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Methods and Devices to Determine Hemoglobin Non Invasively: A Review

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Abstract— ***Aim of this study is to review the methods used to determine hemoglobin non invasively while many conventional devices and techniques are available for measurements readily in the market. This paper discusses the advantage of non invasive measurement specifically focusing on techniques like pulse oximeter, occlusion spectroscopy, opto acoustic method, diffuse reflectance spectroscopy and the devices that are based on these technologies. The study also explores the frontier involving new methods such as image processing techniques which hold even better scope applied for hemoglobin detection.***

Index Terms—Pulse Oximetry, Opto acoustic, Near Infra red Spectroscopy, Diffuse reflectance spectroscopy

Introduction

A person is said to be anemic when the number of red blood cells or their oxygen carrying capacity is insufficient to meet the physiological needs. Deficiency in iron is said to be the main cause of anemia around the world. Anemia continues to be one of the most serious problem in the world. It is estimated that nearly 1.6 billion people suffer from Iron Deficiency worldwide [1].

Hemoglobin is the total blood count in the blood sample which is important in carrying oxygen from lungs to various other parts in exchange of carbon dioxide. Any abnormality seen in the hemoglobin count would cause anemia. Hematocrit is defined as the volumetric determination of red blood cells in the blood. The standard hematocrit value for men is 42% to 52% , for women 37% to 47% and for new born it is 53% to 65%[2]. A normal hematocrit value defines normocytemia, lower valueis defined as oligocytemia, and higher value is defines as polycythemia. Amongst the erythrocyte parameters hematocrit, hemoglobin, red cell count, we can establish the diagnosis of anemia. General medical and nutritional practices assumes that both hemoglobin and hematocrit are equally useful in detecting anemia and that they can be used interchangeably for anemia screening [3]. Both invasive and non-invasive methods have been used to detect hemoglobin count in the blood. General hospital setting utilize spectrophotometric analysis of light absorbance based on Beer- Lambert law, the other methods have advantage of varying conductivities of blood at different concentrations [4].

In the present days, most commonly used method for hemoglobin measurement is by collecting blood by pricking the finger and transferring it to a cuvette which is then put in a analyzer and the hemoglobin is measured spectrophotometrically [5]. Attempts to develop more accurate, easier-to-use, and sustainable hemoglobin detection technologies have been under way for many years. Noninvasive technologies have been of special interest, and with recent advances in technology and expertise and continued concern about the risks of blood-borne diseases, there have been renewed efforts among researchers and manufacturers to develop such technologies.

Methods : Pulse Oximetry

This technique has been widely accepted in non invasive measurements since there is no patient interface. The recent developments have shown pulse oximetry as an effective non−invasive technique. In pulse oximetry, oxygen saturation is calculated from the signal which is related to inflow of arterial blood to other body segments. The intensity of light transmitted across the fingertip, varies and a pulsatile signal, that varies in time with the heart beat, is superimposed on a d.c. level. Generally amplitude of this pulsatile signal is approximately 1% of the d.c. level. It is assumed that increase in attenuation of light is due to the flow of arterial blood to the fingertip, which in turn enables to calculate the oxygen saturation by removing the attenuation from the total attenuation leaving only pulsatile part for the dual−wavelength determination of oxygen saturation[21].

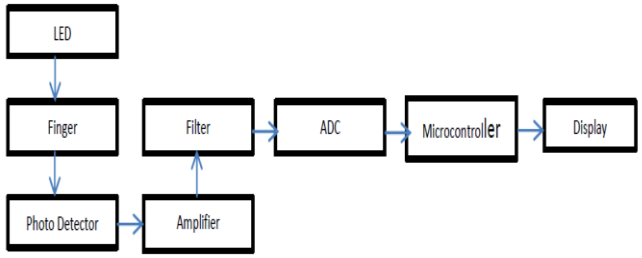

Fig 1 Pulse Oximeter Block diagram

Barker et al[6] reports a review on multiwavelength pulse oximetry. The New rainbow Technology developed by Masimo Corp. have enabled the measurement of carboxyhemoglobin(COHb) , methemoglobin (MetHb) and the total hemoglobin (Hbt) non invasively using multiwavelength pulse oximetry. The device has overcome the earlier limitations of the pulse oximetry, which had only two wavelengths to be considered which has resulted in serious SpO2 errors.

Fig 2.a Masimo- Pronto 7(Pulse Oximeter) Coutesy :www.masimo.com

Doshi et al[12] have proposed an optical sensor system for hemoglobin measurement. Basically this technique uses principle of pulse oximeter. Oxygenated and deoxygenated hemoglobin absorbs different amount of light at two wavelengths 660nm and 940 nm. Light is transmitted through an area of skin on finger which is detected by a photodiode. Hb is calculated by determining the ratio of pulasating to nonpulsating component of both red and IR signal. The authors claim to have tested the system for 60 subjects and selected wavelengths are promising for hemoglobin measurement.

Fig 2.b Biosense – TouchHb (Pulse Oximeter)
Coutesy : www.biosense.in

Opto acoustic Method

In the optical sensing methods, opto acoustic technique has proven to be an effective one which mainly focuses on using the differences that occur in absorption coefficients of oxyhemoglobin and deoxyhemoglobin in accurate monitoring and quantifying blood oxygenation. This technique uses short laser pulses which generate optoacoustic waves also known as ultrasonic waves in absorbing media [21].These waves are detected using a acoustic transducer and depth of the signal determines the time resolution of the resultant signal. Scattering and attenuation of ultrasonic waves in tissues are much less compared with those of light waves. Detection and analysis of the temporal characteristics and amplitude of the optoacoustic pressure waves can be used for tissue characterization with submillimeter resolution. [21].

H.-P.F. Brecht et al[9] reports a non invasive measurement of hemoglobin concentration with optoacoustic technique. In this method the optoacoustic probe was used which laterally scans blood vessels phantom. An average of 32 signals where captured and processed. Blood vessels were simulated using a Plexiglas chamber with attached silicone tubes of different diameters. The obtained result suggested that this technique would provide accurate, noninvasive measurement of total hemoglobin (Hbt) in real time.

Fig 1.c Orsense – Glasswing (Occlusion Spectroscopy)
Coutesy : www.orsense.com

Diffuse reflectance spectroscopy

Diffuse reflectance spectroscopy is a non invasive technique that measures the characteristic reflectance spectrum produced when the light is passed through the medium. The basic mechanisms involved are absorption and scattering, which always vary with the wavelength to produce the reflectance spectrum which is recorded and has the information about the optical properties and also structure of the medium being measured [13].

Bender et al[13] have proposed UV-VIS diffuse reflectance spectroscopy based device for monitoring tissue hemoglobin. Authors claims to have conducted a study on 10 patients of which 9 undergoing surgery which checks the feasibility of this method in the visible wavelength range for blood loss during surgery. Ratios of raw diffuse reflectance at wavelengths pairs were calculated as first pass for estimating hemoglobin concentration. Authors claim to have found the best hemoglobin correlations when the ration at isobestic points of oxy and deoxyhemoglobin, specifically at 529/500nm. Diffuse reflectance spectroscopy measurements were performed using SkinSkan(JY Horiba, Edison, NJ)spectrophotometer.

Saigo et al[11] have proposed evaluation of efficacy of non invasive hemoglobin monitoring device(Astrim, Sysmex, Kobe, Japan). This device uses near infrared spectroscopy with the optical images taken by the CCD camera located at other side of the light sources. The incident light is transmitted from LED and CCD into the finger, which undergoes absorption and scattering in the human finger. Hemoglobin displays absorption and tissue scatter the incident light. Images of vessels located at the interphalangeal joints are first detected, after which the absorption pattern of near infrared radiation is analyzed to calculate hemoglobin levels. The authors claim to have evaluated efficiency of Astrim for healthy volunteers and patients with blood related disorders. The results indicated that the efficiency of Astrim at this level of precision is restricted at the clinical usage.

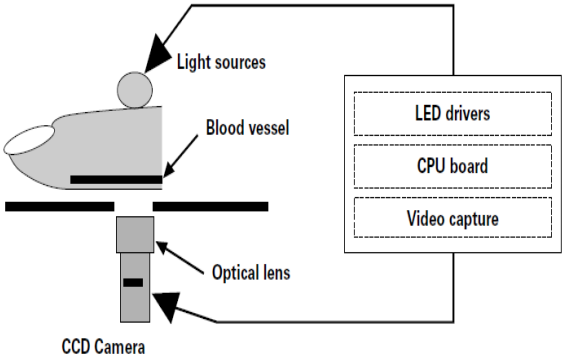

Fig 2 : Image capture using principle near infrared radiation
Saigo et al[11]

Photoplethysmography

The other optical technique which has been used in measuring the blood volume changes is photoplethysmography (PPG). The basic components of PPG are a light source and a photodetector for illuminating the skin, and measuring the smallest variations in light intensity respectively. Variation in the intensity is due to

associated changes in perfusion in the catchment volume. Red or near infrared wavelength are the operating regions of PPG. The most recognized waveform feature is the peripheral pulse, and it is synchronized to each heartbeat. Despite the simplicity the origins of the PPG components of the PPG signal are not fully understood [22]. The two main PPG operational configurations are trans-illumination mode operation where the tissue sample (e.g. fingertip) is placed between the source and detector, and in the reflection ('adjacent') mode operation the LED and detector are placed side-by-side. Out of the two modes, the transmission mode PPG imposes more restriction than the reflection mode PPG on the body locations available for study.

Phillips et al[10] have proposed an evaluation of two types of sensor using a tissue phantom which is perfused with a blood substitute. In this technique an electrical sensor and infrared optical sensor where used to measure blood volume changes during every cardiac cycle and detection of erythrocyte bound hemoglobin respectively. The authors claim to have identified the changes demonstrated by both sensors to changes in pulse volume (plethysmography). The authors conclude that a technology dependent on measuring the pulse signal requiring adequate blood supply to the peripheral vessels may produce unreliable readings under low blood pressure.

Imaging Based Technique

There has been a study proposed, whether digital photography can be used to determine hemoglobin values.

Suner et al[14] have proposed non invasive determination hemoglobin by digital photography. Authors propose to estimate amount of hemoglobin in a bodily fluid from the color of perfused tissue surface of a subject using digital camera, the method involves non invasively capturing single image of light reflected from the surface of palpebral conjunctiva of an eyelid. This blind study was conducted in tertiary care emergency department. The authors report that it is possible to derive an objective method that correlates to the conjunctiva color with the measured hemoglobin. Authors claim to have found this application useful in regions with limited resources.

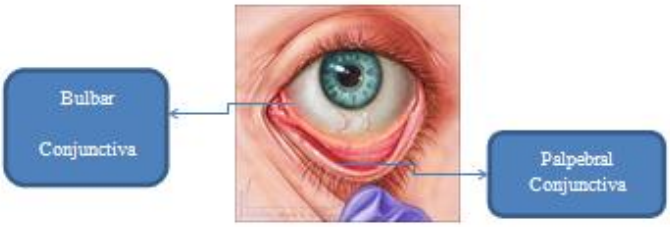

Figure 3 : Conjunctiva
Courtesy : www.magnummedical.com

Discussion

In this paper we provide an overview of various methods and the devices used to determine hemoglobin non invasively. Its evident that each method has its own merits and limitation for practical application for large scale deployment. Substantial amount of research has been done in the optical based techniques. There have been number of devices in the market which are approved by FDA and other government agencies. Pulse oximetry, opto acoustic method, near infra red spectroscopy, photoplethysomography and imaging techniques have been analyzed by various groups and the devices of the same have been tested on the patients under different settings. We have identified that following reasons may be responsible for failure in wide spread recognition of these techniques,

- Existing devices based on optical methods needs patient interface which may be infectious and in turn may lead to complications.

Figure 4.1 : Factors effecting Hb measurement
Courtesy : www.who.com

Figure 4.2 : Factors effecting Hb measurement
Courtesy : www.who.com

- Procurement and maintenance of technologies such as Photoplethysmography adds hardware cost per health worker.
- People in developing countries have not shown interest in using these devices due to their cost.

There hasn't been substantial research in the imaging based techniques to determine hemoglobin. A group which has worked on the digital photography method has shown the importance of having a non invasive and non interface device. But calibration for illumination, skin color, genetic differences, change of color due to illness, stabilization of the image haven't been taken care of.

There have been other developments in the imaging based techniques like android applications, Mac applications which are used to determine the hemoglobin count which we haven't reviewed in this paper. Table 1 gives a comparison of optical methods and imaging methods

Usability Criteria	Optical Methods	Imaging Method
Skill Level	High	Low
Cost	High	Low
Language Independence	No	Yes
Biocompatibility	Infectious due to patient interface	No Patient Interface
Wireless	No	Yes
Portability	Yes	Yes
Weight	More	Less
Battery Life	Less	Rechargeable

Table 1 : Comparison of Optical and Imaging techniques

Conclusion

Non Invasive methods have been in use and also have been most promising due to the convenience, cost and scalability. The paper has reviewed the methods and devices used to determine hemoglobin count. Imaging based techniques have shown lot of advantages over the optical methods. There needs to be focus in calibration for illumination, skin color, genetic differences, change of color due to illness, stabilization of image in imaging based techniques. Further exploration of applying imaging techniques for other potential sites for enhancement of accuracy is a matter of scientific research. Pursuing further work in this offers a great promise in early detection of disease conditions.

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