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Saturation of stool color in HSV color model is a promising objective parameter for screening biliary atresia☆,☆☆,★

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ABSTRACT

Purpose: We aimed to study whether saturation in HSV color model could be a parameter for acholic stool and utilized for designing a mobile application for screening biliary atresia (BA).
Methods: Saturations of the colors in the three validated stool color cards (Taiwan, Japan, Britain) were read using PHOTOSHOP. Stools from 40 BA patients and 40 in-hospital neonates with pneumonia were photographed and analyzed with color-analyzing mobile applications.
Results: Saturations of normal colors in the published stool cards were all >50% (67% ~ 99%, median 85%) and were all <50% (7 ~ 47%, median 25%) for abnormal colors. With saturation < 60% as a cutoff line, acholic stools could be identified with a sensitivity of 100% and a specificity of 85%.
Conclusion: Saturation of stool color in HSV model is a promising objective parameter for acholic stool and could be utilized in designing mobile APPs for screening BA.
Level of evidence: Study of diagnostic test, level II.

Biliary atresia (BA) is the first common indication of pediatric liver transplantation. Operation age is critical for native-liver survival and the best outcomes occur in infants who undergo Kasai procedure within 60 days of life [1]. Screening programs for BA in neonates have improved the outcomes of BA and were cost-effective in Taiwan [2–4], Japan [5], United States [6] and Canada [7]. Stool color card is used in such programs to help parents recognize acholic stools. However, the judgment is subjective and acholic stool could not be reliably identified by parents or family doctors [8]. A simple and objective tool to identify acholic stool is potentially helpful and smartphone may provide a promising platform to develop such a tool.

PoopMD [9], developed by Johns Hopkins University School of Medicine, is the first and so far the only application (App) to detect acholic stool for cholestatic infants. In PoopMD, the acholic stool was defined as a range from white to pale color hexes captured from the acholic stools on the Taiwan stool card. Though effective in small-sample study, the actual effectiveness of PoopMD in screening program is unknown yet. Similar Apps could be developed, utilizing other potential parameters of stool color. Color could be numerically described in different color models. HSV color model, which stands for hue (H), saturation (S) and value (V), is one of the most intuitive and perceptually relevant color models. Here we studied the potential usefulness of HSV color model in identifying acholic stool and to determine whether HSV color model could be utilized in designing a mobile App for screening BA.

1. Material and methods

Patients, stool collection and photography.

Forty patients (male 18, female 22, 35-94d) were diagnosed with BA by intra-operative cholangiography consecutively from October 5th, 2015, to December 10th, 2015, in Children's Hospital of Fudan University. Stools were collected before operation. Forty in-hospital neonates (male 24, female 16; 18–48 d) with oral feeding who were admitted for pneumonia were selected as control. Stools were collected in the morning the next day after admission. Stools were photographed with Nikon D7000 in controlled incandescent lighting. Photos were reviewed by two pediatric surgeons experienced in BA (SZ, ZS) and were rated as "normal" and "acholic" independently. Only stools whose color was agreed on by the two surgeons were defined as "normal" or "acholic". Stools whose color was not agreed on were defined as "atypical".

1.1. Color-analyzing apps, usage and devices

ColorMeter (https://itunes.apple.com/us/app/colormeter-rgb-hex-color-picker/id713258885?mt=8) and Color Detector (https://play.google.com/store/apps/details?id=com.mobialia.colordetector) were

Abbreviations: BA, Biliary atresia; App, application.

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selected as color-analyzing Apps on iphone5s and Huawei C199, respectively. Once stool was collected, its color was immediately read by Huawei C199 under enough incandescent lighting and the three parameters (hue, saturation and value) were recorded. Colors were read on three representative spots of each stool and mean values were calculated.

1.2. Validated stool cards and saturation reading

Validated stool cards used in screening program or educational program from Taiwan [2], Japan [5] and Britain (http://www.yellowalert.org) were selected. Adobe Photoshop CS6 for Mac was used to read the parameters in HSV color model. Each stool color in Taiwan and Japan stool cards were read on three representative spots and mean saturation were calculated.

1.3. Simulation of stool color using Chinese traditional painting pigments

Chinese traditional painting pigments (yellow and white) were produced by BIYOUMI, Nanchang. Pigments were mixed in a palette according to a series of ratios (4:1, 3:1, 2:1, 1:1, 1:2, 1:3, 1:4, 1:10). Saturations of the mixed pigments were read by Huawei C199 under incandescent lighting.

1.4. Statistics

Statistical analysis was performed using the SPSS 21.0 (SPSS Inc., Chicago, IL) statistical software package. A P value of 0.05 or less was regarded as significant.

2. Ethics statement

Consent was obtained from legal guardian of each BA and control patients. The study was approved by the Institutional Review Board of Children's Hospital of Fudan University.

3. Results

1. Saturation of stool color in HSV color model was correlated with the concentration of bile.

   Yellow and white pigments of traditional Chinese painting were used to simulate bile and stool substrates, respectively. Stools of cholestatic patients were simulated by mixing these two pigments according to a series of ratios. Saturation of pure yellow pigment and pure white pigment is 100% and 0%, respectively. As the ratio of yellow-to-white decreased, the saturations of the mixed colors decreased while the hues and values were stable (Fig. 1). It indicated that saturation in HSV color model was correlated with the concentration of yellow pigment and thus, would be correlated with the concentration of bile in stool from cholestatic patients.

2. Saturations of acholic stools in the validated stool color cards were all under 50%

   Saturations of acholic stools in the validated stool color cards were significantly lower than that of normal stools ($p < .001$), while hues and values were not significantly different (hue, $p = 0.87$; value, $p = 0.76$). Saturation was under 50% (7–47%, median 25%) in all the acholic stools and over 50% in all the normal stools (67–99%, median 85%) (Fig. 2).

3. Saturation is sensitive in identifying acholic stools in BA patients

   Thirty-eight stools from BA patients were agreed on as true "acholic". The rest 2 were considered "atypical", so the incidence of acholic stool was 95.0%. For the acholic stools, saturation was under 50% in 35 BA patients (92.1%) and 50–60% in 3 patients (Fig. 3). The saturations of the two "atypical" stools (Fig. 4a) were 67% and 72%, respectively. In the control group, agreement was reached on all stools from 40 patients. Saturations were under 50% in 3 patients (Fig. 4b, c), 50–60% in 3 patients and over 60% in 34 patients (85.0%). Because the aim of the study was to design an App for screening, we set 60% as the cutoff line, with the aim to maximize the sensitivity. With that standard, the sensitive was 100% (38/38) and the specificity was 85.0% (34/40).

4. Variability of saturation in different light environments and between different smartphones

   Five normal stools and 5 acholic stools were photographed under nature light, incandescent lighting by 2 different smartphones (iphone5s, Huawei C199), respectively. Though saturations varied quantitively, the saturations of normal stools were all within normal range (>60%), while saturations of acholic stools were all <60%.

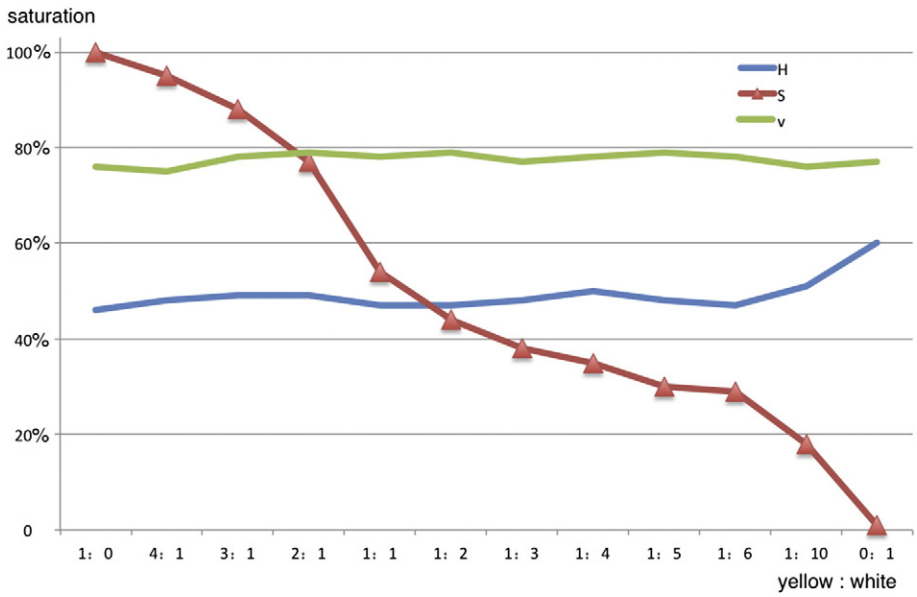

Fig. 1. Hue, saturation and value in HSV color model of the mixed pigments of Chinese traditional painting. As the ratio of yellow-to-white decreased, the saturation of the mixed colors decreased while the hues and values were stable.