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Optimization of Phototherapy Machine for Advanced Treatment of Neonatal Jaundice

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ABSTRACT

Neonatal Jaundice is a medical condition in which high number of unconjugated bilirubin exists in infant's blood resulting in yellowish colour of baby's skin and whites of the eye. Unconjugated bilirubin is potentially toxic to neural tissue both brain and spinal cord. Entry of unconjugated bilirubin into the brain can cause both short-term and long-term neurological dysfunction, bilirubin encephalopathy, which needs serious attention. Even though hospitals use phototherapy machine to treat jaundice, there are a number of gaps on the machine related to its effectiveness. Among the gaps long hospitalization time, biological hazards from strong optical radiation and limitation to higher hospitals are the major ones. The main objective of this research was to optimize phototherapy machine for advanced treatment of neonatal jaundice. Before optimization activities, necessary clinical study was performed and the results from the clinical study were used as an input for optimization work. The optimization work included integration of non-invasive bilirubin measurement, light intensity measurement, back treatment and different power supply options to overcome the gaps. The actual device using 465 nm light emitting diode was developed and tested against specifications. Non-invasive measurement system avoids invasive bilirubin measurement, comfortable and makes tracking treatment progress easier. Addressing all skin surface of a baby by the device improves treatment efficiency and plays vital role in baby to mother bond as it reduces treatment time.

Keywords: Jaundice, Light intensity, Neonates, Non-invasive bilirubin meter, Phototherapy

INTRODUCTION

When the lifecycle of the red blood cell comes to an end, the hemoglobin part of its composition breaks down into 'heme' and 'globin'. The 'heme' part of the dead cell is further decomposed into iron and bilirubin, illustrated on figure 1. Clinically two types of bilirubin are known; conjugated and unconjugated bilirubin. Unconjugated bilirubin mostly circulates in the bloodstream bound to albumin although some of it is 'free' and hence able to enter the brain. The color of bilirubin is an orange/ red pigment in the blood. The unconjugated bilirubin that circulates in the bloodstream enters into the liver to be metabolized and transformed into conjugated bilirubin. Then the metabolized (conjugated) bilirubin is largely excreted from the body as stool. When excretion process is low, it does not work efficiently, or it is overwhelmed by the amount of endogenously produced bilirubin. When the amount of bilirubin in the body increases, it results in hyperbilirubinemia or jaundice. Newborns appear jaundiced when the amount of bilirubin becomes >7 mg/dl [1].

Neonatal jaundice is a very common condition worldwide occurring in up to 60% of term and 80% of preterm newborns in the first week of life. As bilirubin begins to build up, it deposits on the fatty tissue under the skin causing the baby's skin to be white and the baby's eyes to appear yellow.

It is one of the most common conditions requiring medical attention in newborn babies. According to study done in Nigeria, the most common cause of admission to this hospital and Children's Emergency room within neonatal period was hyperbilirubinemia which accounts for 17% [2]. According to this study hyperbilirubinemia was among the cause of morbidity and mortality in neonates.

Neonatal hyperbilirubinemia is a recognized cause of brain damage with unconjugated bilirubin causing kernicterus, which results in long-term

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sequel like sensory-neuronal hearing loss [3]. One study conducted on neonatal hyperbilirubinemia estimates that about 1.1 million babies would develop hyperbilirubinemia with or without bilirubin encephalopathy worldwide yearly. Among those neonates, 481,000 were term neonates of whom 114,000 die annually and more than 63,000 survive with moderate or severe disability. The vast majority, 75% of affected neonates, reside in sub-Saharan Africa, the region where Ethiopia is located, and South Asia [4].

Mortality rate of neonates in Ethiopia was 37 in 1000 live births according to Ethiopian demographic health survey of 2011 [5]. Hyperbilirubinemia was among the causes of neonatal admission and death in Gondar Teaching Hospital. Among neonates admitted to neonatal unit 31.7% of them were due to hyperbilirubinemia. Among all neonates admitted to the hospital 23.1% were died [6].

Even though hospitals use phototherapy machine to treat hyperbilirubinemia, there are a number of gaps on the machine related to its effectiveness. Among the gaps long hospitalization time, biological hazards from strong optical radiation, invasive measurement of bilirubin and limitation to higher hospitals are the major ones.

MATERIALS AND METHODS

Materials

Research Design

Clinical study was done and the results from the study were taken as input for the optimization work done on the machine. Optimization and efficiency improvement work focuses on covering the maximum skin surface with required level of irradiance to reduce treatment time, providing treatment progress indicator and multiple power supply options to extend the service of device in lower-level health institutions. The overall procedure for this study was according to the following flow chart.

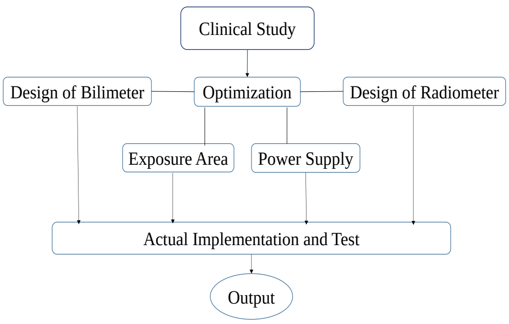

Fig.1. Flow of research work

Clinical study

Clinical study was needed to identify the core problems on the current jaundice management systems across health institutions. The main points under clinical study includes side effects from exposure to light, availability of treatment progress indicator, need for extra phototherapy device, action taken for overflow of patient, recommendation of phototherapy for health centers and drawbacks of the existing systems. The outcomes of this clinical study were taken as key input for optimization work done on the phototherapy machine.

Optimization

Non-invasive bilirubin measurement technique is less painful and gives fast result compared to invasive measurement technique. By using the concept of optical reflection and absorption, bilirubin concentration can be monitored in early stage. The bilirubin concentration will absorb wavelength of light between 457nm until 473nm. In order to achieve this, the system was designed according to the following block diagram.

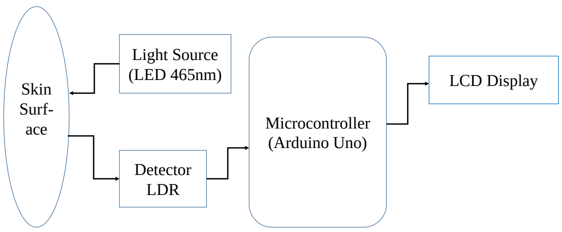

Fig.2. Block diagram of Non-invasive bilirubin meter

In order to get uniform distribution of light intensity, LED light was used as light source. Blue LED devices emit a narrow spectrum that overlaps the absorption spectrum of bilirubin. They are power-efficient, portable devices with low heat production that can be kept close to the baby. They are durable and long lasting with low power consumption. Light intensity is monitored by Pulse width modulation instead of monitoring distance. The light from the device pass though blue light filter before reaching the light sensor. Blue light filter is needed to block the interference of another visible light spectrum from the surrounding. The blue light reaching light sensor (photodiode Bpw34) will be converted to electrical energy and sent to microcontroller (Arduino Uno R3). Then the proportional light intensity will be displayed on LCD screen.

RESULT AND DISCUSSION

Non-invasive bilirubin meter

Transcutaneous measurement of bilirubin through non-invasive technique was implemented for the intervention of the current invasive measurement of bilirubin. The test was performed on mock skin as shown below with different concentration of yellow pigment. Variation in skin color of baby is considered as the main source of noise, but according to the study done on the influence of skin color on diagnostic accuracy of transcutaneous bilirubin meter, the variation is insignificant. The study was done in three categories such as light skin, medium skin and dark skin infant by comparing the result of transcutaneous bilirubin meter with total serum bilirubin measurement in laboratory. The result indicated 95%, 94% and 96% correlation for light, medium and dark skin neonates compared with total serum bilirubin measurement [7].

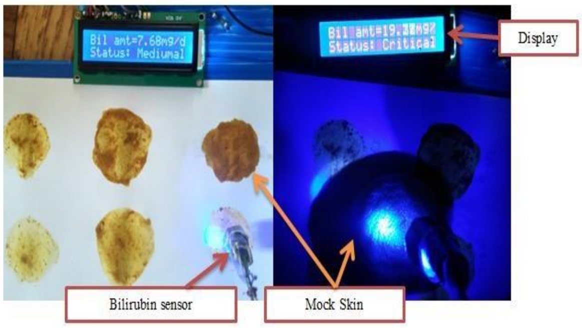

Fig.3. Non-invasive bilirubin meter test on mock skin

Light intensity

Light intensity measurement at various distances from light source is compared with the actual radiometer and the result is shown below. The mean accuracy of the developed system is 96% compared to actual radiometer.

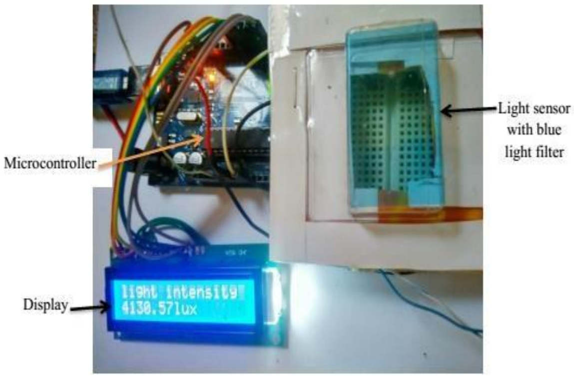

Fig.4. Light intensity control system

Prototype of the device

The overall system is implemented having the features; Non-invasive bilirubin meter, light intensity indicator, modified power supply options and back treatment. For light source LED with wavelength of 465nm was used since this is appropriate wavelength of light absorbed by bilirubin. The board for lighting assembly was prepared by researcher and the wiring and soldering of the circuit was done in lab by researcher. The prototype of the device was carefully assembled as shown below. The dimension of the device considered the treatment of one baby at a time. Therefore, the base dimension of the device was 50cm by 40cm; this means the height is 50cm while the width is 40cm. The gap between overhead light and baby is 20cm which can be adjusted.

Fig.5. Functional prototype of the device

With existing phototherapy machines care givers need to turn the infant every two hours to cover all skin surfaces, but with this system the maximum skin surface will get treatment with provision of back side treatment option. The other advantage of back side treatment is reduction of treatment time which increases mother to baby bond.

CONCLUSION

This research work addresses the major gaps identified on phototherapy machine. The non-invasive bilirubin measurement system developed for the intervention of the existing invasive bilirubin measurement system demonstrates high efficiency during test on mock skin and it can be used for measurement of bilirubin from dark skinned babies as it demonstrates 94% to 96% accuracy when compared with invasive bilirubin measurement system in laboratory. This solves the issue with treatment progress indicator and device use in health center level as the existing system is tedious for clinicians and baby under treatment. On the other hand, the implemented light intensity measurement system in this research gives accuracy of 96% when compared with actual radiometer which makes it ideal for continuous monitoring. Beside this the implemented light intensity measurement system is monitored using pulse width modulation system to help clinicians deliver the required amount of light based on the bilirubin content without moving the overhead light. The added back treatment option reduces the treatment time by 32 to 44% based on the bilirubin amount. This increases baby to mother bond as the time taken for baby to stay under phototherapy machine is reduced. The overall system was implemented with different power supply options i.e., AC power, Solar power and battery. This makes the device very appropriate in areas where power supply from main AC is limited. In general, the outcome of this research work produces a phototherapy machine equipped with non-invasive bilirubin measurement system which continuously monitor the bilirubin amount of baby under treatment, digital light intensity monitoring system that monitors amount of light reaching neonates skin, back treatment system which allow treatment from front and back side at the same time and multiple power supply options. Finally, since the need for phototherapy machine is very high even in higher hospitals in our country, the concerned bodies have to facilitate the manufacturing of the device in our country to address the need since it could be easily implemented.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper

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