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*by* Mekar Anggraeni

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# Non-invasive neonatal jaundice determination using smartphone camera

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**Mekar Dwi Anggraeni, Amin Fatoni and Eni Rahmawati**

# Non-invasive Neonatal Jaundice Determination using Smartphone Camera

Mekar Dwi Anggraeni[1, a)], Amin Fatoni[2, b)], and Eni Rahmawati[1, c)]

[1]*Department of Nursing, Faculty of Health Sciences, Universitas Jenderal Soedirman, Jl Dr Soeparno 61, Purwokerto, Indonesia*
[2]*Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Jenderal Soedirman, Jl Dr Soeparno, Purwokerto, Indonesia*

[a)] Corresponding author: mekar.anggraeni@unsoed.ac.id
[b)] aminfatoni@unsoed.ac.id
[c)] eni.rahmawati@unsoed.ac.id

**Abstract.** Neonatal jaundice is one of the common clinical conditions where the bilirubin levels are above the normal condition, which needs medical attention. It is important to the early determination of neonatal jaundice, especially in a rural area with limitations of medical instruments for bilirubin determination. This research was performed to determine neonatal jaundice using a smartphone camera. The smartphone was used to capture the arm of the neonatal. The arm images were then analyzed using ImageJ software to extract the color intensity of red, green and blue (RGB). The color intensity and the blood bilirubin concentration of neonatal were analyzed to obtain the linear regression. The results showed the blue (B) color intensity had a high correlation ($R^2 = 0.8081$, $y = -4.968x + 165.97$) with blood bilirubin concentration of neonatal observed. This study showed an important aspect of the use of smartphone camera for early detection of neonatal jaundice as an alternative of the visual assessment mainly in remote area when the laboratories analysis is not immediately available.

## INTRODUCTION

Neonatal jaundice is commonly found in newborn infants and commonly a reason for hospitalization. In the first week of life, about 60 to 80% of newborn infants develop jaundice, shown in yellow discoloration of the skin and sclera [1]. In Indonesia, almost 48% of newborns showed hyperbilirubinemia [2]. Hyperbilirubinemia is one of the contributors to the high Infant Mortality Rate (IMR) in Indonesia [3]. The IMR in Indonesia is very high at 26.9/1000 live birth and that of the highest IMR in southeast Asia.

Various methods have been reported to determine the blood bilirubin concentration in the newborn infants, for the invasive [4] and non-invasive methods [5]. Bilirubin is neurotoxic to the newborn infants. Hyperbilirubinemia would be caused the deposition of bilirubin in the basal ganglia, resulting in kernicterus [5]. Other effects of hyperbilirubinemia in infants including loss of hearing [6], general movement disorders [7], speech delay with hearing loss [8], bilirubin encephalopathy, moro reflex disorders, opisthotonos, vomiting, and death. Long-term manifestations of hyperbilirubinemia in infants are spasticity, choreoathetosis, and sensorineural deafness [9].

Bilirubin monitoring and phototherapy have been significantly reducing the effect of hyperbilirubinemia in infants [10]. However, in developing country IMR is still high due to the lack of access to medical equipment, especially for the remote areas or rural areas. Hyperbilirubinemia is easily characterized by the yellow color of the skin and sclera. The skin yellow color as an indicator of an increase in bilirubin levels could be observed through physical examination in infants by expert medical care [11]. The physical examination of visual inspection could be inaccurate and it is highly subjective, dependent on experience, and may give inaccurate results [12]. On another side, the laboratory protocol using instruments such as spectrophotometer to determine the blood bilirubin concentration provides accurate results. However, the equipment and reagents are relatively expensive, requires special expertise, and it is not available

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in a remote area. A new method is needed to determine the newborn bilirubin concentration for neonatal jaundice monitoring at a portable, low cost, providing good results. accurate, real-time and easy to use.

Smartphones have been reported to be used as analytical devices, replace conventional visual observation. The methods of the use of smartphone cameras such as to predict the hemoglobin level [13], food safety[14], iron in water [15] and also and glucose[16]. The basic principle of the use of a smartphone camera for analytical device is the digital image capturing of the object, extracting the color and analyzing the color intensity relative to the targeted analytes. The neonatal jaundice prediction using a smartphone could be used to replace the conventional method of a visual examination of skin and sclera [11]. This work reports the use of a smartphone camera to capture the arm of infants with bilirubinemia during hospitalization of neonatal jaundice. The images were then analyzed and related to the blood bilirubin obtained by the hospital protocol to get the equation further used to predict the neonatal jaundice.

## METHOD

### Study design

Respondent of 31 newborns have been asked for participating the research with criteria of newborn had jaundice and hospitalized. The informed consent has been explained to his/him mothers by the research assistant, and then signed my mother's when agree to participate in this research. The participants have been collected from a local district hospital with the inclusion criteria of newborn showed symptoms of hyperbilirubinemia and need hospitalization. The newborn image was captured in their hospital ward accompanied and with the consent of the newborn's mother. The newborn's blood bilirubin concentration has been analyzed according to the standard method and procedure in the hospital care for neonatal jaundice without any researcher intervention.

### Neonatal arm image capturing

Arm images of the participants have been captured using a smartphone camera (Redmi, Camera 13 MP, f/2.0, PDAF) under sufficient lighting without using a camera flash. A standard color chart [17] has been prepared and placed beside the newborn when capturing the images (Fig. 1). Image capture was taken for about 50-60 cm distance, with several repetitions to obtain the best images.

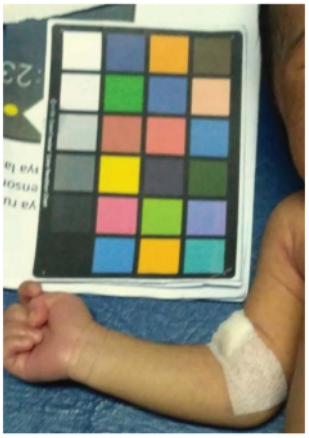

**FIGURE 1**. Example of neonatal arm image with the standard color chart

### Image analysis

Arm images from the smartphone have been analyzed using a laptop (MacBook Air, Apple Inc.) without any treatment or image processing. The images were then extracted to their color intensity of red, green and blue (RGB) using a free software ImageJ software ver. 1.52k (National Institute of Health, USA. http://imagej.nih.gov/ij). Three

different spots in the arms image have been analyzed the color intensity to get the representative image sampling site. The standard color chart was used to correct the possible bad lighting and colored light effect.

### Data analysis

Newborn arm image color intensity of RGB was collected and analyzed. The standard color chart spot of the white and yellow boxes was also analyzed. The RGB color intensity of the newborn arm was adjusted when the standard color chart showed a significant difference. The newborn blood bilirubin concentration reported in the medical record has also been collected. Arm image color intensity as a dependent variable was then related to the blood bilirubin concentration (as independent variables) using a simple regression equation (Microsoft Excel). The three RGB color intensities were separately analysis and the color with the highest coefficient of determination has been selected as the best color to predict the bilirubin concentration.

## RESULTS DAN DISCUSSION

### Respondents characteristics

Respondents who agreed to participate in this research was newborn/neonatal with inform consent signed by mothers. The average of mother's ages were 32 years, with a range of 19 to 41 years and 93.5% of mothers were multipara. None of the mothers had a newborn with hyperbilirubinemia in previous birth. The newborns have a range of neonatal jaundice for 2 days from birth to 26 days with the birth weight in the range of 1526 g to 3900 g and a birth weight average of 2761.4 g. The gestational ages of the newborns were 31 to 41 weeks. The blood bilirubin concentrations were 11 to 25.9 mg/dL with an average of 16.6 mg/dL. The neonatal were 69% cesarean birth and the rest natural birth. These participants' data could be important information for further neonatal jaundice profiling and analysis.

### Image Capturing

The newborn arm images were captured by a research assistant with the permission of him/his mother (inform consents have been signed by mother). The research assistant was first explained the aim of this research. There is no compulsion to become a respondent in this study. The arm image has been selected since this body part is easy to capture and almost always exposed even the newborn was dressed. Neonatal jaundice initially causes the skin to become yellow, therefore, neonatal jaundice could be easily observed the yellow color mainly showed in the face, chest, stomach area, arms and legs[18]. The arm images were captured several times to get the best images with the clear arm and sufficient light condition. The captured newborn arm images were then analyzed. A standard color chart was used to correct the images by adding or reducing the color intensity. The white and yellow boxes in the color chart was used to correct the light condition and the effect of colored light may exist. The arm images were corrected when the standard color chart of yellow and white had significantly (more than 3 points) different from other images. The average color intensities of standard white color in the captured images were R = 201.5, G = 237.5 and B = 239. Whereas the average color intensities of the yellow standard color chart were R = 202, G = 200.7 and B = 0.8. The use of a standard color chart was also previously used to correct the digital image processing [17]. Many strategies to correct the digital image analysis were also reported such as software white balance correction [19], the use of white paper [13] and red label-based white balance [20]. The use of a standard color chart in this research was selected for further smartphone software development where all standard color box available for analysis.

### Data Analysis

There was a linear relationship of newborn arm image color intensity and blood bilirubin concentration of the participants obtained by standard hospital procedures (spectrophotometric method). The arm images contain red, green and blue color intensities with the blue color intensity showed the highest relationship ($R^2 = 0.8081$) with the blood bilirubin (Fig. 2). On another side, the red color intensity showed the lowest relationship. The standard color chart or yellow box also showed the blue color intensity was almost zero, while the red and green colors showed similar intensity (RGB = 200,200,0).

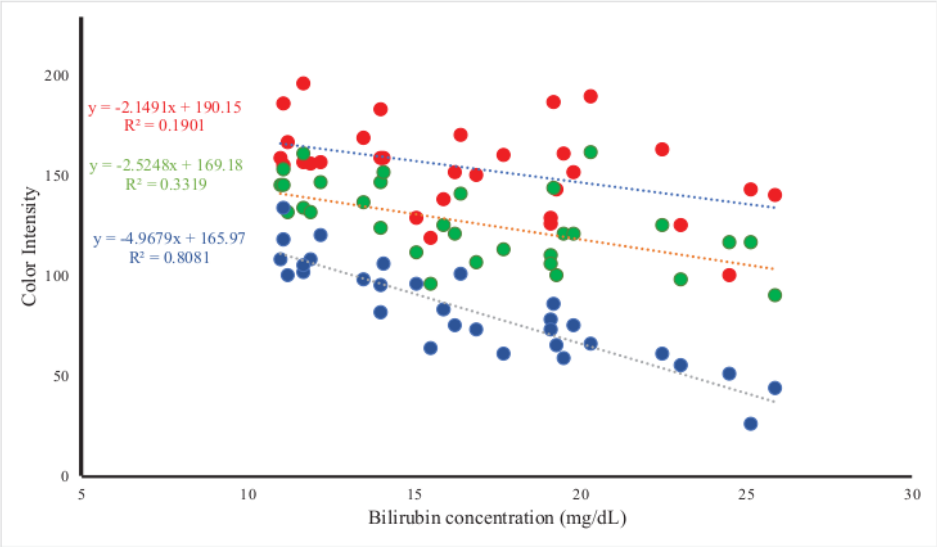


**FIGURE 2**. The red, green, and blue color intensity of neonatal arm images relations with blood bilirubin concentration. Blue color intensity showed the best relationship compare to red and green color intensity.

## Neonatal jaundice related factors

Excess neonatal blood bilirubin (hyperbilirubinemia) is the main cause of neonatal jaundice. Neonatal jaundice is common cause of hospitalization and commonly occurs in the first week of birth [21]. Bilirubin is responsible for the yellow color of neonatal jaundice, which is a normal part of pigment released from the breakdown of red blood cells. Imbalance the metabolism of rapid red blood cells breakdown by immature liver leads to an increase in the blood bilirubin concentration. A newborn immature liver often failed to remove the bilirubin quickly enough resulted in the excess of bilirubin. The conditions that can cause neonatal jaundice could be several factors [22], such as jaundice observed in the first 24h, premature birth [23], significant bruising during birth, blood type, breastfeeding and race [11]. Premature birth or gestational age of 35-36 weeks was the major risk factor, whereas the gestational age of 37-38 was the minor risk factor of neonatal jaundice [11]. The gestational age for more than 40 weeks showed a decreased risk of neonatal jaundice. The participants of this research showed that the average gestational age was 37.8 weeks, with a minimum of 31 weeks and maximum of 41 weeks. Premature newborns also may feed less and have fewer bowel movements, resulting in less bilirubin eliminated through stool [24]. Induced labor was also reported to slightly increase the neonatal jaundice incidence [23]. The result of data analysis in the participants showed the 43.5% were neonatal from the induced labor.

## CONCLUSION

The neonatal jaundice prediction method has been developed using arm images of neonatal captured by a smartphone camera. The blue color intensity of the neonatal arm showed a high correlation with the blood bilirubin concentration performed using the standard method in the hospital. The use of a smartphone to capture neonatal arm images and predict neonatal jaundice would be important as an objective preliminary screening of neonatal jaundice compared to the visual assessment, for the area where hospital instrumentation is not available.

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