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Research Article

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Eye Goggle Configuration Icterometer for Neonatal Jaundice Screening in Low Resource Settings

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ABSTRACT
Neonatal jaundice, also known as neonatal hyperbilirubinemia, is a common condition among newborns in the first week after birth. Persistent challenges due to inadequate, inefficient or financially inaccessible diagnostic alternatives for its management in resource-constrained settings leads to ongoing and unacceptable rates of morbidity, disability and mortality. Notable, neonatal jaundice is a leading cause of death and disability for newborns in low-resource nations, to include Southern Africa nations. Therefore, a need exist for low-cost low-tech diagnostics means for neonatal jaundice screening in low resource settings. Here, we present preliminary result with a novel eye-goggle configuration icterometer for neonatal jaundice screening exploiting the yellow discoloration of the sclera, effectively avoiding the interference effects of melanin in skin color determination. For in-situ real-time visual assessment of the eye sclera color, the eye-google type icterometer integrate jaundice severity color cards. Verification of visual assessment is by image analysis involving processing the mean pixel colour values of the sclera to predict the total serum from the digital photographs of newborn infants' eyes. We envisage the screening tool will be useful in meeting the need to improve referrals from home, community or peripheral health facilities to higher-level facilities with capacity for bilirubin testing and/or phototherapy.

Keywords: Icterometer, Neonatal Jaundice, Screening, Low-Resource Setting

Introduction

Neonatal jaundice, also known as neonatal hyperbilirubinemia, is a common condition among newborns in the first week after birth. Although it is sometimes associated with prematurity and other health conditions, it often occurs in healthy, full-term newborns [1,2]. As newborns' red blood cells break down in normal cellular lifecycles, a yellowish waste product called bilirubin is produced. However, during the early days after birth, many newborns' livers are not mature enough to keep up with the volume of bilirubin being produced, resulting in elevated levels of bilirubin in the blood, or hyperbilirubinemia, causing a yellowish tint to the skin and the whites of the eyes, or sclera.

Annually, neonatal jaundice has been estimated to contribute to the loss of 4.3 million disability-adjusted life years globally. Notable, neonatal jaundice is a leading cause of death and disability for newborns in low-resource nations, contributing to more than 114,000 deaths each year and leading to long-term disability among another 63,000 newborns. Sub-Saharan Africa has the highest incidence of bilirubin-related toxicity in the world, with a rate of 667.8 per 10,000 live births (compared to 4.4 per 10,000 live births in the Americas). Most causes of neonatal jaundice are easily treatable when diagnosed early [3].

Jaundice typically develops in the first few days after birth, after newborns have been discharged home from an institutional birth or in the days following the first post-natal check-up for babies born at home. To-date a number of diagnostics approaches summarised as Table 1 that differ in complexity and cost have been developed.

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Table 1: Summary of Neonatal Jaundice Diagnostic Technologies

Device Type	Name	Maximum Processing Time	Cost Indicator	References
Icterometer	BiliStrip™	Instant	Low	[4-14]
	Bili-ruler™	Instant		
Bilirubinometer	BiliDx®	< 10 Minutes	High	
	Bilistick®	< 10 Minutes		
	BiliSpec	<10 Minutes		
Smartphone-Based Bilirubinometer	BiliCam	Immediate	High	
	BiliScan	Immediate		
	Picterus	Immediate		

In well-resourced clinical settings, hyperbilirubinemia is assessed using either total serum bilirubin (TSB) method requiring a blood draw and laboratory testing or transcutaneous bilirubin (TCB) measurement, involving use of a light-refracting device. TSB method involves a painful and time-consuming invasive blood test, while on the other hand TCB, though non-invasive is costly.

A prominent feature of jaundice readily exploited in low-cost diagnostics that operate by analysing skin colour, is the appearance of yellow discoloration on the patient skin and sclera caused by a higher level of total serum bilirubin (yellow in colour) in the blood. Therefore, to meet the jaundice diagnostics needs of lower-level health facilities in resource-limited settings without access to TSB or TCB technologies, to include home-settings, a number of low-tech, hand-held Icterometers of various configurations as well as smartphone camera-based bilirubinometer have been developed [4,14], representing continuing improvements on the Gosset Icterometer [15]. The need for an energising source for battery recharging limits the application of smartphone camera-based Icterometers when compared to the low-tech hand-held Icterometers BiliStripTM and Bili-rulerTM. However, these low-tech hand-held Icterometers presents handling challenges as they have to be positioned against the skin in order to conduct visual assessment.

In this study we present preliminary results using a low-cost low-tech eye goggle configuration icterometer (egci) for neonatal jaundice screening ideally suited for low resource settings. As a wear on device, the egci is free from any handling challenges during visual assessment. Notable, the diagnostic device integrates a colour card of various yellow shades of expected jaundice-induced sclera discoloration and some whites, to allow for in-situ real-time visual assessment with improved accuracy from comparing scoring the observed sclera colour against the jaundice colour card shades. The proposed icterometer for neonatal jaundice screening exploits the yellow discoloration of the sclera, effectively avoiding the interference effects of melanin in skin color determination [16-18].

Methods and Materials

The experimental prototypes of the eye-goggle configuration icterometer with a square rim profile is shown in Figure 1. The prototype was fabricated from recycled plastic sheets while the jaundice severity colour cards are normal laser printer paper.

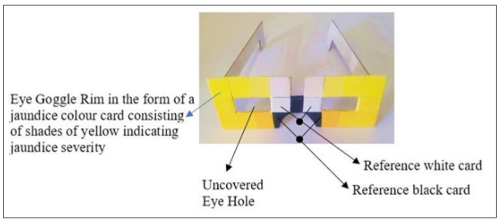
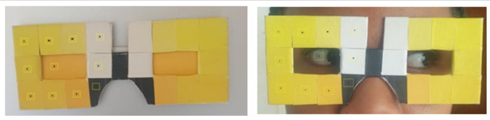


Figure 1: Prototype of the square rim profile eye goggle configuration icterometer

The prominent features of the device for the intended application are (i) the uncovered eye hole through which the patient eye can be viewed either with the naked eye for visual assessment or with a camera, for the purpose of acquiring digital photographs for computer-based image analysis; (ii) the eye goggle rim integrating (a) the jaundice severity colour cards featuring the yellow shades commonly associated with neonatal jaundice severity as well as (b) white and black reference colour cards.

For the preliminary result reported in this communication, two studies were performed with the square shaped eye goggle configuration icterometer. The first study involved mimicking a jaundiced eye by covering the eye hole with a randomly selected colour card and asking a human viewer to score the colour card against the reference jaundice yellow shades. A photo image was also captured with Samsung Galaxy Note 9 smartphone camera and analysed using Image J, a free and opensource image processing software [19]. Figure 2(a) shows a typical digital photograph for analysing with Image J by calculating the mean RGB value for the pixels in the region of interest area.



(a) (b)

Figure 2: Photo images for (a) mimicking jaundiced eye and (b) human volunteer. Regions of interest (overlayed numbered rectangles) for Image J analysis to confirm human observer score are marked

The second study involved a volunteer human subject (who is also a co-author of this communication) of African descent after obtaining informed consent. The volunteer was requested to wear the eye goggle configuration icterometer and their sclera colour was scored by a human viewer against the jaundice colour card after visual assessment. Following after, a digital photograph of the same eye, as shown in Figure 2(b) was taken with a Samsung Galaxy Note 9 smartphone camera for analysis with ImageJ.

Results and Discussion

Figure 3 shows the initial results. In both instances there was agreement between the human viewer score and the Image J analysis score. The color of the region of interest for the mimicked jaundiced eye (Figure 3(a)) and the human volunteer sclera (Figure 3(b)) was matched to the corresponding color on the icterometer as shown by the arrows. However, we noted the strong interfering effect of ambient light fluctuation when performing analysis with the Image J software.

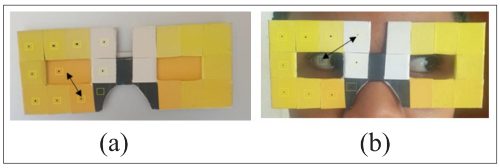


Figure 3: Mimicking jaundiced eye and (b) human volunteer. Arrows indicator matching regions according to the human observer.

Conclusion

Improving jaundice screening in low-income countries is needed to prevent bilirubin encephalopathy and mortality. Towards a solution, this study introduced an eye goggle configuration icterometer as well as initial results, representing as an improvement over the current icterometers. Our preliminary results are encouraging especially in the context of novel, economically viable solutions for high diagnostic accuracy neonatal jaundice screening in low-resource settings that satisfy the need to improve referrals from home, community or peripheral health centres to higher-level facilities with capacity for bilirubin testing and/or phototherapy.

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