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ABSTRACT

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USE OF PULSE OXIMETRY WITH PLETHYSMOGRAM REGISTRATION IN CHILDREN WITH ACUTE PNEUMONIA

Introduction. Clinical examination of the patient includes first of all the assessment of heart rate by peripheral pulse. Assessment of pulse rate is simple and can be done manually or with devices such as pulse oximeter which registers pulse waves in photoplethysmogram. Photoplethysmogram provides a means of low-cost physiological monitoring that is popular in many wearable devices but with the accuracy, robustness and useful for clinical studies and healthcare.

Materials and Methods. A total of 50 children aged 7 to 12 years were enrolled in the study and divided into two groups: 28 children with acute pneumonia in early recovery stage and 22 healthy children. The cardiovascular parameters were assessed by blood pressure, pulse rate and pulse oximetry with photoplethysmogram pulse wave analysis.

Results. The pulse rate was nearly the same in both groups (acute pneumonia patients – 87.6±2.3 bpm and healthy subjects – 85.1±1.9 bpm), but a mean systolic blood pressure in acute pneumonia patients was significantly lower than in the healthy children (103.6±3.1 and 114.7±2.8, $p<0.05$). Measurements of photoplethysmogram indices in both groups showed no significant differences, with the exception of the dicrotic wave amplitude, which was lower in acute pneumonia patients (0.78±0.29 mm and 1.41±0.39 mm, $p<0.05$). These changes were assessed as a result of endothelial dysfunction, impaired microcirculation, and higher peripheral resistance to blood flow in patients with acute pneumonia.

Conclusions. In addition to assessing blood oxygen saturation, pulse oximetry utilizes photoplethysmography to register pulse waves, providing important information regarding vascular system function. Pulse wave analysis indicates changes at the microcirculatory level and an increase in peripheral resistance to blood flow in children with acute pneumonia.

Keywords: acute pneumonia, photoplethysmogram, pulse wave, pulse oximetry, children.

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ЗАСТОСУВАННЯ ПУЛЬСОКСИМЕТРІЇ З РЕЄСТРАЦІЄЮ ПЛЕТИЗМОГРАМИ У ДІТЕЙ ХВОРИХ НА ГОСТРУ ПНЕВМОНІЮ

Вступ. Клінічне обстеження хворого включає в першу чергу оцінку частоти серцевих скорочень за периферичним пульсом. Оцінка частоти пульсу проста і може бути виконана вручну або за допомогою такого пристрою, як пульсоксиметр, який реєструє пульсові хвилі на фототоплетизмограмі. Фототоплетизмограма надає засоби недорогого фізіологічного моніторингу, популярного в багатьох переносних пристроях, але з точністю, надійністю та корисністю для клінічних досліджень і охорони здоров'я.

Матеріали та методи. В дослідження було включено 50 дітей віком від 7 до 12 років, які були розподілені на дві групи: 28 дітей з гострою пневмонією у період раннього одужання та 22 здорових дитини. Серцево-судинні параметри оцінювали за артеріальним тиском, частотою пульсу та пульсоксиметрією з аналізом пульсової хвилі фототоплетизмограми.

Результати. Частота пульсу була майже однаковою в обох групах (у хворих на гостру пневмонію – 87,6±2,3 уд/хв та у здорових – 85,1±1,9), але середній систолічний артеріальний тиск у хворих на гостру пневмонію був значно нижчим, ніж у здорових дітей (103,6±3,1 та 114,7±2,8, $p<0,05$). Показники фототоплетизмограми в обох групах відрізняються незначно, за винятком амплітуди дикротичної хвилі, яка була меншою у хворих на гостру пневмонію (0,78±0,29 мм та 1,41±0,39 мм, $p<0,05$). Ці зміни оцінювалися як результат ендотеліальної дисфункції, порушення мікроциркуляції та підвищення периферичного опору кровотоку у хворих на гостру пневмонію.

Висновки. Пульсоксиметрія, крім оцінки насичення крові киснем, також містить фототоплетизмограму з реєстрацією пульсових хвиль, яка дає важливу інформацію про функціонування судинної системи. Аналіз пульсових хвиль свідчить про зміни на мікроциркуляторному рівні та про підвищення периферичного опору кровотоку у хворих на гостру пневмонію.

Ключові слова: гостра пневмонія, фототоплетизмограма, пульсова хвиля, пульсоксиметрія, діти.

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ABBREVIATIONS
PPG – photoplethysmogram
AP – acute pneumonia
BP – blood pressure

INTRODUCTION

The clinical examination of the patient includes, first of all, an assessment of the heart rate by peripheral pulse. Assessment of pulse rate is simple and can be done manually or with a device [1, 2]. There are many physiological and pathological conditions that influence pulse rate and aren't heart or circulatory diseases. Different causes change heart rate – including exercise, anxiety, medications, infection, anemia, dehydration, disease of the thyroid gland, as well as other health conditions [3, 4].

At the same time, classical pulse analysis has many of its characteristics, attention to which has decreased significantly today. A complete patient physical examination includes the assessment not only of the number of beats per minute but also of arterial pulses in all locations, and while examining the pulse, the observer should note its intensity, rhythm, blood vessel tenderness, tortuosity or nodularity, variability, etc [5, 6, 7]. Detailed pulse analysis thus represents a valuable supplement to routine cardiovascular measurements to aid biomedical research, clinical decision making, and patient management. Pulse assessment can sometimes be challenging due to various factors. These difficulties may arise from patient-related issues, environmental conditions, or examiner experience. This type of interpretation may be impractical in many clinical settings, where a specialist may not always be available or, indeed, the feature changes are not always obvious to the naked eye. Secondly, these techniques often focus on a snapshot window of data rather than looking at a longer time (e.g., a patient trajectory over hours or days), which may mean important pulse waveform feature changes are missed. Thirdly, there is great inter-individual variation even amongst healthy individuals, which makes setting any broad guideline measures relating to pathological changes in pulse wave morphology challenging. Next, the palpation by the investigator carries a greater likelihood of confusion with the examiner's own pulse. Thus, whilst there are many technological advances in waveform analysis that derive potentially useful measures, translating these into readily usable and understandable formats is by no means straightforward [6, 8, 9].

The last epidemic of coronavirus disease targets special attention to several tissues of the human body; among these, a serious impact has been observed in the pulse and microvascular system characteristics [10]. Patients with suspected of this disease remain at risk for clinical deterioration and may benefit from monitoring of oxygen saturation level and pulse characteristics using portable pulse oximeter devices [8].

The oximeter data obtained by pulse are registered in devices by photoplethysmogram (PPG), which is an optical technique that measures changes in blood volume in the microvascular bed of tissue using a light source and a photodetector [11]. British investigators Ray D et al. (2023) indicate that PPG provides a means of low-cost physiological monitoring that is popular in many wearable devices [12]. However, the accuracy, robustness, and generalizability of single-wavelength PPG biophysical models are significant, given the increasing use of single-wavelength wrist-worn PPG devices in clinical studies and healthcare. Detailed pulse waveform morphology analysis thus represents a valuable supplement to routine cardiovascular measurements to aid clinical decision making and patient management. Figure 1 shows the PPG waveform of one pulsation and various feature points.

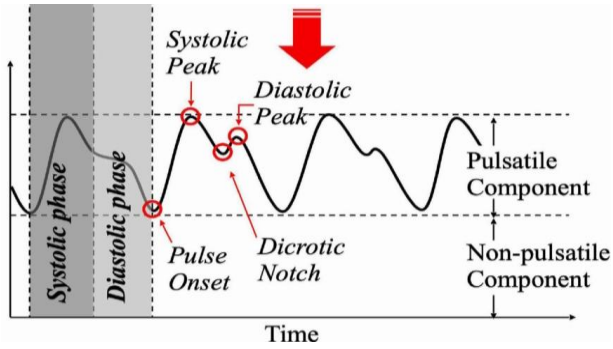

Fig. 1. Principle of photoplethysmogram generation and waveform features (by Park J et al., 2022) [1]

The PPG waveform changes according to cardiac activity – it has a rising curve (systolic phase) according to an increase in capillary blood flow by cardiac contraction, and a descending curve (diastolic phase) according to a decrease in capillary blood volume by cardiac dilation. PPG waves may also depend on respiration, autonomic nervous system activity, arterial and venous activity, microcirculation, etc. [13, 14]. The systolic peak is defined at the point where blood volume is maximized [15]. The amplitude of the systolic peak, a representative characteristic of the PPG waveform, has been reported to have a significant correlation with microvascular expansion and is in proportion to the cardiac output and blood pressure [16, 17]. In addition, results from studies related to anesthesia, sympathetic activation, and the use of vasoconstrictors related to autonomic nervous system activity have confirmed that when the peripheral vasculature is dilated, the amplitude of the systolic peak is increased, while when the vasculature is constricted, it is decreased. Transient rising and falling of the PPG waveform during diastole occur when blood volume in capillaries temporarily increases again because of the occurrence of a pressure gradient in the opposite direction to the blood flow, just

before the aortic valve closes. The dicrotic notch is a recessed point at which the first derivative of the waveform is closest to zero after the systolic peak. It is caused by the closure of the aortic valve, reflecting backward pressure waves in the arteries, and the diastolic peak depends on the opposite direction of the blood flow [18]. PPG waveform can change because of body composition, physiological status, external stimuli, and pathological processes. Pulse waves are indirectly used to detect respiratory rates by monitoring variations in heartbeats during breathing cycles. Moreover, the PPG baseline is affected by respiration, vascular compliance, vascular tone, pain, and drug use. Inflammatory responses in acute respiratory diseases, especially in acute pneumonia (AP), can result in increased vascular permeability, leading to fluid leakages into the interstitial space and thus impairing effective microcirculation [19-21]. As characterized by impaired vasodilation, pro-inflammatory state, and pro-thrombotic properties, endothelial dysfunction in AP can lead to imbalances in local blood flow and tissue oxygenation, thereby contributing to pulse waveform changes [6, 22]. Understanding the peculiarities of pulse waveform characteristics in children could have clinical implications in the optimization of management of hemodynamics and microcirculation [16].

MATERIALS AND METHODS

In the study, 50 children aged 7 to 12 years were enrolled. The participants were presented in two groups without age-sex difference between them: a main group comprising 28 children with AP and a control group consisting of 22 healthy children. Inclusion criteria were a mild or moderate form of AP, and exclusion criteria for both groups were the presence of any congenital heart disease or other chronic illnesses that could influence cardiovascular parameters. All participants underwent a comprehensive assessment that included a detailed medical history, physical examination, systolic, diastolic, and pulse blood pressure (BP), and evaluation of other cardiovascular parameters. In the main group, all measurements were done in the period of early recovery on the 5th-7th day, in the absence of intoxication syndrome and normal body temperature. Pulse rate was assessed on the radial artery of the left hand. During pulse oximetry the following PPG measurements were done (Fig. 2): amplitude (h1 – amplitude of main wave; h3 – amplitude of predicrotic wave; h4 – amplitude of dicrotic notch; h5 – amplitude of dicrotic wave) and time (t1 – time between start point of and main wave; t4 – time between start point and dicrotic notch; t5 – time between dicrotic notch and end point of pulse wave.

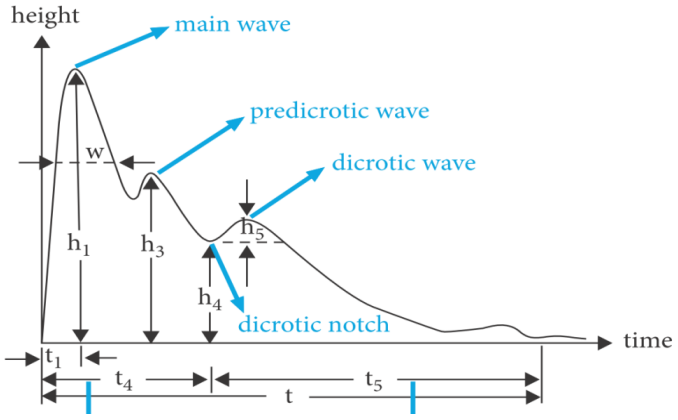

Fig. 2. Complete pulse wave period and measurements

Statistical analysis was conducted with the program Statistica (version 5.11, StatSoft Inc.). Data were expressed as numbers of cases for frequency histogram, and as mean ± standard error for quantitative variables, with the Mann-Whitney U test, and $p<0.05$ was considered statistically significant.

The study was conducted in accordance with the principles of the World Medical Association`s Declaration of Helsinki, «Ethical Principles for Medical Research Involving Human Subjects». Informed consent to participate was obtained from all those included in the study (parents of children or their guardians), which emphasizes the absence of invasive interventions. The study protocol was discussed and approved at a meeting of the Biomedical Ethics Committee of Bukovinian State Medical University.

RESULTS AND DISCUSSION

Children from both groups did not have a significant difference in anthropometric measurements, especially those that could influence BP – height and body mass index. Height and weight were in the middle percentile range. Resting BP was classified as normotensive, and the pulse rate was in the main groups nearly the same as in healthy persons (AP patients – 87.6±2.3 bpm and

healthy – 85.1±1.9, p>0.05). But the mean systolic BP in the group of AP patients was significantly lower than in the healthy children (103.6±3.1 and 114.7±2.8, p<0.05). Measurements of PPG indexes in both groups differ nonsignificantly, with the exception of dicrotic wave amplitude (Table 1). The level of main wave amplitude (h1) usually correlates with the level of BP [15], and in our investigation, it was a little lower in the AP group.

Table 1

Comparison of PPG data in AP patients vs. control group

	Index	Group	
		AP	Healthy
1	h1 – amplitude of main wave (mm)	20.7±0.98	22.5±0.99
2	h4 – amplitude of dicrotic notch;	11.1±0.73	12.7±0.86
3	h5 – amplitude of dicrotic wave	0.78±0.29*	1.41±0.39
4	t1 – time between start point of and main wave (msec);	312.5±12.8	317.4±23.5
5	t4 – time between start point and dicrotic notch;	632.8±28.3	648.1±32.8
6	t5 – time between dicrotic notch and end point of pulse wave	770.2±31.1	769.2±34.3

*Note: * - probability of difference, p<0.05*

The only significant difference between groups of children in PPG data was in the level of the dicrotic wave. A more detailed analysis of the dicrotic wave amplitude (Fig. 3) indicates that in 12 patients (53.6%) with pneumonia, it was lower than the amplitude of the dicrotic notch, while in children of the control group, this phenomenon was recorded only in 4 subjects (18.1%).

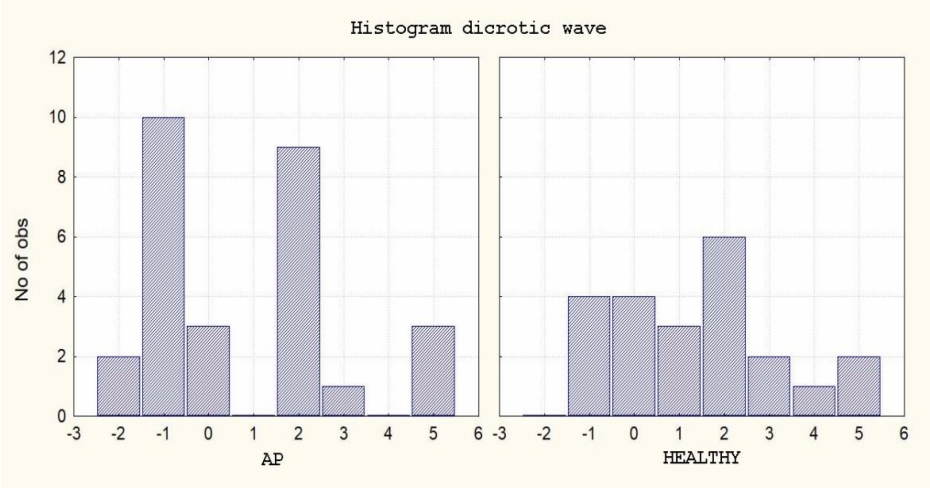

Fig. 3. Frequency of dicrotic wave changes

These changes are well illustrated by the shape of PPG curves (Fig. 4), where the record curve takes on a flattened appearance in AP patients. The level of the dicrotic wave is usually associated with diastolic blood pressure, with a revolving wave from the large vessels of the extremities [14]. With an increase in peripheral resistance to blood flow, a decrease in pulse pressure is also recorded [23]. In our study, there was a weak correlation between the level of the dicrotic wave and pulse BP (R=0.24, p>0.05).

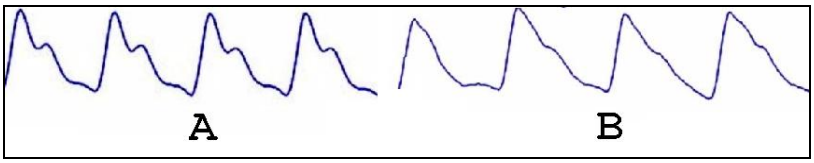

Fig. 4. PPG of healthy child (A) and patient with pneumonia (B)

According to the opinion of American scientists, pneumonia is a highly pro-inflammatory disease, and patients with AP have high circulating levels of cytokines and chemokines that increase malfunction and disorders in the functioning of the cardiovascular system [14]. These differences suggest that AP may have an impact on the cardiovascular system in children, with the presence of microcirculation disorders in a majority of children, underscoring the potential systemic effects of this condition. Our results are in line with previous research (Kartal Öztürk G et al.) reporting altered cardiovascular parameters in children with respiratory disorders [11]. The close result was registered in our previous investigation with obstructive bronchitis in children [24]. The observed alterations in cardiovascular parameters in children with AP may be associated with such factors as hypoxia, endothelial dysfunction, impaired microcirculation, and increased arterial stiffness [16]. In some way, such changes are similar to the effect of COVID-19 infection with systemic microvascular dysfunction and serum cytokines involved in the regulation of vascular function [25].

CONCLUSIONS

Pulse oximetry is widely used in clinical practice in acute pneumonia, and, in addition to assessing blood oxygen saturation, it also contains the results of pulse waves according to photoplethysmogram, which provides important information about the functioning of the vascular system.

Analysis of the pulse waves' nature according to the plethysmographic curve indicates changes in the microcirculatory level and an increase in peripheral resistance to blood flow.

There is an importance of early detection and monitoring of cardiovascular changes in children with AP and developing targeted interventions to ameliorate the circulation process to prevent some complications and improve overall health outcomes.

PROSPECTS FOR FUTURE RESEARCH

It may be rational to select a scoring system for assessing PPG changes and comparing with data in another respiratory pathology, acute bronchitis and bronchiolitis.

AUTHOR CONTRIBUTIONS

All authors substantively contributed to the drafting of the initial and revised versions of this paper. They take full responsibility for the integrity of all aspects of the work.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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