CONFOUNDING PHYSIOLOGIC PARAMETERS IN PULSE TRANSIT TIME MONITORING OF CHILDREN

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ABSTRACT

Pulse Transit Time (PTT) measurement has showed potential in non-invasive monitoring of changes in blood pressure. In children, the common peripheral sites used for these studies are a finger or toe. Presently, there are no known studies conducted to investigate any possible physiologic parameters affecting PTT measurement at these sites for children. In this study, PTT values of both peripheral sites were recorded from 64 children in their sitting posture. Their mean age with standard deviation (SD) was 8.2 ± 2.6 years (ranged 3 to 12 years). Subjects’ peripheries path length, heart rate (HR), systolic (SBP) and diastolic blood pressure (DBP) were measured to investigate any contributions to PTT measurement. The peripheral pulse timing characteristic measured by photoplethysmography (PPG) shows a 59.5 ± 8.5 ms (or 24.8 ± 0.4%) difference between the two peripheries (p < 0.05). The results also revealed PTT is directly proportional to age (p < 0.05). HR, SBP, peripheral path length and peripheral site also contributed significantly (p < 0.05) to PTT variations, except for DBP. Results also suggest an upward trend in PTT with age. Hence, changes in any of these physiologic parameters can affect the nominal PTT value of a child.

KEY WORDS

Measurement and Instrumentation, pulse transit time, blood pressure, and arterial compliance

1. Introduction

Blood pressure (BP) measurement is a physiologic parameter that is usually obtained to determine cardiovascular status of an individual. Assessment of BP over a predefined period can provide the necessary information to determine any association with systolic hypertension or cardiovascular abnormalities [1-2]. There is convincing indication of a strong association between increased arterial stiffness and increased risk of cardiovascular disease. BP abnormalities that characterise cardiovascular complications can originate from an increase in arterial stiffness [1]. Both the arterial compliance and stiffness are important components of the elastic nature of the arterial system [3-4]. During childhood, any abnormalities in the vascular characteristics of the arterial wall can have profound or prolong effects on the child. Over the recent decades, an indirect alternative to monitor changes in BP is by measuring the transit time of the pulse wave after each cardiac contraction [2].

Pulse transit time (PTT) is a simple and yet non-invasive clinical measurement to assess abrupt variations of the arterial properties in children. PTT is defined as the time taken for the arterial pulse pressure wave to travel from the aortic valve of the heart to its subsequent arrival at a peripheral site. This is usually measured as the time delay between the R-wave on the electrocardiogram (ECG) and its subsequent arrival at the peripheral site. PTT is approximately 250 ms in a healthy adult [5-6]. However, limited information of PTT measurement for children is available. This may be due to the inadequate knowledge about age-related changes in the arterial elastic properties in children [4]. These properties may vary with age, given that changes in arterial size and maturation of its wall structure may occur during childhood [7]. With these anatomical changes occurring, nominal PTT measures may vary in children of different age group. Several methods have been suggested to measure PTT at the peripheral sites, of which photoplethysmography (PPG) is one of the common preferences. Finger and toe are the two commonly used peripheral sites. The finger is generally used on older children and adults. However, for younger children, this can be switched between the two sites depending on the suitability of the studies and cooperation of the young child. Hence, the formation of normative child PTT data can be useful for comparison of future pathological studies.

The objectives of this study were: (1) to understand the age-related variations trend of PTT for sitting posture in children, (2) examine the probable contributions of peripheral path length, heart rate (HR), systolic (SBP) and diastolic blood pressure (DBP) on PTT measurement of a child, (3) assess the normative range of PTT measurements at the finger and toe peripheral sites in children and (4) investigate any possible PTT differences between using either the finger or toe as the periphery.
2. Materials and Methods

2.1. Subjects
64 children (44 male and 20 female) were recruited from the community. The parent and the child were given the study information verbally. Only those with no clinically apparent arterial disease were recruited. Their mean age with their standard deviations (SD) were 8.2 ± 2.6 years (range 3-12 years). Their arm and leg length were 602.3 ± 90.9 mm and 1027.5 ± 149.8 mm respectively. Their mean SBP were 107.9 ± 9.9 mmHg, DBP were 66.3 ± 8.5 mmHg and HR were 86.2 ± 12.7 bpm. Informed consent and institutional ethical approval were obtained for this study.

2.2. Methods
The child was asked to rest for 5 minutes to allow cardiovascular stabilisation. Measurements were performed in a typical clinical environment. PPG was first measured on an index finger and then on a toe using the same PPG probe. The PPG recordings were measured in conjunction with ECG signals. Both examinations were performed for 2 minutes with the child sitting back on the chair and arm resting on the chair. This sitting procedure was done to minimise the possible effects hydrostatic pressure has on the BP at the measured arm as recommended [8]. A minimum of 30 PTT measurements free from motion artefacts were obtained from each examination. After these examinations, the child was asked to relax for 1 minute. The SBP, DBP and HR were measured from the child in the sitting position. An appropriate arm cuff was chosen from the 3 available sizes as suggested [9]. The child was then asked to stand up for the arm and leg peripheral path length to be recorded. Both path lengths were taken with the sternal mammary notch as the reference point. Unlike adults, there were both inter and intra age-related BP differences in the selected group of children. In order to compensate these changes, all measured BP were normalised to known age-specified changes. Furthermore, to reduce the possible gender BP differences, the measurements were also normalised accordingly with known reference [10].

A stand-alone PTT system using a microcontroller to continuously acquire physiologic data from a single-lead ECG (S&W Medico, Teknik, Denmark) and PPG signals from a pulse oximetry (Novametrix Medical Systems Inc, Wallingford, USA) was developed. The system has an accuracy of 1 ms for all taken measurements. The flowchart of the said system is shown in Figure 1. SBP and HR measurements were manually recorded off an automatic oscillometric sphygmomanometer (Dinamap, Critikon Inc, Florida, USA). Statistical analysis was performed using SPSS version 10 (SPSS, North Chicago, Illinois, USA) and Microsoft Excel XP for windows software programs. The effects of age, SBP, DBP, HR, arm and leg path length on PTT were assessed by multivariate linear regression analysis. If statistically significant, the variant effect of each physiologic parameter was also calculated. Correlation analysis was used to determine if these effects were independent or not. A value of p<0.05 was considered significant and all data was expressed as mean ± SD.

3. Results
From the 64 subjects, their finger and toe PTT were 239.9 ± 18.4 ms and 299.4 ± 22.6 ms respectively. With the obtained finger and toe PTT, the mean transit time difference between the two was found to be 59.5 ± 8.5 ms or 24.8 ± 0.4% using the former as the baseline.

<table>
<thead>
<tr>
<th>Peripheral Site</th>
<th>Slope</th>
<th>r²</th>
<th>p</th>
</tr>
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<tr>
<td><strong>Finger PTT change with:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (ms/year)</td>
<td>+5.58</td>
<td>0.64</td>
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<td>Normalised SBP (ms/mmHg)</td>
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<td>&lt;0.05</td>
</tr>
<tr>
<td>Normalised DBP (ms/mmHg)</td>
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<td>0.06</td>
<td>&gt;0.05*</td>
</tr>
<tr>
<td>Arm Path Length (ms/mm)</td>
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<td>&lt;0.05</td>
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<tr>
<td>HR (ms/min)</td>
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<td><strong>Toe PTT change with:</strong></td>
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<tr>
<td>Age (ms/year)</td>
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</tr>
<tr>
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<td>Leg Path Length (ms/mm)</td>
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<td>&lt;0.05</td>
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<tr>
<td>HR (ms/min)</td>
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<td>0.35</td>
<td>&lt;0.05</td>
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Table 1: The univariate linear regression analysis of PTT where an (*) denotes data were not significant.

Of the 4 physiologic parameters, peripheral path length had less contributions to changes in PTT, but was significantly related (p<0.05). The effect was stronger at the toe when compared between the both peripheral sites. Significant changes in PTT with normalised SBP were also found at both sites (p<0.05) and had shown an inversely proportion relationship with PTT. HR had a greater contribution effect on changes in PTT and was also inversely proportional to PTT changes. However, the contributions of DBP to changes in PTT were not significant. A tabulated summary of the univariate analysis of PTT changes from the contributions of age, SBP, DBP, peripheral path length and HR were presented in Table 1. No statistically significant dependence on...
individual age was derived in the current study due to the limited number of subjects in each age group. From Table 1, it can be seen that age was the strongest contributor to changes in PTT at both peripheral sites, with the ageing effect greatest at the toe, +6.40ms/years ($p<0.05$).

4. Discussions

The developmental increase in arterial size and decrease in arterial wall distensibility are closely associated with age during childhood [3-4]. To predict linear increase in arterial stiffness with age, pulse wave velocity (PWV) can be used as an index [11-12]. There is a strong correlation between changes in arterial stiffness and increasing age [3-4]. PTT is largely determined by the wave propagation of a pulse between the measuring sites. This is basically derived from the principle of PWV [13]. The former has become an increasingly known non-invasive measure of arterial stiffness and the fluid properties of blood. An increase in arterial stiffness can lead to a decrease in PTT [4-5]. In this study of age-related changes in PTT, the greater increase was found to be at the toe. This study showed similar results as a previous adult study [14].

Studies of developmental changes in arterial structure during childhood have demonstrated progressive increase in both medial thickness and density of the elastic fibres of media after birth [4]. These observations suggested that arterial distensibility reduced with increases in age for children and consequently, increases the duration of PTT. This finding echoed that of Cheung et al [3] that SBP is not the sole contributor to transit time changes. By including the 3 other parameters; DBP, HR and path length, differences in PTT can be more readily compared. From the results obtained, it can be seen that PTT is not dependent on one physiologic parameter only. SBP can increase with age in normal child subjects [11] due to the age-related changes in arterial stiffness or compliance. In general, PTT has an inversely proportional relationship with SBP [5-6] and that was also clearly demonstrated in this study. Hence, a higher SBP corresponds to a lower PTT value. However, the relationships between the age-related changes in BP and PTT are less clear in this study since the nominal BP of children can increase with age during childhood [10]. Conflicting reports from previous studies suggested that the contributions from DBP were significant [2] while others disagreed [15-16]. The results attained from this study echoed the latter.

With an increase in the peripheral path length, it can be expected that PTT increases as the pulse wave needs to propagate further before arriving at the peripheral. Interestingly, for the convenience of PTT measurement, additional time delay is induced for the pulse wave to travel from the aortic valve to the periphery [5-6]. By using the ECG R-wave as the starting point, left ventricular isometric contraction time or the time delay between the R-wave and opening of the aortic valve is now added to the measured PTT. This delay is approximately 160ms [17] and PWV cannot be calculated accurately unless this time delay is excluded from the obtained PTT. In this study, the derived PWV is calculated by using the mean PTT value (less 160ms) and peripheral length obtained. The derived PWV for finger and toe PTT are $7.69 \pm 1.19$m/s and $7.37 \pm 0.85$m/s respectively. This corresponds well with known PWV quoted as between 4.3 and 10.0m/s for similar studies performed on children [3], [18]. However, the exact length of arteries in the upper and lower limbs was not measured, these figures can best seen as approximations.

The effects of HR on PWV was often dismissed or even overlooked, however recent studies have suggested otherwise. Studies conducted on animals have established that arterial distensibility is a function of HR. Even though this has not been so clearly demonstrated in humans, an increase trend of PWV with HR was still reported [19]. In this study, it can be seen that HR not only has a significant contribution to PTT measurement, but also a higher HR corresponds to a shorter PTT. Wilkinson et al [12] and Lantelme et al [19] observed that changes in BP do not necessarily lead to changes in HR. However, it is suggested that there is a link between resting heart and arterial stiffness [12]. While in other studies, Drinnan et al [20] and Cavalcanti et al [21] reported otherwise that changes in BP are generally followed by a change in HR. Based on these conflicting findings, it is reasonable to conclude that both the parameters can influence each other but they may not be solely dependent on one another. The degree of correlation between HR and BP on their effects on PTT requires further investigation. Most of the previous studies are done to compare the corresponding changes on the nominal PWV of individuals in response to changes in HR. The present study focuses on the correlation between the nominal PTT value and the resting HR. Nevertheless, it is still worthwhile to note the HR had contributions on the variations of PTT. There is a strong association with PTT and HR as the latter increases in parallel with increased arterial distensibility [19]. From the obtained results, HR is inversely proportional with PTT. A slower HR can be reflected by a longer corresponding PTT value.

In short, physiologic parameters like SBP, HR and peripheral path length have shown to have significant
effects on the nominal PTT in a child. The present studies are not adequate to address their individual contributions for individual age group due to the limited numbers of children in each age group. However, this study did provide an understanding of the PTT trend with age.

5. Conclusions

There has been recent published data about the association of PTT with age and BP for adults. However, limited efforts were put in similar studies for children. This can partly due to the misconceptions about the importance of pediatrics studies. In this study, the data describes the associations for normal young subjects aged between 3 to 12 years. As childhood undergoes marked physiological changes, all measured physiological parameters except DBP, have shown to have significant effects on PTT individually. In assessing PTT, the effects of SBP, peripheral path length and HR need to be taken into consideration when establishing a normative range or when examining pathological results for abnormalities. Hence, the assessment of PTT in normal young subjects can be a useful clinical tool for future respiratory and cardiovascular studies. Both peripheral sites have demonstrated that normative PTT of individuals can be affected by age-related changes in peripheral path length, SBP and HR accordingly.

References:

[14] J. Allen & A. Murray, Age-related changes in peripheral pulse timing characteristics at the ears, fingers and toes, Journal of Human Hypertension, 16(10), 2002, 711-717