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ORIGINAL ARTICLE

The Effect of Hand Blood Flow on the Peripheral Fingertip Plethysmographic Waveforms Morphology and Pulse Wave Velocity

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ABSTRACT
Photoplethysmography (PPG) is a non-invasive optical technique that employs variations in light absorption produced by alteration in the blood volume in capillaries at the skin during the cardiac cycle. This study aims to understand factors related to PPG morphology; a hand-elevation, the study has modified blood flow to and from the finger was conducted in the laboratory. It is widely established that the position of the limb relative to the heart has an effect on blood flow in arteries and venous. Peripheral digital pulse wave (DPW) signals were obtained from 15 healthy volunteer participants during hand-elevation, and hand-lowering techniques wherein the right hand was lifted and lowered relative to heart level, while the left hand remained static. The pulse width, time to peak (TTP), the time to the maximum slope (TTMas) were computed from 30sec DPW signals at three positions of the right hand with regard to heart level, i.e. 35 cm above heart level (+35 cm), at the level of the heart (0 cm), and 35 cm below the level of the heart (-35 cm). DPW characteristics were found to alter with hand position. On lowering the hand to -35 cm relative to heart level, DPW width from the middle finger increased by (6%), but lowering the arm decreased the TTP (by 11 %), TTMas (by 18 %). These changes in time-dependent DPW indices may be attributed to changes in hydrostatic pressure and the venoarterial reflex that changes the blood vessels filling from completely filled one at -35 cm due to arterial vasoconstriction and decreased venous return to partially emptied blood vessels due to arterial vasodilatation and increased venous return at +35 cm. It was assumed that these time-dependent morphological DPW indices alterations were controlled by changes in downstream venous resistance rather than arterial or arteriolar, resistance.
Keywords: photo plethysmography, hand elevation, vasoconstriction, vasodilation, vascular mechanics

INTRODUCTION
Monitoring blood perfusion and vascular assessment (arterial disease, arterial compliance, aging, and endothelial function) is vital for cardiovascular health. For these reasons, several techniques have been modified. Photoplethysmography, or PPG for short, is an optical technique that analyses changes in blood volume in vascular tissue. It is best recognized for its application in pulse oximetry, which determines the arterial blood oxygen level [1].

A pulsatile alternating current (ac) waveform is superimposed on top of a slowly shifting direct current (dc) baseline in the PPG waveform. The pulsing of the arterioles and arteries that occur with each pulse creates the ac component, which in turn results in a change in the amount of light absorbed [2].

The ac component is comprised of two phases: the upstroke is primarily associated with vessel distension during systole (which is referred to as the systolic phase), and the downstroke is associated with vascular resting during diastole and wave reflections from the periphery (which is referred to as the diastolic phase). Patients who have arteriosclerosis have a "diminution or disappearance of the dicrotic wave," whereas healthy people with compliant arteries generally have a dicrotic notch on the downstroke of the PPG. In many cases, the dc component is related to the light absorption in non-pulsatile arterial blood, venous blood, and tissue [3, 4].

The PPG pulse will have a different appearance depending on the numerous vascular variables. The dicrotic wave either becomes less prominent or completely disappears when the arteries are older and develop arteriosclerosis. In addition, the peripheral PPG pulse gets "damped, delayed, and decreased" as the severity of vascular disease increases. In order to quantify the morphological changes that were seen, several components of the ac PPG pulse were extracted, studied, and analyzed [5].

The PPG pulse amplitude, which is often referred to as the systolic amplitude, is the most frequently mentioned morphological trait in the literature. It has been proven that a number of cardiovascular reactions, including vasoconstriction as a result of a cold pressor test and vasodilation as a result of reactive hyperemia, can change this variable. It is hard to distinguish the compassion between the systolic amplitudes between patients or measurement sites due to different skin pigmentation, sensor position, etc.) Because local circumstances impact light absorption. [6,7] This makes it difficult to compare systolic amplitudes. worse conditions compared to their counterparts in developed countries. This systematic review and meta-analysis aims to provide evidence on prevalence of depressive symptoms among healthcare workers in Pakistan during the COVID-19 pandemic.

METHODS
The participants in the study were all healthy males, and their average age was 22. Their body mass index (BMI) was 25.9± 4.7 kg/m2, their systolic blood pressure was 126.5± 14.2 mmHg, and their diastolic blood pressure was 74.1±16.2 mm Hg. The research was conducted in room temperature of 25±1oC from November 2020 to May 2021 at Mustansiriyah University's College of Medicine. The temperature range ranged from 0 to 100 oC.

The research was carried out in accordance with the guidelines for medical ethics, and all of the subjects provided their informed consent. Before beginning the measurements, the participants were given a five-minute break to settle down and take it easy while seated. During this time, repeated heart rate, and blood pressure was measured by an automatic Omron 705IT upper arm sphygmomanometer (Omron Healthcare, Japan). These measurements were taken until a stable BP and HR were achieved to ensure that the patient's hemodynamic stability was maintained. The participants were instructed to maintain a natural and quiet sitting position during the trial while resting their forearms on their legs. Volunteers who have a previous history of severe medical conditions were not allowed to participate in the study. In order to qualify for this one-time examination, candidates had to abstain from eating, drinking coffee, smoking, engaging in physical activity, or taking any medication for at least one hour before the start of the examination. In a very quiet environment, the experimental measurements were carried out.

ECG and fingertip digital pulse wave (DPW) signals to record: Power Lab analog to digital converter Data Acquisition Unit 26T and a computer Lab Chart Pro version 7.2 Software was purchased from ADInstruments Pty Ltd, New South Wales, Australia, were both used to convert and digitally record the data on the computer. LabChart Pro software was set up to display 4 channels that run synchronously. One channel for the right middle fingertip digital pulse waveform (DPW), one channel for the first derivative of the right middle fingertip digital pulse wave (FDDPW,

dDPW/dt), one channel for the second derivative of the right middle fingertip digital pulse waveform (SDDPW, d2DPW/dt2), and one channel for ECG recording (Fig.1) by pass filter and cut-off frequency of 35 Hz. SDDPW was a sophisticated approach to contour analysis of the DPW developed by Japan [8,9].

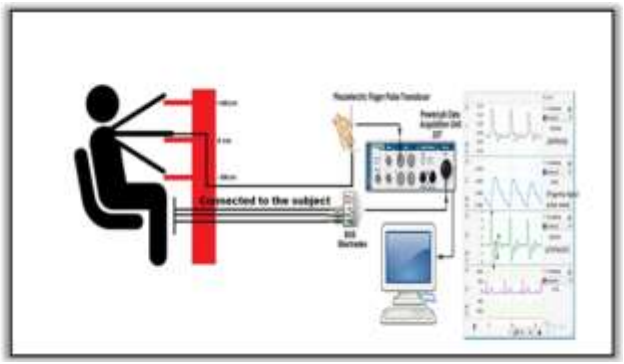

Figure1: Illustration of the investigational set-up for the hand-raising and hand-lowering study.

The entire test volunteers were instructed to take a seat on a chair, the height of which was modified as required to ensure that both of their arms rested at "heart level," which was defined as being parallel to the vertical midpoint of the sternum. To avoid putting unnecessary stress or strain on the arms of the subject, special attention was paid to ensuring that they were in a posture that was comfortable for them. With the use of an adjustable hand rest, the right hand was able to be positioned at three distinct heights: 35 cm above heart level, zero cm at heart level, and 35cm below heart level. Using measurement equipment that was specifically designed for this purpose, finger pulse transducer signals were obtained from the index finger of the right hand. All of the individuals had their right hands held in a variety of situations while the measurements were obtained. Initial measurements were collected with the hand resting at heart level (0 cm), then the hand was raised to rest 35 centimeters above heart level (+35 cm), and then it was lowered to rest at heart level once again (-35 cm). Following a period of rest for three minutes in each position, the most recent thirty seconds of all signals were recorded. In addition, a wrist automated sphygmomanometer was applied to the right wrist in order to evaluate the variations in blood pressure caused by the different hand positions.

Data analysis: This is achieved by the use of LabChart Pro for offline calculation of the following indices:

Maximum Slope: Displays the maximum slope of the data in the selection. The maximum slope is calculated as the maximum increase (which could be negative) between successive sample points in the selection, divided by the sampling interval.

Time at Maximum Slope: Displays the time at the maximum slope of the data in the selection. This time is the first of the two sample points between which the maximum slope occurred. The width of the pulse when it is at half the height of the systolic peak amplitude is referred to as the pulse width at half height (Width 50).

Statistical Analysis: All data were calculated using Microsoft Office Excel 2013. The statistical significance of the mean and standard deviation of measurement difference was determined using the student's paired t-test. Statistical significance was defined as a P value of less than 0.05.

RESULTS

The width of DPW was changed according to the change of the hand position (Fig. 2). At -35, the width was 700.5±107.1 msec. When the arm was elevated to the heart level, there was no significant change in the DPW width, while the elevation of the arm to +35 cm, the width of DPW was increased by 6%.

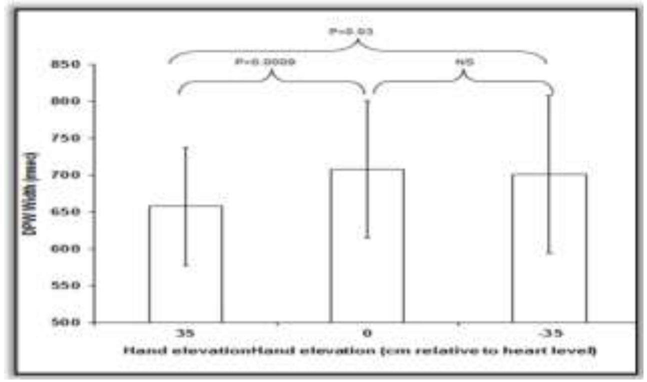

Figure 2: Digital pulse wave (DPW) width at various hand elevation positions. N=15.

Moreover, the results showed a clear difference between the three positions of the hand and TTP. The TTP increased with the hand elevated from -35 cm to the heart level by about 6% (Fig. 3). On the further elevation of the hand to +35 cm relative to the heart level, the TTP was further increased by 21% relative to the heart level.

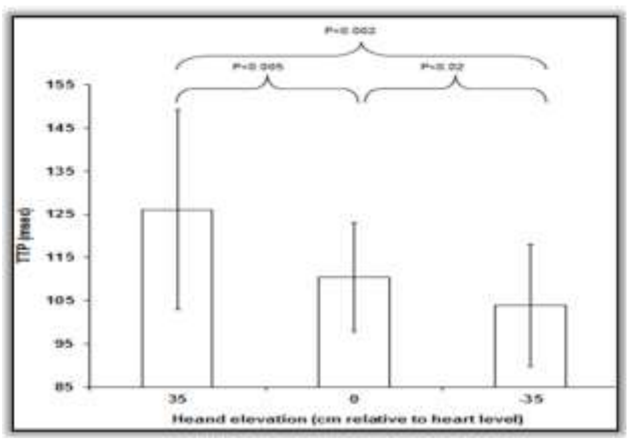

Figure 3: The digital pulse wave's time to peak (TTP) at various hand positions. N = 15

Fig. 4 shows the TTMaS of the DPW at various hand positions. At -35cm relative to the heart level, the TTMaS was 31.2±5 msec. The hand to the heart level elevation did not affect the TTMaS, while a substantial effect was observed when the hand was elevated to +35cm relative to the heart level, and TTMaS was increased by 22%.

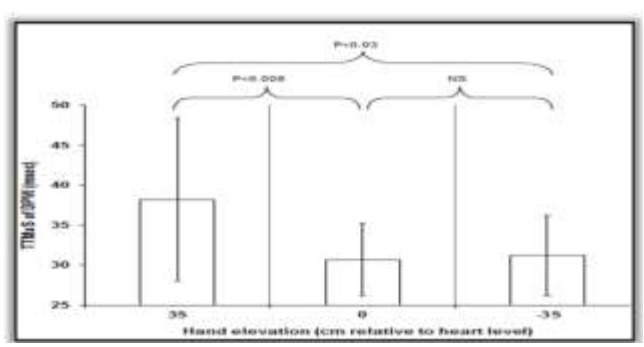

Figure 4: Time to the maximum slope (TTMaS) of the digital pulse wave (DPW) at various hand elevation positions. N = 15.

DISCUSSION

Good quality DPW signals were obtained from all volunteers at all positions of the right hand. An algorithm effectively detected all fifteen subjects' systolic and diastolic endpoints in their DPW signals for feature detection based on the DP waveform's second derivative. The plethysmogram, also known as a PPG, has seen widespread application in the field of hemodynamics and peripheral circulation research. It is important to note that little shifts in arm position can create considerable differences in the morphology of the DPW. Accordingly, the height of the assessment region in relation to the level of the heart needs to be controlled in any study that looks at the characteristics of the DPW or PPG signal while measuring vascular resistance. In addition, it would be especially helpful to understand better the degree to which arterial and venous resistance are both contributors to these morphologies and factors.

The current research showed that DPW width was increased during the hand-lowering position (- 35 cm). During this hand position, heart rate was found to be increased, suggesting that a systemic sympathetic stimulation is more activated as a result of venoarterial reflex, which manifested itself by an increase in the heart rate. Consequently, peripheral vascular resistance is expected to increase. Therefore, it is possible to put forward that the increase in DPW width during hand lowering (-35 cm) is due to an increase in peripheral vascular resistance as a result of sympathetic stimulation. This suggestion is supported by [10], who suggested that the pulse width correlates with the systemic vascular resistance better than the systolic amplitude. The connections that existed between the parameters of the hand plethysmographic waveform and the systemic vascular resistance were solid. This observation might be explained by the fact that the innervation of the finger is predominately adrenergic, which results in a considerable sensitivity of finger blood flow to a vasoconstrictive challenge. When the hand is positioned lower than the level of the heart, there is an increase in the SVR, which increases the breadth of the finger pulse (Fig. 2).

Time-dependent DPW indices represent the time through which a volume of blood moves through a given vascular bed. It is possible to suggest that these time-dependent DPW indices that increased during hand-elevation (TTP, TTMaS) were the result of the time duration needed to fill the partially emptied vasodilated blood vessels of the forearm, hand, and fingers, i.e. their ability to fill during the systolic phase, and thus, the filling time (i.e. extended arteriolar filling), is increased [11]. During hand-elevation, blood approaching the finger is less due to hydrostatic effect that causes a reduction of the filling pressure, and it is occupied by vasodilated blood vessels of the forearm, hand, and fingers. Consequently, the blood is now rerouted to the new larger volume of blood vessels and at less filling pressure. The blood flow rate in the arterio-venous anastomosis dropped whenever the thumb pulp or toe was lifted above heart level, which corresponded to a falling pressure head (filling pressure) [12]. Consequently, upon the arrival of the DPW to these expanded blood vessels, there should be more time to fill these larger diameter blood vessels, i.e. prolongation of the time required for transmission of the pulse wave at the level of the arteriolar vessels. This excess time required to fill the forearm, hand, and fingers expanded blood vessels gave the time-dependent DPW indices. This increased values during hand-elevation relative to hand-lowering position. Therefore, it is possible to suggest that the extended arteriolar filling and the drop in vascular filling pressure are responsible for the TTP. TTMaS is larger in the elevated hand than the limb in a lower position than the heart level.

Our findings suggest that the influences of the venous resistance on the DPW morphology are stronger than the arterial resistance. The study results are consistent with a study by (Michelle et al., 2016) [11].

CONCLUSION

1 Due to its unobtrusiveness and its cheap and easy obtainability, automated interpretation of the digital volume pulse waveform measured by piezoelectric finger pulse transducer will play a significant role in the development of novel hemodynamic monitoring devices.

2 The data indicate that pulse width of finger DPW tracing is more sensitive to changes in SVR than the other indices. An appreciation of changes in pulse width may provide valuable evidence with respect to changes in peripheral vascular tone.

3 The time-dependent DPW indices (TTP, TTP/W, TTMaS, TTMiS, TRise) were increased during hand-elevation as a result of the time duration needed to fill the partially emptied vasodilated blood vessels of the forearm, hand, and fingers, i.e. the capacity for systolic filling, and hence the filling time (i.e. arteriolar filling), is increased. Therefore, it is possible to suggest that the morphological changes of the peripheral DPW waveform are more sensitive to changes in downstream venous resistance, rather than arterial/arteriolar resistance. Further work is required to fully understand and further quantify morphological analysis of the DP waveform.

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