

A LOW COST LED BASED BILIRUBIN METER

Description and Evaluation of a Low Cost Spectrophotometer Bilirubin Analyzer

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Abstract: Jaundice is a disease caused by excessive levels of bilirubin in the blood. It is very common in newborns and mainly in premature ones. By using resources such as LEDs with high luminous intensity and light to digital photoreceptors, the present article describes and evaluates a low cost bilirubin meter (Bilimed), which measures the total bilirubin in the blood serum samples of neonates, using the technique known as direct spectrophotometry. Samples of newborns were collected and measured in the equipment. The result was compared with reference values of a commercial bilirubinometer and with laboratory analysis in order to evaluate the equipment's performance.

1 INTRODUCTION

During the first weeks of a newborn's life it is common the appearance of the illness called jaundice or hyperbilirubinemia defined as a yellowish discoloration of the skin and the mucous membranes, caused by the accumulation of a yellow pigment called bilirubin (Odell, 1980). It is manifested in about 60% of the newborns, being this rate much bigger in premature neonates (Knudsen, 1989, Taksande et al., 2005). The increase of the bilirubin concentration in the blood is generally caused by the immaturity of the liver in processing it, among other external factors such as breast-feeding, hepatic malfunctions and blood incompatibility (Askin and Diehl-Jones, 2003). The high value of bilirubin is toxic for the brain and may cause an encephalopathy called kernicterus, leaving irreversible sequels to the child's brain (Diamond, 1970).

The determination of the bilirubin levels is generally carried out by three types of equipment known as bilirubin meters or bilirubinometers: the portable analyzer which measures the transcutaneous bilirubin; the spectrophotometers which use the photometric analysis in the blood serum to measure the total bilirubin; and laboratory photometric analyzers which analyze chemically reacted blood samples by using scientific methods. The transcutaneous bilirubinometers are the state-of-the-

art bilirubin measurement method and although some authors have shown good correlation between the transcutaneous bilirubin and the direct bilirubin (Bhutani et al., 2000), not all the results show that they are totally independent of factors such as race, gestation and birth-weight (Maisels, 2006).

The bilirubinometers that use the spectrophotometry as a principle - based on the light absorption by the bilirubin molecule - are known as direct spectrophotometers. This equipment was firstly proposed in the 60s (Jackson, 1961) and presented reliable results compared with the transcutaneous method and other laboratory methods (Grohmann et al., 2006).

The aim of this work is to describe the main resources used by the direct spectrophotometer Bilimed bilirubinometer, its technological innovations, as well as to evaluate the equipment performance through measurements in newborns blood samples.

2 MATERIALS AND METHODS

The bilirubin molecule has a peak of light absorption of about 455 nm. In this same wavelength there is interference of the oxyhemoglobin molecule, being necessary to measure its absorption (peaks of 545 nm or 575 nm) in order to make a compensation (Roggan et al., 1999). The difference in absorption

in the bilirubin and oxyhemoglobin 455 and 575 nm wavelengths is used to measure the concentration value of the total bilirubin. The figure 1 shows the absorption spectrum of bilirubin and oxyhemoglobin.

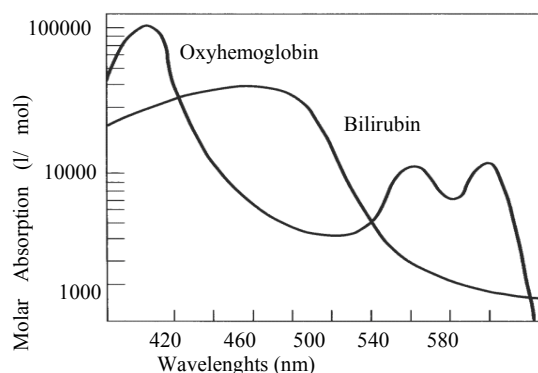


Figure 1: Absorption spectrum of bilirubin and oxyhemoglobin. (Du et al., 1998, Zijlstra et al., 1991).

The direct bilirubinometer's operation principle is the use of a high intensity light source in order to generate the necessary light for the spectrophotometric process. A white Philips Lumiled Luxeon K2 LED is used as light source and a circuit drives the LED through signals sent by the microcontroller. The capillary tube containing the serum to be analyzed is inserted in the optic set through a holder. The light goes through the sample; the light shaft is split and goes through 455 and 575 nm band-pass filters. The luminous signal is then transformed in digital signal by the TAOS TCS 230 photosensors which are positioned just after the filters. This signal is sent to the microcontroller and a routine converts the frequency sent by the photosensor into a value correspondent to the luminous intensity. In order to make the calculation of the bilirubin absorption, a measurement of a capillary tube containing distilled water, which will serve as a reference value, is carried out. The signal is processed and is converted into a concentration value of total bilirubin (mg/l or $\mu\text{mol/dl}$).

The user interacts basically using two switches and a LCD display. The figure 2 illustrates the system.

Products which use high power LED have recently revolutionized the medical area. Among their application can be pointed out: lighting of surgery rooms using surgical focus; source of lighting which offers low level of photo biological influence in closed environments, reducing malfunctions in night workers and the "Jet-Lag" effect; dermatological treatment for acne, psoriasis

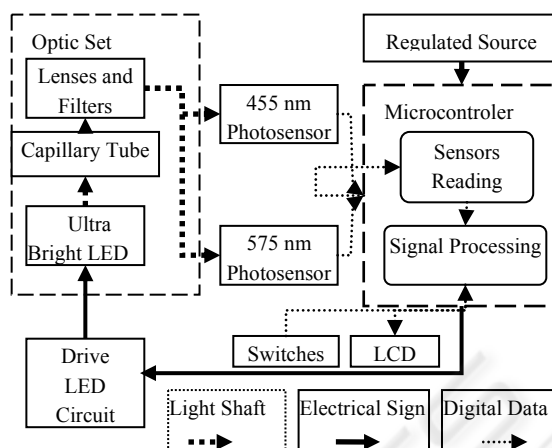


Figure 2: Chart of the electrical (continuous arrow), luminous (dashed arrow) and digital signals (dotted arrow) in the system of the bilirubinometer.

and eczemas; phototherapy for the treatment of jaundice; ultraviolet LED based disinfection systems (Jones and Barnett, 2006). The programmable photosensors which convert the light into frequency in a sole CI operate with photodiodes matrix in series with a current to frequency converter circuit. The frequency of the signal out is directly proportional to the incident light, and may be connected to a microprocessor without the need of any additional electronic or analogical to digital converter. There are many laboratory and medical applications using these ICs, such as low cost LED based spectrophotometer (Yeh and Tseng, 2006) and glucose meters (King, 2006).

3 RESULTS

130 measurements were analyzed based on 26 samples from different bilirubin concentrations, besides their respective zero measurements, which formed a data base for the Bilimed analysis. The samples were collected in different newborns hospitalized in the pediatric sector of the Clinical Hospital of the Faculty of Medicine of Ribeirão Preto - Brazil.

The obtained values were compared with the value which was measured by using a commercial bilirubinometer (Photo Ictometer OHC Model IV-O'Hara & Co LTD) and by laboratory analysis carried out in the pediatric laboratory of the same hospital. From the collected data, 41 measurements (30% of the results) have concentrations which is greater than 10 mg/dl (171 $\mu\text{mol/dl}$). Figures 3 and 4 show the relationship of the concentration measured by the Bilimed and the linearity of the results.

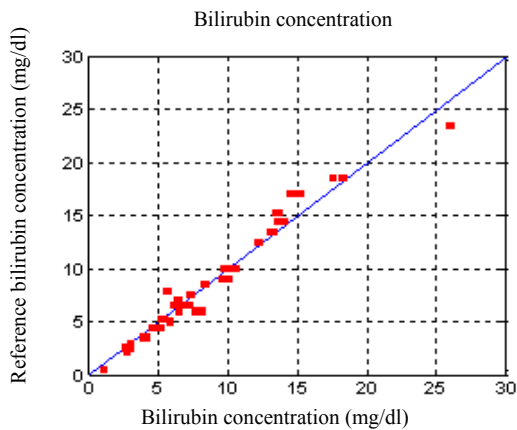


Figure 3: Graphic of the bilirubin concentration by the concentration of the Bilimed, where the straight line is the tendency found and the dots are the collected data.

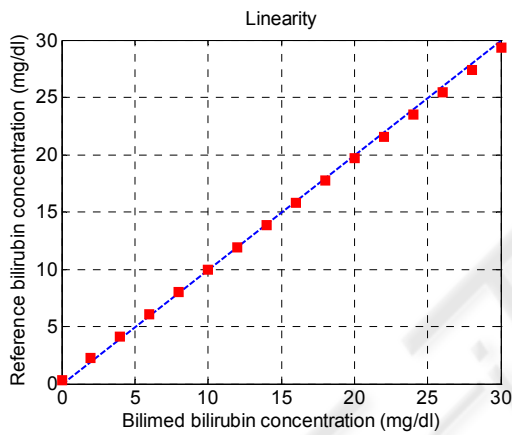


Figure 4: Linearity of the Bilimed equipment (dots) by the reference (straight line).

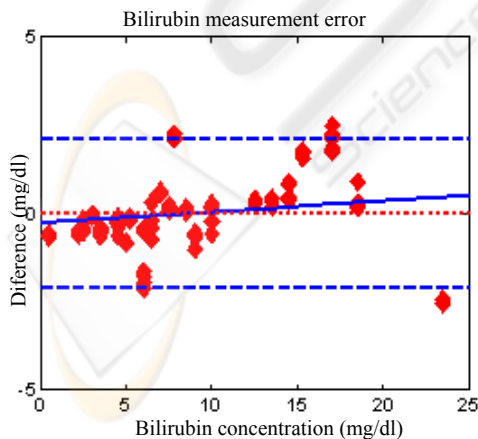


Figure 5: Error in the measurement of the Bilimed bilirubin concentration (points). The mean is equal to 0 mg/dl (dotted line), the double of the standard deviation is 2,093 mg/dl (dashed line), and the tendency line is shown by the full line.

The reading error graph, generated by the difference between the concentrations measured and the reference ones, is shown on figure 5. The statistical results on table 1 (standard deviation, variance and maximum error) of the Bilimed readings were also calculated.

Table 1: Standard deviation, variance and maximum error found in the Bilimed reading.

Standard Deviation	1,048 mg/dl (17,864 μ mol/dl)
Variance	1,098 mg/dl (18,769 μ mol/dl)
Maximum Error	2,474 mg/dl (42,303 μ mol/dl)

3.1 Result Analysis

There is a large linearity in the measurements carried out by the Bilimed. Through the analysis of the graph's tendency curve of the bilirubin concentration and of the signals sent by the photosensors, the measurements are safe up to 30 mg/dl (513 μ mol/dl), as for this value the absorption of the 455 nm light shaft is still within the limit of the photosensor reading error. Above this value the luminous intensity and the signal become very low, significantly increasing the reading error. The equipment presents standard deviation of $\pm 1,05$ mg/dl ($\pm 17,1$ μ mol/dl), a result within the direct bilirubin meters expectation. The maximal reading error was 2,5 mg/dl (42,75 μ mol/dl) for a concentration of 23,5 mg/dl (401,85 μ mol/dl). There is a greater difficulty in obtaining samples with values above this one, thus limiting the data base.

The main reasons for reading errors are related to the temperature variations between the measurements, the bad positioning of the capillary tube in the holder, the bad separation of the serum in the centrifugation process, and flaws and dirt in the capillary tube.

In order to ensure the quality of the results it is very important to follow the instructions correctly, to carry out the measurement from zero before each analysis, to avoid direct contact with the capillary tube, and to centrifuge the sample so that a homogeneous serum is obtained.

4 CONCLUSIONS

The measurement of the bilirubin concentration is a very common procedure in hospitals and the bilirubin meters are equipment which allow for a quick evaluation of the patient's condition. The

direct spectrophotometers have been in the market for a long time and Bilimed has the same reliability, accuracy and simplicity of these equipments.

In spite of the limited data base, the tests carried out with the Bilimed equipment show an optimal linearity in the result, with accuracy of 1mg/dl, upper range limit of 30 mg/dl and strong co-relation with the results obtained with the commercial bilirubinometer used as reference. In order to assure the reliability of the data, some procedures must be used.

Bilimed offers technological improvements contrasting with available devices. There is a strong tendency in the use of LEDs to substitute high intensity luminous sources. Due to the use of the white ultra bright LED and special photosensors, the size and the number of electronic components involved in the project were reduced. Another point that must be emphasized is the reduced production cost and, as consequence, the final client price. With the use of filters, lenses, LEDs and photosensors, the Bilimed equipment can get to 20% of the price of a transcutaneous bilirubinometer and 50% of a conventional bilirubinometer.

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