ORIGINAL ARTICLE

Current Landscapes and Future Directions for Non-Invasive Hemoglobinometers

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ABSTRACT

Hemoglobin estimation plays an essential role in medical diagnostics, serving as a key indicator of oxygen-carrying capacity, and is an important index for conditions like anemia, polycythemia, and chronic diseases. The determination of HB is a measure of erythrocyte count and it is measured through invasive methods like venipuncture or fingerstick samples and is frequently performed by using laboratory-based hematology analyzers. Although these methods have been highly accurate, easy to use, they are associated with discomfort, risk of infection, and present practical challenges, particularly in under-resourced areas or in patients requiring frequent testing. Non-invasive hemoglobinometers provide an innovative alternative, as they obviate the need for blood draws. Prediction of haemoglobin levels by such devices depends on optical and bioimpedance-based technologies- including near-infrared spectroscopy, pulse oximetry, photoacoustic spectroscopy and laser sensors- by analysing the interaction of light with haemoglobin and the changes thereof caused by different variables. They are mobile, easy to use, and offer rapid results, making them ideal for use in critical care, pediatric, geriatric, and perioperative settings. Non-invasive devices are better tolerated by patients and are safer, but there are several limitations, including decreased accuracy in individuals with darker skin tones, variability in blood flow, and the influence of environmental factors. Advanced algorithms have been implemented to improve the reliability, but further develpoment is needed for universal clinical acceptance. The future of non-invasive hemoglobinometry is promising, particularly in emergency care, mobile health applications, and global health initiatives. Timely, cost-effective diagnosis and management of hematological conditions, especially in underserved populations could be feasible by integration with broader health monitoring systems.

KEY WORDS: Hemoglobin, Diagnostics, Non-Invasive Hemoglobinometers

INTRODUCTION

Hemoglobin estimation is a crucial component of medical diagnostics, serving as a key indicator of a person's overall health. Hemoglobin (Hb) is a protein in red blood cells responsible for transporting oxygen from the lungs to the body's tissues and carrying carbon dioxide back to the lungs for exhalation. Accurate measurement of hemoglobin levels is important for assessing the blood's ability to deliver oxygen effectively and identifying potential underlying health problems.[1]

Anemia is one of the most common issues detected through hemoglobin measurement, a condition where a person has insufficient hemoglobin or red blood cells to meet their body's oxygen needs. Anemia can result from a variety of causes, including nutrient deficiencies (such as iron or vitamin B12), chronic illness, or inherited disorders like sickle cell anemia and thalassemia. Timely detection for diagnosing anemia through hemoglobin testing and beginning appropriate treatment is critical to avoid complications like fatigue, weakness, or organ damage.[1-3]

Hemoglobin levels can also provide valuable insights into other health conditions. For example, high hemoglobin levels might indicate polycythemia, a disorder in which the body produces too many red blood cells, potentially increasing the risk of blood clots and stroke. Low hemoglobin levels may point to other problems, such as chronic blood loss, kidney disease, or bone marrow disorders.[4]

Monitoring hemoglobin levels is essential for patients undergoing treatments such as chemotherapy or surgeries that can affect blood production or result in significant blood loss. It also plays a key role in assessing the health of pregnant women, as pregnancy can impact hemoglobin levels due to changes in blood volume.[1-2,5] Invasive techniques for measuring hemoglobin typically involve obtaining a blood sample through methods like venipuncture or fingerstick that provide direct and accurate measurements of hemoglobin levels and are widely used in clinical practice. The gold standard for hemoglobin measurement is the laboratory-based hematology analyzer, which involves extracting blood from the patient, followed by its analysis in specialized equipment, often using methods like colorimetric or electrochemical assays to determine the hemoglobin concentration.[6,7]

One of the primary advantages of invasive hemoglobin measurement is its accuracy. The blood sample provides a precise and reliable reading, crucial for diagnosing various medical conditions, such as anemia, polycythemia, and blood disorders.[1] Invasive techniques are also capable of identifying subtle fluctuations in hemoglobin levels, which can help in monitoring chronic conditions or evaluating the effectiveness of treatments, such as iron supplementation or blood transfusions.[2]

However, despite their accuracy, invasive methods come with several disadvantages. One of the most significant drawbacks is the discomfort and potential pain associated with drawing blood in patients who are sensitive to needles or who require frequent testing. In some cases, there may be complications, such as bruising, infection, or hematoma formation, at the puncture site.[6,8-9] Another disadvantage is the requirement for specialized medical personnel to perform the procedure, which can be time-consuming and costly. The process also necessitates laboratory facilities and equipment for analysis, making it less convenient for routine or point-of-care testing. Additionally, invasive methods can be unsuitable for certain patient groups, such as neonates, elderly individuals, or those with needle phobia. Furthermore, the need for repeated blood sampling in patients who require frequent monitoring can lead to patient discomfort, increased healthcare costs, and logistical challenges, especially in resource-limited settings.[7,10] Hence the need for non-invasive techniques for hemoglobin estimation is of paramount importance.

PRINCIPLES OF NON-INVASIVE HEMOGLOBIN MEASUREMENT

Non-invasive hemoglobin measurement is based on the interaction between light and blood.[6] These devices work on the principle that hemoglobin has specific optical properties which can be measured using various types of sensors.[11]

Technique	Mechanism of Action
Near-Infrared Spectroscopy (NIRS)	Near-infrared light interacts with hemoglobin in the blood. The absorption of light at different wavelengths helps estimate hemoglobin levels.
Pulse Oximetry	Pulse oximeters estimate hemoglobin levels by utilizing the light absorption properties of oxygenated and deoxygenated hemoglobin.
Photoacoustic Spectroscopy	Combines light absorption and acoustic waves which are absorbed by hemoglobin causing thermal expansion, generating acoustic waves detected by sensors, enabling hemoglobin estimation.
Laser-Based Sensors	Focused laser light interacts with blood to estimate hemoglobin levels, differentiating between oxygenated and deoxygenated hemoglobin.

METHODS OF NON-INVASIVE HEMOGLOBIN MEASUREMENT

Non-invasive hemoglobin meters are portable devices which are handheld or wearable, that works on the principle of bioimpedance thereby providing continuous or periodic readings without the need for blood sampling.[8] Most non-invasive devices rely on optical sensors which emit light that is absorbed by the blood and reflected back to a detector. The amount of absorption and reflection is analyzed to estimate the hemoglobin concentration. Many modern devices incorporate advanced algorithms to adjust readings based on various factors like skin color, ambient light, and blood flow.[12] These devices measure the variation in light absorption with each heartbeat. Where with each contraction, there is a change in the amount of light absorbed.

Pulse oximeters can estimate hemoglobin levels and oxygen saturation continuously while bioimpedance spectroscopy measures tissue impedance to estimate hemoglobin concentration.[13] Changes in impedance, influenced by blood volume and tissue composition, can provide indirect information about the hemoglobin levels.[14,15]

INDICATIONS & CONTRAINDICATIONS FOR NON-INVASIVE HEMOGLOBIN MEASUREMENT

Indications	Contraindications
Chronic anemia[7]	Open wounds[7]
Blood transfusions[9]	Burns[7]
Erythropoiesis-stimulating agents[10]	Rashes[7]
After major surgeries like cardiac or abdominal procedures[11-12]	In individuals with high levels of subcutaneous fat[9]
Critical care units[13]	Extremely hot or cold weather can affect the device's performance[14]
Pregnant women[14]	
Patients with chronic kidney disease or cancer[15]	

ADVANTAGES OF NON-INVASIVE HEMOGLOBIN MEASUREMENT

Advantages	Disadvantages
Comfortable[7]	Skin pigmentation[7-9]
Convenient[7]	Ambient lighting[7-9]
Safe[7]	Blood flow[7-9]
Eliminate the need for needles or blood draws[9]	Fluctuating [7-9]
In patients with chronic anemia[9]	Expensive[7-9]
In cancer patients receiving chemotherapy[9]	Require specialized training [7-9]
In individuals with needle aversion[9]	Influenced by environmental factors[7-9]
In critical care or during surgeries[13]	
In pediatric patients[13]	
In geriatric patients[14]	
Patients requiring regular monitoring[14]	

MECHANISM OF ACTION OF NON-INVASIVE HEMOGLOBIN METERS

Non-invasive hemoglobin meters are compact, portable devices following the principle of optical sensing aiming to provide quick and accurate hemoglobin measurements working in following steps:

Light Emission and Detection: The device emits light through the skin targeting a blood vessel in the fingertip, earlobe, or wrist getting absorbed by the hemoglobin. The remaining light is either reflected or scattered back toward the device's detector.[7]

Signal Processing and Calculation: The sensor detects the reflected or scattered light and analyzes it to determine the specific wavelengths. The device uses this data to calculate the hemoglobin concentration.[9]

Real-Time Results: The results are displayed on screen instantaneously immediately indicating the hemoglobin levels.[14]

FUTURE OF NON INVASIVE HEMOGLOBIN METERS[7,15]

Emergency and Remote Healthcare: Non-invasive hemoglobin meters will play a pivotal role in emergency medicine and trauma where rapid blood loss is a concern as these devices could enable healthcare professionals to perform quick and accurate assessments, potentially saving lives.

Post-Surgical and Post-Transfusion Monitoring: After major surgeries, monitoring hemoglobin levels is essential in real-time, enabling medical staff make timely decisions.

Integration with Broader Health Monitoring Systems: The integration of non-invasive hemoglobin meters with other health monitoring systems can prove to be a boon for patients with chronic diseases or those undergoing complex treatments like chemotherapy.

Mobile Health Applications: Mobile health (mHealth) apps could integrate non-invasive hemoglobin meters enabling patients to track their hemoglobin levels thereby providing them with a more holistic view of their well-being.

Global Health and Accessibility: Non-invasive hemoglobin measurement has the potential to significantly impact global healthcare as they can provide a cost-effective and accessible solution for monitoring anemia and other blood-related conditions. These devices would be particularly beneficial in areas where iron deficiency anemia is prevalent, such as in pregnant women and children.

INVASIVE TECHNIQUES AND DEVICES FOR HEMOGLOBIN ESTIMATION

Traditionally, hemoglobin concentration is measured using both invasive and non-invasive techniques. Invasive techniques have long been the standard in clinical settings due to their accuracy and reliability. While non-invasive techniques are gaining traction for their convenience, invasive methods remain essential in many diagnostic and monitoring scenarios. This discussion focuses on invasive techniques and devices used for hemoglobin estimation.[16]

One of the most common invasive methods for measuring hemoglobin is the spectrophotometric method where a hemoglobinometer is used where blood sample is mixed with a reagent which lyses red blood cells, releasing hemoglobin into the solution. It involves using a blood sample to assess the absorbance of light at a specific wavelength. This method is highly accurate but requires laboratory facilities and skilled personnel to perform.[17] In the cyanmethemoglobin method, blood is mixed with a cyanide-containing reagent that converts hemoglobin into cyanmethemoglobin and this method is preferred due to its high accuracy and reliability.16 The introduction of automated blood analyzers has revolutionized invasive hemoglobin estimation as they provide a complete blood count (CBC) and deliver an accurate hemoglobin concentration.[18.19] These analyzers count, classify and measure hemoglobin levels by detecting the color intensity of the blood sample.[16]

The point-of-care (POC) devices that provide hemoglobin measurements using invasive techniques are portable and designed for use in kind of setup. One such device is the Hemocue hemoglobin system, which involves a small, portable analyzer and microcuvettes. The system uses photometry to measure the absorbance of the blood sample at specific wavelengths. These devices are preferred due to their convenience and rapid results.[16-18]

CONCLUSION

Non-invasive hemoglobin meters present a novel approach for measuring hemoglobin levels thereby eliminating the need for invasive blood samples where the devices utilize advanced technologies to provide quick and painless readings. Patient comfort, less infection, and rapid results are the advantages of this technique making them highly beneficial in critical care, routine check-ups, and remote healthcare.

The future of non-invasive hemoglobin meters is bright as advancements in armamentaria progress; these devices will be more reliable and user-friendly although challenges such as calibration and accuracy in certain clinical conditions tend to persist as of now.

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