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The Changes in Pulse Transit Time at Specific Cuff Pressures during Inflation and Deflation

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***Abstract*—The changes in pulse transit time (PTT) during the continuous slow deflation of brachial cuff were early reported; however, the PTTs obtained for specific cuff pressures during inflation or deflation have not been compared before. Therefore, the objective of this study is to examine the differences in PTT when cuff pressure (P_{cuff}) was raised or deflated to the desired level. Sixteen subjects participated in this study and according to their systolic blood pressure (SBP) and diastolic blood pressure (DBP), 8 levels of P_{cuff} were predetermined for them individually. P_{cuff} was directly raised to each predetermined level while 20 seconds of electrocardiographic and photoplethysmographic signals were recorded for the calculation of PTT. Another set of recordings were taken when P_{cuff} was raised above the SBP and deflated to the predetermined levels. The results of this study showed that PTT increase significantly when P_{cuff} was larger than 80% of DBP, regardless of whether P_{cuff} was reached by inflation or deflation. Overall, no significant difference was found between PTT obtained during inflation and deflation for 12 out of the 16 subjects. To conclude, changes in PTT are mainly induced by the level of cuff pressure when there is no prolonged period of artery occlusion.**

I. INTRODUCTION

Pulse transit time (PTT) can be used to noninvasively assess arterial functions. It is commonly known that aging and cardiovascular diseases such as arteriosclerosis could lead to increased artery stiffness and thus, result in shorter PTT. Nonetheless, changes in PTT can also be induced by external or environmental factors such as local peripheral or ambient temperature and forces exerted to the artery upstream or at the measurement site where the pulse wave is captured [1], [2].

Teng *et al*. reported significant changes in PTT when different degrees of contact force were applied to the transducer [2]. Driscoll *et al*. measured pulse wave velocity by an ultrasonic approach and reported its changes over a range of external forces that was applied on the brachial and radial arteries [3]. Nitzan *et al*. investigated the delay of PPG pulse during the slow deflation of a Riva-Rocci cuff relative to the arrival of the pulse on the contralateral hand [4].

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Unlike the previous studies, this study examines the changes in PTT when, after a relatively rapid inflation and deflation process, the cuff wrapping around the brachial artery is held at different pressures.

II. EXPERIMENT

Sixteen healthy subjects, aged 18-32 years and included 10 males, participated in the study. Subjects were asked to refrain from coffee and alcohol 2 hours before the experiment.

Electrocardiographic (ECG) and photoplethysmographic (PPG) signals were obtained from subjects' fingertips by stainless steel electrodes and a pair of light emitting diode and photodetector (IR91-21C. and IR91-21B, Everlight, Taiwan), respectively. A mercury sphygmomanometer was connected to the automatic blood pressure (BP) meter (Omron HEM-907, Japan) via a Y-tube and the cuff was wrapped around the ipsilateral upper arm of the subject. BP was measured by the automatic BP meter and simultaneously by an experienced nurse using the mercury sphygmomanometer at the beginning and end of the experiment. All measurements were obtained with sitting posture.

For each subject, the averaged BP values taken at the beginning of the study were used as a reference and eight levels of cuff pressure (P_{cuff}) were predetermined, i.e. 0mmHg, 40mmHg, 80% of diastolic BP (DBP), DBP, and 25%, 50%, 75% and 100% of pulse pressure (PP, the difference of systolic and diastolic BP) above the DBP. Note that the last level, 100% of PP above DBP, is equivalent to the reference systolic BP (SBP) obtained at the beginning of the study.

ECG and PPG signals were recorded for 20s when P_{cuff} was directly raised to each pressure level (i.e. during the inflation process). The cuff was completely deflated and the subjects were allowed for a 1 min. rest in between recordings. Another 7 datasets were recorded at each P_{cuff} (except for P_{cuff}=SBP) when P_{cuff} is first raised above SBP and deflates to the desired level (i.e. during the deflation process).

In this study, PTT was measured as the time interval between the peak of R wave of ECG and the upstroke of the PPG pulse in the same cardiac cycle. Results were presented as mean $\pm$ standard deviation. The paired Student's t-Test was used to compare the difference between two variables, and $p<0.05$ was considered statistically significant. For each subject, the mean PTT obtained at all P_{cuff} during inflation were compared with those obtained during deflation. Overall, the averaged normalized PTTs of all subjects obtained during inflation and deflation were also compared.

III. Results

As shown in Fig. 1, PTT maintained at a relatively stable level over a certain range of P_{cuff}, but significantly increased with larger cuff pressures. When P_{cuff} was maintained at a level around the SBP, the pulse was hardly noticeable on all subjects and PTT could only be obtained from 10 subjects. For P_{cuff} equals to DBP+75%PP, an increase of 75.3 ± 19.8 ms was found in PTT as compared to that obtained when P_{cuff} equals 0mmHg (PTT_0).

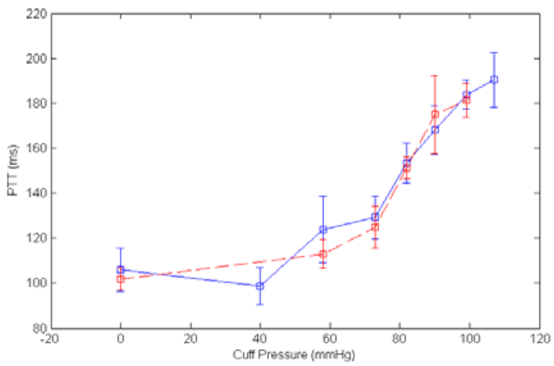

Fig.1. PTT values at different cuff pressures from one subject during inflation (solid line) and deflation (dashed line).

Figure 2 showed the normalized PTT (PTT/PTT_0) at desired P_{cuff} levels from all subjects. Significant differences in the normalized PTT, with respect to unity, could only be observed after P_{cuff} reached 80% of DBP (see Fig. 2).

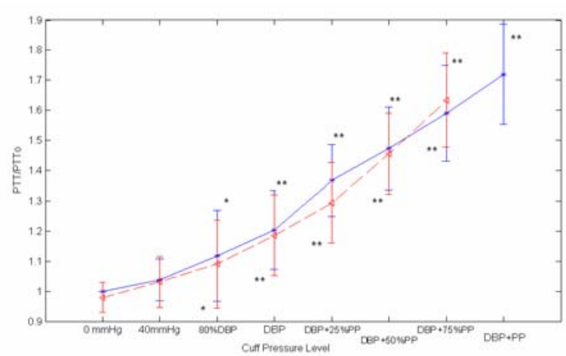

Fig.2. Mean of normalized PTT at predetermined P_{cuff} levels during inflation (solid line) and deflation (dashed line) from 16 subjects. Trials with * implies the mean PTT was significantly different ($p<0.05$) from PTT_0. Trials with ** denotes $p<0.0001$.

When comparing individual PTT obtained at all P_{cuff} levels during inflation and deflation, it was found that only 4 subjects showed significant differences ($p<0.05$) between the inflated and deflated trials. PTT/PTT_0 from the 16 subjects were averaged for each P_{cuff} level and the 2 sets of averaged PTT/PTT_0 obtained during inflation and deflation were found to be insignificantly different ($p= 0.9$). PTT obtained from all subjects during inflation and deflation were only found to be significantly different ($p=0.01$) at P_{cuff}=DBP+25%PP.

IV. Discussion

Regardless of the differences in the study protocol, the trend of PTT changes observed in this study as a result of applied cuff pressure was consistent with that previously reported in [3], [4]. The monotonically increase of PTT with cuff pressure applied over brachial artery could be an indication of changes in artery properties, e.g. the arterial distensibility (the ratio between arterial compliance and the arterial blood volume). As PTT in a conduit artery is related to arterial distensibility according to Bramwell-Hill's equation [5], the applied cuff pressure will ultimately resulted in an alteration of PTT. Yan *et al*. newly described a model of PTT as the function of cuff pressure during the process of upper cuff deflation [6].

Moreover, different with all the previous studies, this study also compared PTT obtained when P_{cuff} was directly increased to a predetermined value with those obtained when P_{cuff} was first raised above the SBP and then deflated to the predetermined value. In general, no significant difference was found between the PTT obtained from these two approaches. This implies that the changes in PTT are not induced by the occlusion of the brachial artery, which only happens in case of the deflation approach. Rather, the amount of PTT changes mainly depends on the applied cuff pressure P_{cuff}.

This observation may not hold if the inflation, deflation or occlusion period is extended, for previous study also reported that smooth muscle relaxation will appear in postocclusive reactive hyperemia, resulting in vasodilatation and further alters the arterial properties. The results of the previous study indicated that smooth muscle relaxation would increases brachial artery compliance and decreases PWV [7].

The analysis of PTT at different cuff pressures during inflation and deflation offer complementary information to factors that could have influence PTT measurements, and may also help in assessing individual arterial properties.

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