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ENUMERATEBLOOD HEMOGLOBIN BY NON-INVASIVE TECHNIQUES: A REVIEW

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ABSTRACT

Blood consists of many parameters such as hemoglobin, oxygen, white blood cell, red blood cell, platelets and plasma. Hemoglobin is the main parameter of human blood, which carries oxygen from the lungs to the other parts of the body and carries carbon di-oxide back to the lungs from other parts of the body. Measurement of hemoglobin helps a medical practitioner to diagnose several diseases as the health condition of patient. Nowadays, Invasive methods are used to measure the hemoglobin concentration, where blood is taken from the patient and subsequently analyzed. Apart from the discomfort of drawing blood samples, an added disadvantage of this method is the delay between the blood collection and its analysis, which does not allow real time patient monitoring in critical situations. A non-invasive method allows pain free, continuous patient monitoring with minimum risk of infection and facilitates real time data monitoring allowing immediate clinical reaction to the measured data. In this review paper,different methods that are used for the non-invasive measurement of hemoglobin are discussed.

Keywords: *hemoglobin, blood, invasive, non-invasive.*

I. INTRODUCTION

Blood consists of many parameters such as hemoglobin, oxygen, white blood cell, red blood cell, platelets and plasma [17]. Hemoglobin is made up of four protein molecules, called globulin chains; each globulin chain contains an important central structure called the heme molecule [19]. Hemoglobin is a metal protein present in the red blood cells of blood plasma [18].Hemoglobin is the main parameter of human blood, which carries oxygen from the lungs to the other parts of the body and carries carbon di-oxide back to the lungs from other parts of the body.Measurement of hemoglobin helps a medical practitioner to diagnose several diseases as the health condition of patient. Hemoglobin (Hb) concentration measurement is among the most commonly performed blood tests, usually as part of a complete blood count (CBC). Lower than normal Hb may be due to anemia of various types, bleeding, erythropoietin deficiency (from kidney disease), lead poisoning, malnutrition, nutritional deficiencies of iron, folate, vitamin B12 and vitamin B6, over hydration and red blood cell destruction associated with transfusion reaction. Higher than normal Hb may be due to congenital heart disease, corpulmonale, increased red blood cells due to too much erythropoietin, pulmonary fibrosis and polycythemia vera. Decrease in Hb level due to different causes leads to symptoms of various types of anemia, wherein iron deficiency anemia (IDA) is the most prevalent among Asians (UNICEF 2004) [7].A hemoglobin test reveals how much hemoglobin is to be found in the blood. With this information anemia (a low hemoglobin level) and polycythemia vera (a high hemoglobin level) can be a diagnosed and monitored [14].

Currently, invasive methods are used to measure the hemoglobin concentration, where blood is taken from the patient's body and subsequently analyzed. Apart from the discomfort of drawing blood samples, an added disadvantage of this method is the delay between the blood collection and its analysis, which does not allow real time patient monitoring in critical situations [2][3]. The drawn up blood is then subjected to chemical analysis and the hemoglobin content in terms of milligram of hemoglobin per deciliter of blood is ascertained. To implement this procedure, the services there is requirement of a trained paramedical staff: To extract the blood sample, a laboratory technician: To perform the chemical analysis and a pathologist: To verify and interpret the results are required

[10][18]. For invasive method, the complete blood count (CBC) is one of the methods to determine the amount of hemoglobin by analyzing the blood component in the tube. Using biosensor is one of the methods to measure the amount of hemoglobin [20]. In rural area, for evaluation of Hemoglobin pallor test or filter paper test or Sahli method have been used [9]. Some of the other methods for evaluation of Hb are Copper sulfate method, Hematocrit method by centrifuge, Lovibond type comparator method, Grey wedge photometer method, Hemocue method and cyanmethemoglobin method. In these methods blood is drawn from the patient and is used to evaluate Hb using different reagents and some equipment [9]. In Hemoglobinocyanide method, hemoglobin is chemically converted to form a cyanmethemoglobin which is having maximum absorption around 540nm wavelengths. The hemoglobin concentration is determined from absorption [19].

A noninvasive method allows pain free continuous patient monitoring with minimum risk of infection and facilitates real time data monitoring allowing immediate clinical reaction to the measured data. Since the near infrared light was found to penetrate a great depth into biological tissues, near infrared spectroscopy has been developed into a non-invasive method for biomedical sensing and clinical diagnosis [2][3][19][15][28]. The non-invasive medical diagnostic techniques including X-rays, ultrasound, thermography and Magnetic Resonance Imaging (MRI) has greatly reduced risk to the patients and has increased the understanding of how the body functioning. The benefits of non-invasive techniques are no incisions, no scars, low risk of infection, low risk of bleeding and blood transfusion and shorter recovery time and faster return to normal work [11]. As an advancement in the field of pathology, numerous non-invasive techniques such as imaging, spectro-photometry, opto-acoustic spectroscopy, transmission spectroscopy, reflection spectroscopy have been proposed in literature for the estimation of blood parameter [23][24].

II. METHOD AND MATERIAL

Katsuyasu Saigo et al. (2004)examined Astrim device to determine hemoglobin levels by using the principle of near-infrared spectroscopy in combination with analysis of optical images taken by charge-coupled device camera located at the opposite side of light sources [1]. Proposed method was based on the principle that absorption and scattering is takes place due to hemoglobin in blood and tissue in the finger respectively. Astrim uses light sources of three wavelengths 660, 805 and 880 nm to detect image of blood vessels and to calculate hemoglobin levels based on absorption of each wavelength. Total 97 volunteers were participated for this study includes 59 men and 38 women. Results obtained by this method were compared with Sysmex SE-9000 to measure total hemoglobin. The correlation coefficient between findings with Astrim-Hb and total-Hb for healthy volunteer r=0.626 and for hematologic disorder patient it is r=0.762.

Jens Kraitl et al. (2011, 2006) presented NIR spectroscopy and photoplethysmography for measurement of hemoglobin [2] [3] [4]. The basic principle for the hemoglobin measurement is that absorption or transmission difference of light in red and near infrared region between oxygenated, reduced hemoglobin and blood plasma is different. They have been developed LASER based photometric device PMD-I in which five LASER diodes emits lights in the range of wavelength 670, 808, 905,980 and 1300 nm. They used LASER diode of wavelength 670, 808, 905 and 980 because it is therapeutic window region in which blood absorption is dominated by hemoglobin derivative whereas at 1300 nm absorption of water is dominant. They also have been developed LED based photometric device PMD-II which uses three LEDs in the range of wavelength 670, 810 and 1300 nm. In their study 43 healthy male and female volunteers in the age group between 19-60 years were participated. Results obtained by proposed method were crosscheck by the Hemocue™ hemoglobin device which is invasive reference method and with the data obtained by Blood-gas-analysis (BGA). Proposed device provided squared correlation coefficient of 0.918.

J Kraitl et al. (2006)used multispectral and near infrared spectroscopy method for measurement of hemoglobin [4]. Absorption coefficient and scattering coefficient for blood differs at different wavelengths and this principle is used for the calculation of the optical absorbability characteristics of human blood yielding information on blood components like hemoglobin and oxygen saturation. The basic principle for the hemoglobin measurement is that absorption or transmission difference of light in red and near infrared region between oxygenated, reduced

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hemoglobin and blood plasma is different. They used five LASER diodes in the range of 600-1400 nm to emit monochromatic light through finger. Four of the five LASER diodes emits light in the wavelength of 670, 808, 905 and 980 nm as well as one laser diodes emits light in the wavelength of 1310 nm. Two photodiodes were used to receive transmitted signal through finger. The measured PPG time signals and the ratio between peak to peak pulse amplitude were used for a measurement of these parameters. They have connected the optical spectrometer with an optical cuvette of the hemodynamic model. They took 19 samples of healthy male and female to test proposed system. All the results obtained by proposed system were compared with sample results obtained by a Blood Gas Analyzer. For the invasive reference measurement they used HemoCue^{TM} device. Squared correlation coefficient was obtained from this trial study is 0.85.

Marlin Wayne Causey et al. (2011) presented optical spectroscopy method for the measurement of hemoglobin using Masimo Radical-7 SpHb station [5]. They collected patient's data in two groups one was major operating room patients and other was ICU patients. In the ICU, they used three separate probes namely Rainbow dc-3 SC-360, Rainbow R125 adult adhesive sensor and upgraded Rainbow125 adult adhesive sensor. They have collected data of 60 patients. Results obtained by the proposed system are recorded and then compared with laboratory hemoglobin method. The overall correlation of the device mean and laboratory evaluation was 0.78 ($P<0.001$) with a mean difference of 0.15 and overall correlation of device mean and laboratory evaluation in operating room was 0.77 ($P<0.001$). Limitation of proposed method is variability of measurement reported between the LabHb and SpHb. In proposed method SpHb accuracies were not validated under motion of low perfusion states and were accurate to 1 g/dL.

Aditya Bhat et al. (2015)examined optical spectroscopy method for the measurement of hemoglobin using Masimo Radical 7 finger probe sensor with rainbow R120L of pulse co-oximeter [6]. Standard automated lab analyzer was used to measure hemoglobin by indirect Cyanmethemoglobin method. 150 patients including neonates and children were enrolled for the test. Bland-Altman method was used to measure and analyze the result obtained by both methods i.e. non-invasive method and automated lab analyzer method. Difference between both the method was -1.52 +/- 1.91 g/dL where SpHb showed excellent positive correlation with Hb-lab r=0.94. For healthy patients SpHb offered clinical acceptable accuracy with mean bias of 0.77 g/dL. Proposed method provided good sensitivity and specificity of 97.7% and 87% respectively.

Vaishal V. Agte et al. (2009) presented nail color scale method to predict hemoglobin concentration [7]. Initially they examined 52 patients and developed single strip with increasing tones of brownish pink for the prediction of hemoglobin. In the year 2007, they choose 67 children, 26 adolescents and 82 adult men and women. They also developed five different strips that were close to natural shades of nail in which lightest color is denoted as 3 to represent 3g/dL hemoglobin concentration and darkest color was given the number 19 to represent hemoglobin concentration 19 g/dL. Nail color scale was evaluated by comparing the predicted values with actual hemoglobin concentration on the subjects estimated by the cyanmethemoglobin method. Results obtained from proposed method shown significant correlation between the observed and predicted hemoglobin levels as R^2 =0.77, coefficient=0.75, intercept=2.95. Proposed method has sensitivity 67.85%, specificity 93.2% and positive predictive value 0.826.

K. Abo Alam et al. (2009) have been reported optical method in which Wang-Mendel method based fuzzy expert system is used to generate fuzzy rule base for measurement of hemoglobin [8]. In their method, they used the inputs having six values of light intensity with different wavelength that were measured at optical stage. Fuzzy expert system with seven inputs and one output was developed with the help of LabVIEW. 122 sample cases were studied for the observation. Total hemoglobin value obtained in range between 7.2 g/dL to 25 g/dL. Obtained results of optical method were compared with invasive reference method. Proposed system reported RMS error's value 1.24 g/dL and the correlation value 0.977 over whole range of hemoglobin. For the hemoglobin below 12.5 g/dL it was 1 g/dL and for higher hemoglobin value it was 1.38 g/dL.

Kumar R. et al. (2013) used optical method for the measurement of hemoglobin [9]. As hemoglobin in blood exhibits optical properties such as absorption, transmission and reflection of photons in various proportions is based

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on wavelength of photons. They used two light sources of wavelengths 741 nm and 805 nm respectively transmitted through the fingertip and the signals were detected by the photodiode. They used light sources of wavelength 741 nm and 805 nm because 741 nm penetrated the skin, tissues and partially absorbed by Hemoglobin whereas at the wavelength of 805 nm portion of light that has penetrated the skin is scattered and a portion of it is absorbed. The extent of penetration of light energy into fingertip was defined by modified Beer's law. For the study they took samples from 100 peoples of different age groups of normal patients as well as patients suffering from Anemia. Results obtained by optical method were compared with invasive cyanmethemoglobin method as reference. Bland Altman plot was used to compare results from described optical method and cyanmethemoglobin method. This method is simple with acceptable accuracies.

Nirupa J et al. (2014) presented optical photoplethysmography method for measurement of hemoglobin [10]. Red and infrared LED of wavelength 624 nm and 850 nm respectively employed on one side and a photodiode on the other side of fingertip. Red and infrared PPG signals were sampled and processed in the LabVIEW platform usingNational Instruments data acquisition card interfaced to the PC by selecting 69 healthy volunteers for this study. Result obtained by optical method was also compared with conventional chemical analysis method. Proposed method provided result of hemoglobin content in blood varied in the range 10.2 g/dL to 17.7 g/dL.

Dr. Raid Saleem Al-Baradie et al. (2013)reported single wavelength spectrophotometry for the measurement of hemoglobin [11]. They illustrated the relationship between wavelengths of light in the range of 400-1800 nm for the absorption coefficient in deoxygenated hemoglobin, oxygenated hemoglobin and water. Proposed system consists of LED as a light source of wavelength 670 nm because at this wavelength the absorption coefficient of oxygenated hemoglobin and deoxygenated hemoglobin are indistinguishable. Beer-Lambert law described the reduction in the intensity of light which is travelling through a homogenous medium containing an absorbing substance. Total 10 samples were used for the proposed study. Data obtained from proposed system was compared with the normal values of the hemoglobin from look up table. The percentage mean relative error of the sampled data calculated as 0.56%.

U. Timm et al. (2011)presented optical spectroscopy method for the measurement of hemoglobin [12]. The basic principle used in this method was based on the fact that absorption or transmission difference of light in the red and near infrared region between oxygenated hemoglobin, reduced hemoglobin and blood plasma is distinguishable. In this method monochromatic light was emitted by LED in the range from 600 nm- 1400 nm through the fingertip. Two LEDs emit light in the range from 600-1000 nm and one LED emits light in 1300 nm range. Obtained data was processed by the application software program in LabVIEW. Bland-Altman plot was used for the validation of result. Total 48 patients were monitored including males and females of different age groups. Results obtained by the proposed device were compared with the invasive Hemoglobin tester Hemocue[R]. This group has reported standard derivation was 0.1817 mmol/l and the mean difference was 0.06363 mmol/l.

Tristan Knutson et al. (2013)used optical spectroscopy method for determination of hemoglobin [13]. Author examined Masimo Radical-7 Pulse CO-Oximeter handheld unit and RDS-2 docking station. Proposed device was able to measure several blood parameters such as venous hemoglobin, heart rate, oxygen saturation, carboxyhemoglobin and methemoglobin. They took samples of 127 adult patients of emergency department those who suggested complete blood count (CBC) test. Bland-Altman analysis was used to verify the result of described device. Proposed device measured venous hemoglobin in the range of 0 to 25 g/dL with the highest accuracy between 8 to 17 +/- 1.0 g/dL. Proposed method did not evaluate the accuracy of serial measurement over time. They concluded that Masimo Radical-7 is not ready for use in clinical decision making.

Timm U. et al. (2010) presented optical method for hemoglobin measurement [14] [15]. As arteries contain more blood during systolic phase and diameter of the arteries also gets increased hence this phenomenon was used to measure hemoglobin. In this system three LEDs in the wavelength of 670, 810 and 1300 nm were used to emit monochromatic light and transmitted through fingertip they also used photodiode tuned to detect specific frequencies. They examined pulse photography waves of AC component such as time varying pulsation of blood flow and DC component such as non-time varying venous blood. Beer-Lambert law used to calculate intensity of

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light which is travelling through a homogenous medium containing an absorbing substance. Data was processed and display using software written in LabVIEW from National Instrument and executes on Laptop or PC. Results obtained by proposed system were compared with the results obtained by invasive method Blood Gas Analyzer.
Khunawat Luangrat et al. (2013) reported optical spectroscopy for measurement of hemoglobin [17] [20]. In their study initially they performed the experiment to check whether there is any relation between the pulse signal and hemoglobin then they developed the algorithm to calculate the hemoglobin from pulse signal. Sensor system consists of single wavelength LED as a light source and a photodiode as a detector. Pulse signal and hemoglobin of Eight healthy volunteer was recorded using pulse BIOPAC^{TM} system and MASIMO^{TM} radical-7 respectively. Masimo Radical-7 gave value of hemoglobin in between 16-17 g/dL.

Khunawat Luangrat et al. (2013) used the principle that as hemoglobin concentration changes as changes in average pulse amplitude [17]. They used BIOPAC system pulse probe and amplifier. Output signals were separated into two period one pre drink acquisition and post drink acquisition. For analysis of data they calculated the average amplitude in each pulse signal and then compared the average pulse signal between pre-drink and post-drink. Five healthy patients of the age group 20 to 24 years were selected for the study. They concluded that the hemoglobin concentration depends on the water and the amount of hemoglobin in the blood stream.

A Mohamed Abbas et al. (2016)presented signal to image photo-plethysmo-graphic method [18]. They used LED that transmits light in the near infrared region through fingertip or earlobe and a photodiode to detect the signals. The output of proposed system was obtained using regressive analysis and the hemoglobin content was displayed in the LabVIEW program. The signals from the photodiode was recorded with Sigview software and then the signal further processed by MatLab. Total 10 patients were approach for the study with minimum 10 readings of each patient. In order to determine hemoglobin content varians, mean values were compared and output was plotted in PPG graph.

Rajashree Doshi et al. (2013) proposed optical pulse photometric measurement method for the measurement of hemoglobin [19]. Measurement of hemoglobin was based on the fact that particular absorption and transmission difference of light in red and near infrared region between oxygenated and reduced hemoglobin is significant. They used red and near infrared light emitted from LEDs of wavelength 660 nm and 940 nm respectively and photo detector. In this photo detector was used to receive an electrical signal consisting of DC as well as AC part of LED emission. DC component to the signal represents ambient background light and transmission of light through invariant that is non-pulsating tissues such as skin, bone and to a certain extent veins. AC component represents varying transmission of light through the pulse varying tissues i.e. arteries and capillaries. Beer-Lambert's law was used to calculate the absorption of light as a function of hemoglobin concentration. Total 58 adult female in the age group of 18-20 years were selected to test this system.

Setsuo Takatani et al. (1988)examined optical spectroscopy method for measurement of hemoglobin [20]. They designed reflection type hybrid optical sensor based on theoretical model using photon diffusion therapy. Sensor system consists of two LED chips at the wavelengths of 665 nm and 795 nm and a photodiode chip. At 665 nm, optical absorption increases when the hemoglobin changes its state form oxygenated to deoxygenated form whereas 795 nm wavelengths is very close to the isosbestic wavelength of oxyhemoglobin and deoxyhemoglobin at 805 nm. This group obtained correlation coefficient that was varied from -0.966 to -0.9988 with improvement in standard deviation of errors from errors from 7.39 to 1.398 % of hemoglobin. Major drawback of proposed method is instability from one measurement to the next.

Dong-Sik Kim et al. (2011) presented optical spectroscopy method for measurement of hemoglobin [21]. They used the principle that hemoglobin molecule absorbs incident light in the visible spectrum and the absorbance is relatively huge in the blue color range. Sensor system employed three typical wavelength of RGB LED and CMOS image sensor. All the images captured within CMOS image sensor were analyzed by JAVA based image processing tool. Beer-Lambert law was used to define the relationship of different wavelength with different hemoglobin derivatives. Total 33 samples were taken to verify the accuracy of proposed system and gives hemoglobin concentration ranges

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of 6.3-18.3 g/dL. Proposed technique provided accurate hemoglobin concentration of 1.88 % and precision of 0.07-0.20 g/dL. Main drawback of this system is the requirement of blood preparation.

Francesco Fabbri et al. (2003) proposed NIR spectroscopy for the measurement of hemoglobin [22]. They used the OxiplexTS which is NIRS instrument having two-channel frequency domain tissue spectrometer for the measurement of cerebral concentration and oxygen saturation of hemoglobin. Proposed instrument consists of sixteen intensity-modulated LASER diodes out of which eight emitting at a wavelength of 690 nm and eight at 830 nm and two photomultiplier tube detectors. For this study nine patients were selected within the age group of 27-57 years.

Chetan Sharma et al. (2013, 2012) presented photoplethysmography method for hemoglobin measurement [23] [24]. Photoplethysmography is the technique of estimation of blood component which is based on the principle of partial absorption of light by blood components. It works on the principle of detection of the blood volume changes in micro vascular bed of tissue and the sampling is done in places where the tissue is close to the skin such as fingertip, earlobe and finger webbings. Principle was used for the detection of blood parameters by photoplethysmography is that different blood components present in the blood of capillaries have differential absorption of infrared/ non-infrared radiation when the patients finger is exposed to IR/ NIR radiation. Proposed device consists of three LEDs of wavelengths 810, 880 and 940 nm because in these wavelengths the spectral absorptivity of hemoglobin and oxy-hemoglobin is considerable whereas other blood component is negligible. They monitor PPG waves at three wavelengths to compensate for the error due to absorption of near infrared radiation by water in the blood. They applied Beer-Lamberts law to find the absorbance of particular blood component at specific wavelength. 3-axis accelerometer was used in order to sense the motion of the subject to reduce motion tolerance. They built analog filter along with the FPGA based filter and both system were tested with same patient to ensure the accuracy of the system. Proposed system provided accurate readings within the range of +/- 0.5 g/dL.

Philips J.P. et al. (2011) presented optical and capacitance method for the measurement of hemoglobin because plasma component of blood is optically transparent and therefore difficult to detect optical method alone [25]. They used the capacitance sensor to detect pulsatile variations in dielectric permittivity of the tissue and optical photoplethysmography sensor developed to measure time-dependent absorbance variation. Optical sensor consisted of red LED and PIN photodiode to make a single wavelength photoplethysmograph sensor. Signals obtained from capacitance sensor and optical photoplethysmography sensor were analyzed and compared for a range of dye concentration and pulse pressure. The capacitance and optical signals were digitized and recorded by National Instruments data acquisition card and recorded to text file for analysis of data using LabVIEW. Proposed system required reservoir filled with a saline solution containing dye with an optical absorbance equivalent to blood with a hemoglobin concentration of 60 g/dL. To check the absorbance value they used a Novaspec 4049 spectrophotometer.

Table 1: Showing Different methods used by the authors, sample size, correlation coefficient and calibration method

Sr. no.	Author / Year	Technique / Method	Sample size	Correlation coefficient (r)	Calibration Method
1.	Katsuyasu Saigo (2004)	Near-infrared spectroscopy	97	0.626	Sysmex SE-9000
2.	Jens Kraitl (2011)	Near-infrared Spectroscopy and photoplethysmography	43	0.918	Hemocue TM device
3.	J. Kraitl (2006)	Multispectral near-infrared spectroscopy	19	Sq r =0.85	Hemocue TM device
4.	Marlin Wayne Causey (2011)	Optical Spectroscopy	60	0.78	Lab hemoglobin method
5.	Aditya Bhat (2015)	Optical Spectroscopy	150	0.94	Automated lab Analyzer Cyanmethemoglobin method
6.	Vaishal V. Agte (2009)	Nail color scale method	(2009) 52 (2007)	Sq r = 0.77 0.75	Cyanmethemoglobin method

			175		
7.	K. Abo Alam (2009)	Optical method	122	0.977	Invasive reference method
8.	Kumar R.(2013)	Optical Method	100		Cyanmethemoglobin method
9.	Nirupa J. (2014)	Optical Photoplethysmography	69		Conventional chemical analysis
10.	Dr. Raid Saleem Al-Baradie (2013)	Single wavelength spectrophotometry	10		Look up table
11.	U. Timm (2011)	Optical Spectroscopy	48		Hemocue (R) tester
12.	Tristan Knutson (2013)	Optical Spectroscopy	127		Arterial blood gas analyzer
13.	Cedrick Zaouter (2012)	Optical Spectroscopy	9		Arterial blood gas analyzer
14.	Timm U. (2010)	Optical method			Blood Gas Analyzer
15.	Khunawat Luangrat (2013)	Optical Spectroscopy	8 / 5		
13.	Mohamed Abbas (2016)	Photoplethysmography	10		
16.	Rajashree Doshi (2013)	Optical pulse photometric method	58		
17.	Setsuo Takatani (1988)	Optical Spectroscopy		-0.966 to -0.9988	
18.	Dong-Sik Kim (2011)	Optical Spectroscopy	33		
19.	Francesco Fabbri (2003)	Near-infrared spectroscopy	9		
20.	Chetan Sharma (2012)(2013)	Photoplethysmography			
21.	Philips J.P. (2011)	Optical and Capacitance			
22.	O. Abdallah (2008)	Optical Spectroscopy & Photoplethysmography			
23.	Eran Hadar	Occlusion Spectroscopy	63	Sd=0.86	LH-750 Beckman Coulter counter

O Abdallah et al. (2008) used optical spectroscopy and photoplethysmography technique for hemoglobin measurement [26]. They developed the earlobe and fingertip sensor to detect the PPG signal. This sensor used high intensity 7 LEDs of wavelength between 595 nm and 940 nm, which can differentiate between the absorption of the different hemoglobin components along with the photo detectors. Photo detector signals were digitized using National Instruments data acquisition card and processed by application software LabVIEW. Luminous intensity of red and infrared light was expressed by Beer-Lambert law. In their study they found that earlobe absorbs less light hence it requires less power as compared to fingertip sensor.

Cedrick Zaouter et al. (2012) presented Optical spectroscopy method for hemoglobin measurement [27]. They used Rad-57 pulse co-oximeter for the measurement of carboxyhemoglobin and methemoglobin. To obtained accuracy and the precision of the system, Rad-57 results were compared with an arterial-blood-gas analyzer. Bland-Altman comparison method was used to assess level of agreement of these two techniques. Nine healthy volunteers were selected for the test. Rad-57 system provides reading in between -6% to +4% of the true COHb value for 95% of all samples. Mean bias and precision for MetHb measured with Rad-57 was 0.0% to 0.3 % respectively. Authors concluded that Rad-57 was rapid and useful method for initial screening of the patients arriving to the emergency department.

Eran Hadar et al. (2012) examined NBM-200 device for the measurement of hemoglobin based on occlusion spectroscopy technology in the red/ near-infrared range [29]. Blood hemoglobin was evaluated on an LH-750 Beckman Coulter counter acting as the reference ‘gold standard’. Total 63 womens were selected for the study. Mean error (bias) of the NBM 200 readings compared to the reference was 0.1 g/dL and the accuracy, defined as the standard deviation of error was 0.86 g/dL. Bland-Altman comparison of the NBM-200 versus the coulter device

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shows that the 95% limits of agreements was -1.59 to 1.79 g/dL. Masimo Radical-7 monitor which is based on multiwavelength pulse co-oximeter technology. Masimo pronto-7 monitor and orsense NBM 200 MP. Light sources comprised of 10 spectrally stabilized emitters (LED's) in wavelength ranging from 600 nm to 950 nm, photo detector and an air-cuff pneumatic occlude for application of over-systolic pressure to finger during the spectrophotometric measurements. Reference Hemoglobin values were obtained from a venous blood sample and evaluated on a Beckman Coulter LH 750 counter.

III. RESULT AND DISCUSSION

The review of different methods for the non-invasive measurement of hemoglobin such as Near-infrared Spectroscopy, Photoplethysmography, Optical Spectroscopy, Capacitance method, Optical pulse photometry, and spectrophotometry. Each proposed techniques has relative merits and demerits according to patient's health condition, sensor system and instrumentation.

IV. CONCLUSION

Many techniques reviewed here have been shown excellent accuracy, sensitivity and specificity in measuring hemoglobin, so in the future scenario many non-invasive methods will be used for different applications. Among different reviewed techniques Near-infrared Spectroscopy has shown excellent correlation coefficient of 0.626 proposed by Katsuyasu Saigo. Most of the authors used fingertip for the non-invasive measurement of hemoglobin but earlobe can also be the best option for future systems because it requires less power as compared to fingertip sensor.

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