SHORT REPORT

Pulse transit time as an index of vascular reactivity

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Abstract

Pulse transit time (PTT) is a non-invasive method for measuring arterial compliance and stiffness, which are excellent predictors of cardiovascular disease. This study aims to determine whether PTT can be used to precisely monitor vascular reactivity in response to changes in hand posture and whether the digital pulse wave index of time-to-maximum slope (TMS) is a suitable alternative to PTT. Fifteen healthy, 22-year-old males participated in the study. The PTT was monitored from electrocardiogram (ECG) to digital pulse wave (DPW), and the morphological variable TMS of the DPW wave was estimated in beat-to-beat intervals for the individuals while their arms were raised and dropped. The results demonstrated that the PTT increased significantly with elevating the hand, and the correlation probability of the second polynomial fitness equation neared infinite. In addition, the PTT significantly correlated ($P < 0.007$) with the TMS of the DPW throughout the hand motions. The data indicate that PTT can represent local vascular responses during changes in hand position. In this study, we developed a new DPW index and suggest a TMS index as a viable substitute for PTT.

Keywords: Cardiovascular, Electrocardiography, Pulse

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Introduction

The propagation time of a pulse wave going from the heart to the peripheral arteries is defined as the duration between the R-peak of the electrocardiogram (ECG) and the end-diastolic foot of the photoplethysmography signal during systole[1]. Pulse transit time (PTT) is frequently used to evaluate arterial stiffness, vascular compliance, sympathetic activity, endothelial function and blood pressure[2]. Blood pressure (BP) is directly related to the velocity of the artery pressure wave. When blood pressure rises rapidly, vascular tone also increases, causing the artery wall to stiffen and the PTT to decrease[3,4]. When blood pressure drops, vascular tone relaxes and the PTT lengthens. In addition, arteries stiffen with age, atherosclerosis, and diabetes, causing the PTT to shorten[5,6]. Photoplethysmography, also known as PPG, is a non-invasive technique that measures the amount of backscattered light by transferring infrared light into the tissue. This light is then used as an optical measurement tool to correlate with the variation of blood volume (vascular expansion and contraction) caused by the change in blood flow that occurs with each heartbeat[7]. PPG can be replaced by a finger pulse transducer, which uses a piezo-electric device to transform the applied force on the active surface of the transducer into an electrical analogue signal. When there is a change in either the systolic or diastolic blood pressure, there is a corresponding change in the blood flow, and as a result, the blood volume in the finger changes. In fact, Shriram et al (2017) demonstrated that the signals obtained through PPG are identical to those acquired by the use of a piezo-electric finger pulse transducer[8]. In most cases, the PTT and the pulse wave velocity (PWV) are related to one another in an inverse fashion (PWV = distance/PTT). PWV is the measure of arterial stiffness that is considered to be the gold standard and is a reliable indicator for predicting cardiovascular disease[9]. As a consequence of this, the PTT is recognised as having a significant value in the investigation of cardiovascular disorders[10,11]. This study's primary objective is to investigate the viability of employing the digital pulse wave index time-to-maximum slope (TMS) as a wave morphological variable that evaluates arterial stiffness.

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Materials and Methods

The study involved 15 healthy, 22-year-old males. It is a simple random sampling cross-sectional study carried out between October 2021 and May 2022 at the Department of Physiology, College of Medicine, University of Mustansiriyah, Baghdad, Iraq, in a room with an average temperature of 25±1° C. A consecutive non-probability sampling technique was adopted.

This research was approved by Human Research Ethics Committee, Mustansiriyah University, College of Medicine (No: 0014; date: 2 / 9 / 2021).

All subjects were informed about the aim and the suspected benefit of the study before obtaining their agreement for participation; although a written informed consent should have been obtained from all enrolled participants, our participants preferred a verbal consent for privacy reasons.

Prior to this one-time test, the participants were required to abstain from eating, drinking coffee, smoking, exercising, and taking any medications for at least one hour. Before obtaining their measures, the volunteers were instructed to sit for five minutes. During this time, we assessed their blood pressure and heart rate regularly using an automatic Omron 705IT upper-arm BP monitor (Omron Healthcare, Japan) until a stable BP and heart rate were achieved to ensure haemodynamic stability. Volunteers were instructed to sit quietly and naturally with their forearms resting on their legs. The examinations were done in a relaxed setting.

ECG and fingertip digital pulse wave (DPW) signals recording

The data was converted and digitally recorded on a computer using a PowerLab analog-to-digital converter Data Acquisition Unit 26T and a computer running LabChart Pro version 7.2 software from ADInstruments Pty Ltd, New South Wales, Australia. The LabChart Pro software was configured to display the right middle fingertip digital pulse waveform (DPW), the first derivative of the DPW (FDDPW, dDPW/dt), the second derivative of the DPW (SDDPW, d2DPW/dt2), and the ECG recording using a low-pass filter with a cut-off frequency of 35 Hz on four channels simultaneously (Figure 1). SDDPW is a sophisticated method for analysing the DPW's contours that was developed by Japanese researchers[12]. Later, researchers devised the second derivative of the DPW (d2DPW/dt2), also known as the acceleration photoplethysmograph, to discern five successive waves termed as the DPW (a, b, c, d, and e waves). The right middle fingertip DPW signals (recorded using a piezo-electric finger pulse transducer) and Lead II ECG were recorded at three places (-35 cm, 0 cm, and +35 cm relative to the heart level) over the course of 30 seconds. Three surface electrodes attached to the PowerLab Data Acquisition Unit 26T were used to record ECG signals. Two electrodes were placed on the right arm and left leg (Lead II) and one electrode was attached to the right leg for ECG measurements (serving as earth). A Velcro strap secured the finger pulse transducer to the finger without restricting blood flow. The tester made certain that the finger pulse transducer was not resting on any surface and that the fingers were free to hang. Figure 1 shows the experimental setup used for this study. To guarantee that both arms rested at heart level, which was defined as the vertical midpoint of the sternum, all participants sat in chairs whose height could be adjusted as needed. Thanks to an adjustable hand rest, the right hand could be positioned at various heights, including +35cm above heart level, at heart level (0cm), and -35cm below the heart level. The middle finger of the right hand was used to measure finger pulse transducer signals with custom-made measurement equipment. The right-hand measurements of each respondent were taken in a variety of postures. The initial measurements were taken at 0cm, followed by +35cm, and subsequently -35cm. After a three-minute rest period, the last 30 seconds of all signals at each point were recorded.

The PTT is the interval time between each R-wave peak of an ECG cycle and the highest first peak of SDDPW (the "a" wave). The "a" wave occurs when the signal voltage at the foot of the DPW is 10% greater than the preceding baseline value (Figure 2)[13]. Labchart's peak detection module was used to identify ECG R-wave peaks and SDDPW peaks. The time at the maximum slope of the DPW signal is the period from the start of the signal and the first of two sample sites where the maximum slope occurred.

Statistical analysis: Microsoft Office Excel 2013 was used for all calculations. Using the student's paired t-test, the statistical significance of the mean and standard deviation of measurement difference was established. A P value of less than 0.05 was considered statistically significant.

Results

The mean systolic blood pressure of the volunteers was 126.5±14.2 mm Hg, and the diastolic blood pressure was 74.1±16.2 mm Hg. The body mass index (BMI) was 25.9 ± 4.7 kg/m^2. The PTT at -35 cm relative to the heart level was 229.1± 18.6 msec, as shown in Figure 3. The PTT increased by 5% when the individual raised his arm to the heart level. The PTT rose significantly by 12% when the hand was lifted to +35cm relative to the heart. The time-to-maximum slope of the digital pulse wave was positively and substantially linked with PTT (r = -0.40, P <0.007). (Figure 4).

Discussion

In this study, PTT increased progressively when the subject elevated his hand; it was significantly longer when the hand was raised +35cm above the heart than when the hand was at the heart level. The results demonstrate that hand positioning changes have a significant effect on local PTT measurements. PTT can track reactions because they are linked to changes in both HR and BP. These

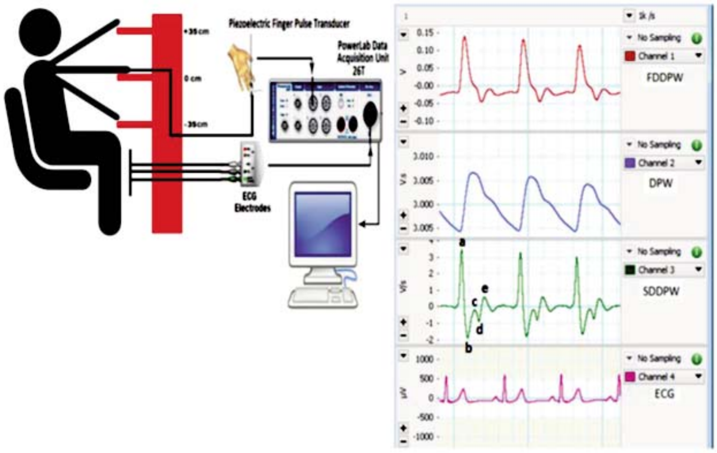

Figure-1: Illustration of the investigational set-up for the hand-raising and hand-lowering study.

Figure-2: Method of calculation of PTT using LabChart Pro software.

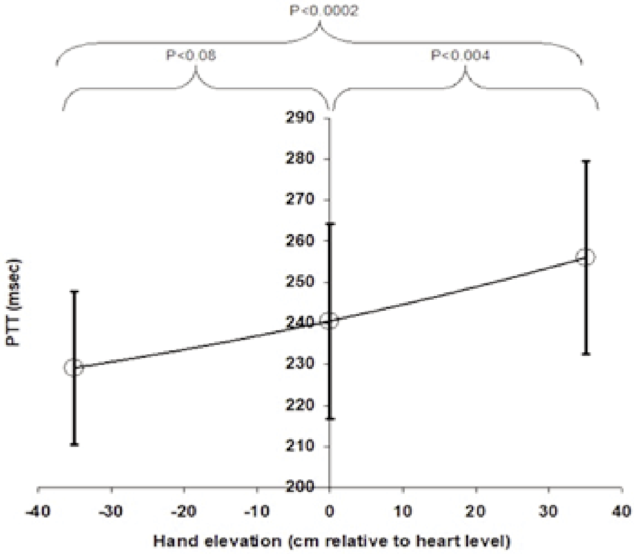

Figure-3: The relationship between digital pulse transmission time (PTT) and hand position. N = 15.

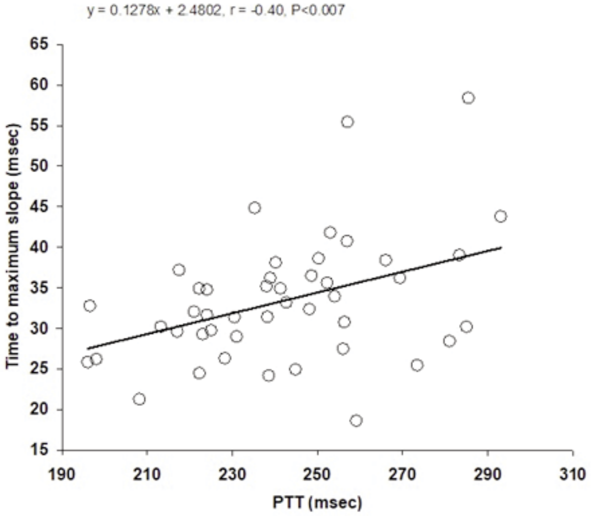

Figure-4: The relationship between pulse transmission time (PTT) and the Time to maximum slope of the digital pulse wave throughout various hand positions relative to the heart level. N = 15.

findings are consistent with those of Foo et al (2005).[8] The rise in PTT could be attributed to changes in hydrostatic pressure and autoregulatory systems inside the limbs.[8] The venoarterial reflex (VAR) is most likely responsible for the shift in PTT[14]. When the venous return is obstructed, blood pools, causing the venous walls to dilate. When the hand is in a dependent position, the venoarterial reflex reacts to venous wall distension by inducing arterial vasoconstriction[15]. According to Zakaria and Mengko (2017), the increase in blood vessel diameter when lifting the arm is part of the reactive hyperaemia process, which reduces blood vessel resistance. This blood vessel dilation is caused by the production of nitric oxide (NO) from the endothelial cell in response to the decreased blood flow[16]. The findings of the current study suggest that PTT is directly proportional to time-to-maximum slope and can be utilised as an alternative PTT index. Several morphological DPW indices were obtained, and clinical applications were identified. The systolic amplitude of DPW, for example, is directly proportional to local vascular distensibility over a remarkable range of cardiac output[17]. Furthermore, pulse width (measured at the half-height of the systolic peak) is linked to systemic vascular resistance[18]. In addition, in pre-eclampsia patients, the area difference ratio was observed to be related to maternal arterial stiffness[19]. The DPW inflection and harmonic area ratio were utilised to predict cardiac output[20]. As part of the DPW contour analysis, the time- and height-related properties of the reflected wave, mirrored by the notch, were employed to quantify artery stiffness[21]. The augmentation index of the aorta and carotid arteries has been linked to an increased risk of cardiovascular disease, mortality, and morbidity[22]. TMS is now offered as a morphological index of DPW that can be used to assess the vascular reactivity noted in this study, according to a previous study.

Limitations: The sample size was not calculated by using a scientific method. This could influence the statistical power of the study.

Conclusion

Because PTT is a physiologic parameter, the results of this study imply that it can be utilised in cardiovascular investigations as a surrogate marker for changes in arterial stiffness, and that TMS is a suitable alternative. Despite differences in hand placement, PTT has the capacity to continually evaluate local circulatory responses.

Disclaimer: None.

Conflict of Interest: None.

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