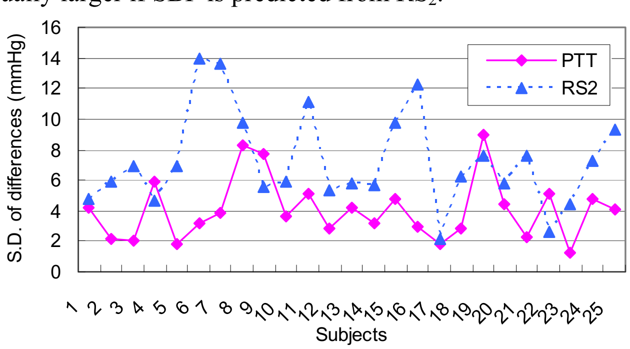

Fig. 5. The standard deviations of differences between the measured and predicted SBP in each subject (S.D. stands for standard deviation).

IV. DISCUSSION

Previous literatures usually showed that PTT is linearly correlated to BP and it is a potential parameter to provide continuous BP measurement [1]-[3]. Zhang and Zhang recently proposed using RS_2 for the same purpose and reported that the correlation between SBP and the reciprocal of RS_2 was larger than 0.88 [5]. This study compared the capabilities of PTT and RS_2 on SBP estimation and found that predicting SBP from RS_2 have larger deviation than that from PTT after exercises.

The large deviations resulted from the RS_2-approach is possibly associated with the deep breath after exercises. Compared with PPG signal, deep breath immediately after exercises may affect PCG signal more pronouncedly than it does on PPG signal. The deep breath may induce the variation of contacting force between the measuring site and the sensor which has been shown to affect the waveform of PPG signal [6] [7]. The same applies to the collection of PCG signal, but since the sensor for collecting PCG signals is manually hold onto the chest wall of the subject, it is expected that the variation in contacting force will be greater. Moreover, the noise induced from deep breath may override the heart sound and result in noisy PCG signal. As a result, the effects of deep breath may induce unavoidable error on the peak detection of PCG signal when it is acquired immediately after exercises.

V. CONCLUSIONS

Experiment was conducted on 25 healthy subjects, aged 24±3 years, to compare the capabilities of PTT and RS_2 on SBP estimation after exercises. The preliminary results indicated that the correlation between SBP and RS_2 (r=-0.85) was not as high as that between SBP and PTT (r=-0.95). Larger mean standard deviation of the differences is resulted from the RS_2-approach but the difference is considered to be acceptable. To conclude, the study further confirms using RS_2 for providing continuous monitoring of SBP is possible. In the future, it is important to investigate more robust techniques for locating characteristic points on the PCG signals.

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