ANNALES ACADEMIAE MEDICAE SILESIENSIS

ACCEPTED MANUSCRIPT

Ann. Acad. Med. Siles. (Online) 2026; DOI: 10.18794/aams/219103

Review

Photoplethysmography (PPG) as a non-invasive technique to measure the level of the LDL-Cholesterol in population

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Received: 18.02.2026, Revised: 05.03.2026, Accepted: 10.03.2026, Published: May 2026

Publisher: Medical University of Silesia, Katowice, Poland

ABSTRACT

Photoplethysmography (PPG) is a low-cost, non-invasive optical technique widely used in clinical settings and wearable devices, which is very up-to-date in cardiovascular diseases. This method is promising to test the level of lipid profile. This review aims to synthesize current evidence on the application of PPG in assessing atherosclerosis and its correlation with lipid profiles, while discussing the technological foundations and future directions of wearable cardiovascular monitoring. A narrative review was conducted based on a literature search of PubMed, IEEE Xplore, Google Scholar and Scopus databases. The analysis included studies focusing on PPG morphology, the physics of light-tissue interaction, and emerging technologies such as graphene-based sensors. The literature indicates that PPG signal morphology, particularly features related to pulse wave velocity and arterial stiffness, correlates with subclinical atherosclerosis. Recent proof-of-concept studies suggest that machine learning models can predict cholesterol levels from PPG features with increasing accuracy. The synthesis of PPG and smartwatches (or electronic rings) is prospective in medical diagnosis, e.g. arteriosclerosis, aging of vessels in real-time or LDL-cholesterol level. That light technic is a versatile technology that bridges the gap between engineering and clinical diagnostics. While it cannot yet replace laboratory blood tests, it serves as a powerful screening tool for early cardiovascular risk stratification. Future research should focus on refining multi-wavelength sensors and AI-driven data analysis.

KEYWORDS

photoplethysmography, level of LDL-cholesterol, smartwatch, optical technique, diagnostic of arteriosclerosis

Introduction

Worldwide, the human population has more common problems with obesity (BMI ≥ 30 kg/m^2). That situation has happened due to change of the life style. People do not practice as much voluntary activities as their ancestry. Their diet has changed too, including higher level of consumed of trans fat. All of that factors might cause the growth of LDL-cholesterol [1].

Cholesterol is the common fat-like substance, that changes the flow of the cell membranes and, as a precursor of bile acids and steroid hormone, flows with other blood cells in blood vessels. There are a few types of cholesterol but the most common is the low-density lipoprotein cholesterol (LDL-C) [2]. The primary element of LDL-C is an apolipoprotein B-100 (apoB). All of the apoB-containing lipids are markers of the major adverse cardiovascular events (MACE). Among patience with a high degree of cardiovascular risk factors, growth level of apoB may prognose a prospect of cardiovascular incident, more than the LDL alone [3]. If the LDL-C level in serum is higher than

160 mg/dl or 4.14 mmol/litter, it is conservative indication for therapy [4]. Moreover, the currently normal level of LDL-C has confirmed strong unfavourable correlation with arteriosclerosis [5] so the common and available method to measure amount of this type of cholesterol could minimalize the chance of vascular blockage or prevent arteriosclerosis. The most affordable measurement of LDL-cholesterol is strict connected with a blood sample via a finger prick, which may be the reason of the complaint during frequent measurement. In the future, is possible to control human health more often but the method to examine our cholesterol level is the variance of method, that was discovered by Alrick Hertzman in 1937. The photoplethysmography (PPG), because it is the main topic of this research, is actually used as the incl. pulse oximeter [6].

This technique is widely known as a low-cost and simple gadget in wearable technology. Paying attention to the numbers, the smartwatches market in 2016 was valued at over $13.2 billion and by the end of 2020 the forecast of its was over $34 billion. It shows that the modern wearable devices are no longer only focused on pulse oximeter and simple calories measurement (including number of the steps during whole day) [7]. The prospective of PPG in modern and open-access health care is very promising, especially during examination the level of LDL-cholesterol.

High LDL-cholesterol level – resonance and diagnostic

The growth level of cholesterol in blood is connected with the steady increase of weight and BMI of population. This tendence was shown clearly in the research organized by Cardiology Department, Lady Reading Hospital, Peshawar in 2008-2009, that involving 2,270 individuals. That research was concentrated on the global problem, that is correlated with a change style of life. As a results of the observation, a corelation between Body Mass Index and a general concentration of cholesterol was positive ($r=0,205$; $p<0,000$). The correlation between increasing the body weight and level of lipids states convergent following tends in another researches [8,9].

Too high level of LDL-C may cause arteriosclerosis, the illness which do not have strong and specific symptoms. This dangerous pathophysiological process is made due to aggregation of the LDL-C in the walls of blood vessels. They make aortic walls stiffen and thicken [10]. The results of these changes are shown in B-mode + USG Doppler (duplex). The mentioned technic is so developed way to diagnose the arteriosclerosis. Despite this, few people can do this test immediately from one day to the next. It seems population is not as aware of parlous consequences of detachment of arteriosclerotic plaque. That situation is life-threatening. Focusing on the diagnostic itself, a scanning visualises the stenosis of the main arteries produced by atheroma. In addition, B-mode pictures a structure of wall of vessel and presences of atheroma. The Doppler's method shows that the velocity of blood flow increases in concert with rise of atheroma. Described diagnostic method based on the ultrasounds and their reflection from flowing blood cells. The frequency of reflected wave is changed compared to output wave [11].

Photoplethysmography and biological optic window

One of the most developing non-invasive methods to measure human life function (e.g. pulse or saturation) is PPG, which base on the different wavelengths reflecting from tissues. This technic has also its base in testing the biochemical parameters. Moreover, the PPG signal's morphology of high LDL-C concentration came to researcher notice, especially at the beginning of systolic phase [12]. A phenomenon of transmitted and indenting the light is described by physic. The initial law describing a mechanism of PPG is the Beer-Lambert law, which is expressed by the formula:

$$I = I_0 \cdot e^{-\alpha \cdot d}$$

I – transmitted light intensity, I_0 – incident light intensity, α – molar absorptivity, which is wavelength-depend, d – the optical path length.

Unfortunately, the BLL is used only for some specific type of medium, that must be homogenic, without distracts or local's field distracts. That was the main reason why this law has modern modifications, that might enable the measurement of the concentration of other substances dissolved in serum [13].

During the cycle of heart nonaction, when the blood volume increases, the fraction of received light is lower than during diastole. By the volume of blood in a vessel is the subjection occurred. This mechanism enables a pulse mensuration by way of PPG [14].

The most significant aspect of PPG is integration of light with tissues, based on the optical attenuation deeper into tissues. The signal is made by absorption and scattering of the photon flux. Scattering in tissues is highly anisotropic. That tendence is done by erythrocytes, which aggregation and orientation is changing during the blood cycle. Whatmore, essential is to isolate the detector and reflector towards to delete a.k.a. the optical crosstalk. Effective signal capture requires minimizing motion artifacts and the influence of ambient light, which is achieved by modulating the emitter signal and using bandpass filters in the receiving system [16].

The crucial fact in mentioned method is the wavelength. A correct choice of length of the wave is also superior aspect. During a selection of the correct wavelength, the researches should concentrate attention on the penetration depth of light in human tissues. The shorter the length of wave is, the surfacer the penetration is. However, the maximum of penetration is observed at 800-900 nm or 1000-1100 nm [14,15]. In the NIR spectral range is the maximum spectral range of lipids (including LDL-C) at 1710-1780 nm, when maximum spectral range of water is 970 nm, 1410 nm and 1925 nm [16]. This interaction between electromagnetic radiation and human biology is governed by the competing forces of absorption and scattering, which typically render the body opaque to most wavelengths. However, a specific spectral gap known as the biological optical

window provides a unique opportunity for light to penetrate deep into living tissue. This phenomenon occurs primarily in the near-infrared spectrum, where the primary absorbers of the human body—haemoglobin in the blood and melanin in the skin—reach their minimum extinction levels, while the absorption of water remains relatively low. There are a few types of biological optic window [17]. The primary optical window, often referred to as NIR-I, spans approximately from 650 nm to 950 nm. Within this range, the molar extinction coefficient of haemoglobin drops significantly, allowing photons to travel several centimetres through highly vascularized zones without being proximately captured by red blood cells. This clearness is further enhanced in the second and third optical windows (NIR-II and NIR-III) at longer wavelengths, where reduced Rayleigh scattering allows for even higher image contrast and deeper penetration. The realistic implications of this window are foundational to modern non-invasive diagnostics. Because blood is relatively "transparent" in this region, clinicians can utilize technologies like pulse oximetry and NIR spectroscopy to monitor arterial oxygen saturation and cerebral activity through intact skin and bone [18,19]. Furthermore, this spectral gap is the basis of photobiomodulation and fluorescence-guided surgery, as it provides a clear pathway for therapeutic lasers and analytic signals to reach targets that would otherwise be obscured by the intense absorption of the visible light spectrum. That different values make an optic window, which could improve the non-invasive method to measure the level of different substances, e.g. LDL-cholesterol.
The commonplace devices, that have built-in ability to PPG, are build of source of light and the photodetector. The system emits the wave, which wavelength is particular definite, and its changed reflection is picked up by the photodetector. There are two options of arrangement of system: transmissional (e.g., in a ring, which is marching in a technological market) and reflectional (e.g., in a smartwatch) [14].

PPG method in diagnose the blood cholesterol levels

To address the limitation of standard invasive cholesterol measurement, a group of researchers investigated a non-invasive approach utilizing PPG. They explored the relationship between extracted PPG waveform features and total cholesterol levels using various supervised learning regression models. The researchers conducted experiment, which included 46 participants. They said cholesterol has better absorbance than other substances dissolved in blood at a wavelength of 1200 nm. To that research they embedded an L13072-0120L (with peak emission wavelength at 1200 nm) and compatible KP-3216P3C photodiode built-in a NellcorTM adult finger clip in order to converted the transmitted light levels into an electrical signal. This signal was digitalized at 100 Hz by the analog-to-digital converter (10-bit resolution) of an Arduino Nano microcontroller. The whole experiment was enriched by the machine learning algorithms. The results of their research demonstrate that a Rational Quadratic Gaussian Process Regression (GPR) model, integrated with the ReliefF feature selection method, significantly outperforms linear regression, regression trees, and support vector machines (SVM).

As the date shows, the coefficient of determination equals 0.832, the computed correlation coefficient *r* equals 0.912 (while $p<0.001$, 95% confidence interval from 0.874 to 0.951) [20]. Moreover, the high level of LDL-C improves the aging of vessels and in the PPG pulse measure method the view of figure is changing [21]. These two things are connected with hardening of vessels. If the tissue is less elastic than it was, the PPG signal is less diverse. That tendence is shown on the Figure 1. In the health, young vessels we come to our attention the presence of two different picks, which represent the systolic and diastolic phase. The systolic phase has higher amplitude of figure because of the power of left part of heart during systole. The second pick of pulse shows the diastole of heart. In health and low LDL-C phase of life these two picks are differentiated by the dicrotic notch. Unfortunately, that tendence is dwindling in the course of time [23]. By the other site, the standardization of the view of figure for e.g. gender, time of life, BMI, could help to point standard's departure. That standardization could speed along the development of health care options in smartwatches.

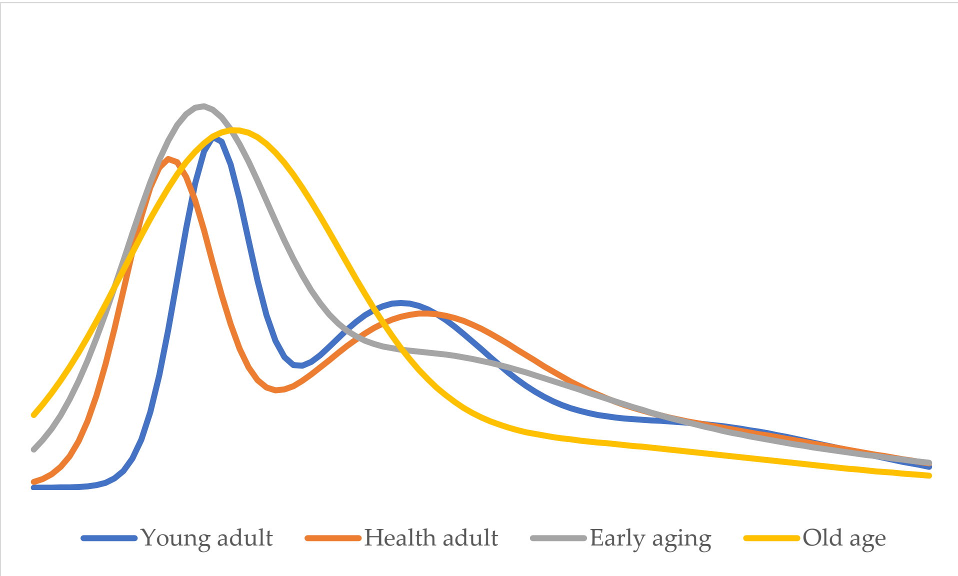

Fig. 1

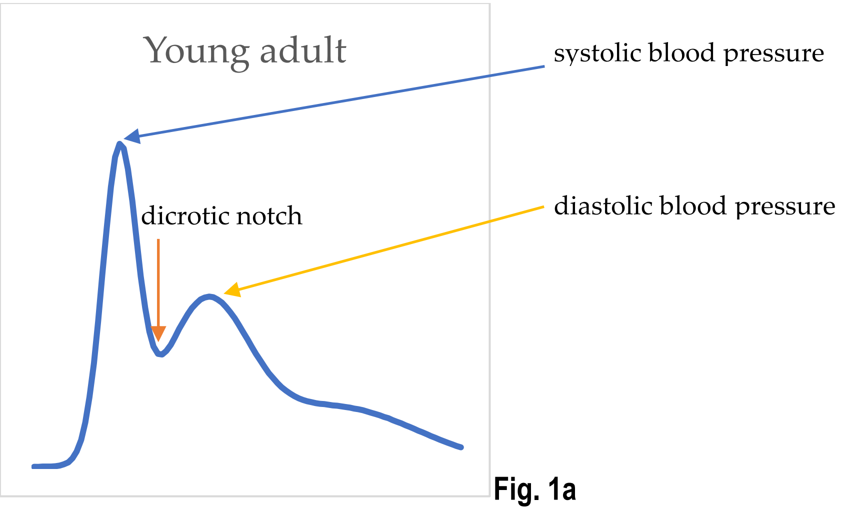

Fig. 1a

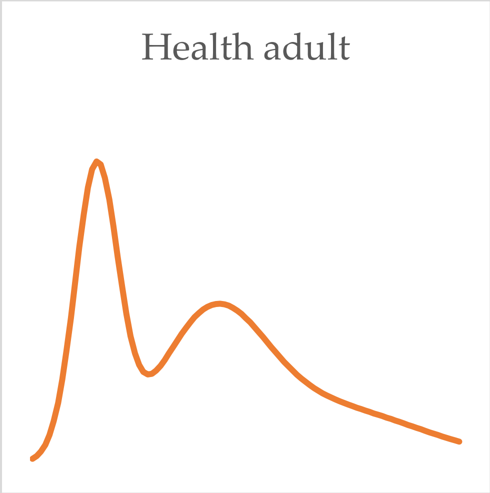

Fig. 1b

Fig. 1c

Fig. 1d

Fig. 1a–1d. Pulse waveform templates in different age group. Redrawn based on Charlton et al. [22] used under CC BY 4.0 and on digitized experimental date.

Future perspective

Like every technical device, the technic of PPG has also a prospect to development. Firstly, the engineers could concentrate on the photodiode. There are so many options to rebuild the detector of the photons. In according to current use silicone diode, one of the most innovative idea is the diode, which base on the graphene-metal junction. This type of detector is befitting to wavelengths, which are responding to NIR or visible [24]. The basic information about that photodetector, which base is graphene and silicon, is that its technical date could burgeon to EQE=98% (external quantum efficiency), when the wavelength is 850 nm [25]. That information might encourage the engineers to develop that photodiode or find the specific structure of low-density cholesterol, that reflect the wavelength at 850 nm value.

Secondly, the subtle change of the wavelength may cause an extremal divide in the technic, that the most important assumption is the change of the wavelength. An optic experimentation may find the most suitable wavelength to reflect photons flux from the LDL-C in blood. That step of developing PPG is also corelated with the decomposition of results into lipoprotein fractions. While the current proof-of-concept model focuses on total cholesterol, clinical cardiology requires precise differentiation between LDL and HDL fractions. Consequently, these observative and findings prompt the following questions regarding the meaning of the view of pulse wave in relation to level of two different type of cholesterol in blood.

To ameliorate the findings, a focus will be placed on expanding the dataset to include diverse clinical patient profiles. This will enable better calibration of the model regarding physiological variables such as age, body mass, and comorbid cardiovascular conditions that may alter PPG waveform morphology. A more extensive cohort of volunteers will enable a robust validation of the ideal wavelength and the specific reflectance properties associated with cholesterol deposits contributing to atherosclerosis.

Conflict of interest

Author declares that she has no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by the author.

Use of AI tools statement

Google Gemini was used to check correctness of language of the article.

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