Study of Equations for the Non-Invasive Calculation of Hemoglobin Levels

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In many medical contexts, hemoglobin measurement is a routine procedure. However, the standard test for this parameter is invasive, which may cause discomfort and increase the risk of infection. Consequently, numerous studies have been conducted to develop non-invasive methods for hemoglobin measurement. This study aims to assess the performance of two equations that utilize optical signal data to estimate hemoglobin levels. The average error between the hemoglobin values calculated by these equations and reference values from the literature was analyzed. The equations yielded average errors of 23% and 4%, achieved by incorporating a correction factor into the second equation. These findings suggest that non-invasive hemoglobin estimation is promising, and including correction factors enhances accuracy.

Keywords: Hemoglobin Levels. Equations. Accuracy.

According to the World Health Organization (WHO), anemia is a condition in which hemoglobin levels in the blood fall below average due to various pathological factors. In Brazil, anemia testing is mandatory when donating blood. However, this test typically involves invasive methods, requiring the extraction of a blood sample for laboratory analysis, which can cause discomfort and pose infection risks for the patient. This has led to a search for non-invasive techniques to measure hemoglobin levels. Photoplethysmography (PPG) is a non-invasive optical technique that uses light sources and detectors to capture variations in light reflection or transmission caused by pulsatile blood flow. Several studies in the literature have employed PPG for hemoglobin measurement. For instance, Jeon and colleagues (2002) [1] proposed a method for measuring hemoglobin using PPG with five wavelengths (569, 660, 805, 940, and 975 nm), achieving a prediction error of 8.5%. Similarly, Pinto, Parab, and Naik (2020) [2] developed a prototype that estimates hemoglobin levels using five LEDs (670, 770, 810, 850, and 950 nm) and a single photodetector. This study explores a system of equations that uses the optical response of PPG to calculate hemoglobin levels to make anemia detection faster and more practical. This approach could facilitate the development of devices that support this technique, making the blood donation process more efficient and reducing the risk of contamination for patients.

Materials and Methods

According to the Beer-Lambert law, the light absorption of a solution is directly related to its concentration. Additionally, the absorptivity of a substance depends on the wavelength of the emitted light. Based on this principle, Pinto, Parab, and Naik (2020) [2] developed a system of equations that relates the ratio of optical responses in pulsatile and non-pulsatile blood to a PPG signal with the concentrations of oxygenated and deoxygenated hemoglobin. This system is represented in Equation 1, where C_{HbO2} and C_{HB} correspond to oxygenated and deoxygenated hemoglobin concentrations, respectively; $R\lambda$ represents the ratio of the optical signal response between pulsatile and non-pulsatile blood at each wavelength, and ϵ_{HbO2} and ϵ_{Hbr} represent the absorptivity coefficients of oxygenated and deoxygenated hemoglobin, respectively, at each wavelength.

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Robles, Chowdhury, and Wax (2010) [3] introduced a correction factor related to the thickness of the absorber in a system of equations used to calculate hemoglobin via the transmission method (Equation 2). In this equation, LLL represents the correction factor, while rrr is a factor related to light reflection.Using the systems presented in Equations 1 and 2, blood hemoglobin levels can be calculated by summing the concentrations of oxygenated and deoxygenated hemoglobin.

Results and Discussion

To evaluate the performance of the equations, we used PPG signal data (both pulsatile and non-pulsatile optical responses, from which the R, body mass index (BMI), and hemoglobin data from the study by Chen and colleagues (2023) [4] involving ten individuals. Table 1 presents the values for the absorptivity coefficients of oxygenated and deoxygenated hemoglobin at different wavelengths.

Figure 1 presents the results obtained using the equation proposed by Pinto, Parab, and Naik (2020) [2]. Figure 2 shows the hemoglobin calculations using the same dataset but applying the system developed by Robles, Chowdhury, and Wax (2010) [3]. The average error using Equation 1 was 23% (3.3 g/dL), whereas Equation 2 showed an average error of 4% (0.5 g/dL), indicating that adding the correction factor in Equation 2 significantly improved accuracy. However, the correction factor is influenced by skin tone, blood perfusion, and other physiological parameters, which were not addressed in this study. Despite this, the results demonstrate that PPG data can accurately calculate hemoglobin levels. Further research on these influencing factors is necessary to achieve even greater precision in hemoglobin calculations.

Equation 1. Equation for calculating hemoglobin by Pinto, Parab, and Naik (2020).

$$\begin{cases} \epsilon_{HbO2}(\lambda_1) * C_{HbO2} + \epsilon_{Hbr}(\lambda_1) * C_{Hbr} = R_{\lambda_1} \\ \epsilon_{HbO2}(\lambda_2) * C_{HbO2} + \epsilon_{Hbr}(\lambda_2) * C_{Hbr} = R_{\lambda_2} \\ \epsilon_{HbO2}(\lambda_3) * C_{HbO2} + \epsilon_{Hbr}(\lambda_3) * C_{Hbr} = R_{\lambda_3} \\ \epsilon_{HbO2}(\lambda_4) * C_{HbO2} + \epsilon_{Hbr}(\lambda_4) * C_{Hbr} = R_{\lambda_4} \end{cases}$$

Conclusion

The evaluation of hemoglobin calculation using the proposed systems of equations yielded

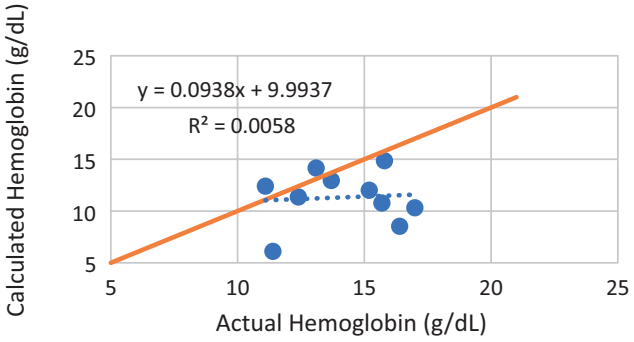
Equation 2. Equation for calculating hemoglobin proposed by Robles, Chowdhury, and Wax (2010).

$$\begin{cases} \epsilon_{HbO2}(\lambda_1) * C_{HbO2} + \epsilon_{Hbr}(\lambda_1) * C_{Hbr} - \frac{1}{L} * \ln(r) = -\frac{1}{L}\ln(R_{\lambda_1}) \\ \epsilon_{HbO2}(\lambda_2) * C_{HbO2} + \epsilon_{Hbr}(\lambda_2) * C_{Hbr} - \frac{1}{L} * \ln(r) = -\frac{1}{L}\ln(R_{\lambda_2}) \\ \epsilon_{HbO2}(\lambda_3) * C_{HbO2} + \epsilon_{Hbr}(\lambda_3) * C_{Hbr} - \frac{1}{L} * \ln(r) = -\frac{1}{L}\ln(R_{\lambda_3}) \\ \epsilon_{HbO2}(\lambda_4) * C_{HbO2} + \epsilon_{Hbr}(\lambda_4) * C_{Hbr} - \frac{1}{L} * \ln(r) = -\frac{1}{L}\ln(R_{\lambda_4}) \end{cases}$$

Table 1. Absorptivity coefficients of oxygenated and deoxygenated hemoglobin at various wavelengths.

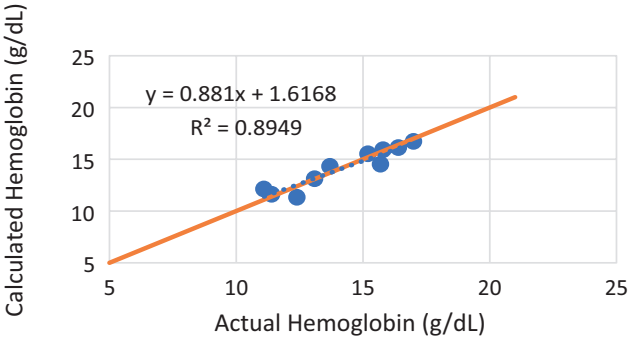
Wavelength	ϵ_{HbO2} cm^{-1}/M	ϵ_{Hbr} cm^{-1}/M
660	319.60	3,226.56
740	446.00	1,115.88
850	1,058.00	691.32
940	1,214,80	708.16

Figure 1. Comparison between actual and calculated hemoglobin using the equation by Pinto, Parab, and Naik (2020).



promising results, particularly with the inclusion of correction factors. A more comprehensive investigation of these factors is recommended to improve the accuracy of hemoglobin estimation further. Chen and colleagues (2023) [4] conducted a similar study, comparing results from logistic regression and machine learning models, and reported deviations of 0.762 g/L. Future studies should investigate comparing different methods and equations for calculating hemoglobin using optical techniques, considering variables such as skin tone, blood perfusion, and temperature. These factors are crucial, as they directly influence the optical signal received during measurement.

Figure 2. Comparison between actual and calculated hemoglobin using the equation by Robles, Chowdhury, and Wax (2010) [3].



References

1. Jeon KJ, Kim S-J, Park KK, Kim J-W, Yoon G. Noninvasive total hemoglobin measurement. Journal Of Biomedical Optics 2002;7(1):45. SPIE-Intl Soc Optical Eng. http://dx.doi.org/10.1117/1.1427047.
2. Pinto C, Parab J, Naik G. Non-invasive hemoglobin measurement using embedded platform. Sensing And Bio-Sensing Research 2020;29:100370. Elsevier BV. http://dx.doi.org/10.1016/j.sbsr.2020.100370.
3. Robles FE, Chowdhury S, Wax A. Assessing hemoglobin concentration using spectroscopic optical coherence tomography for feasibility of tissue diagnostics. Biomedical Optics Express 2010;1(1):310–317.
4. Chen Z et al. Research on a non-invasive hemoglobin measurement system based on four-wavelength photoplethysmography. Electronics 2023.12(6):1346.