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Original article

Estimation of the age of bruises using a colorimeter in a Thai population

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Abstract

***Background**:* It is critical to seek a medical opinion to estimate the aging of bruises. Several techniques have been consistently assessed for this purpose, among these bruise color observation yields promising results.
Objectives: This study aimed to investigate the efficacy of a colorimeter as a tool for dating bruises on living persons.
Methods: This study followed 41 Thai healthy patients who had a history of blunt force injury. By using a colorimeter, the bruise colors were evaluated and expressed in terms of L* a*b* values and compared to the baseline values obtained from the surrounding area near the bruises. These resulted in delta L*, delta a*, and delta b* values, which were used to investigate changes in the healing process over time.
Results: About 70.0% of all bruises showed the peak of color to the naked eye between 72 - 168 hours. The appearance of delta L*, delta a*, and delta b* in the bruise areas were significantly correlated with the time after injuries ($P < 0.0001$). Neither the location of bruises nor the type of skin color was statistically significant.
Conclusions: The results of this study reinforces the utility of colorimetry for the understanding of the dynamics of bruise colors. With additional research and more subjects, the dating of bruises could be established for use in forensic investigation.

Keywords: Bruise, bruise color, colorimetry, forensic medicine

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A bruise, or contusion, is a region of soft tissue bleeding caused by the rupture of blood vessels as a result of blunt trauma. [1] It can vary from the size of a pinhead to a significant blood accumulation in the tissues. As bruise the ages of, the degradation of the hemoglobin causes it to change in color. [2] Forensic pathologists are often asked to provide an expert testimony regarding the age of a bruise. They may be asked whether the wounds they have examined are consistent with the reported history, including timing and the object that caused the wound. For instance, in cases of child abuse, an abusive child may exhibit multiple stages of bruises. Determining the timing of bruises is a crucial evidence that the child was repeatedly tortured, which could result in aggravation of criminal punishment.

Two common techniques used to estimate the age of a bruise are histological examination and color change observation. [1, 3 - 5] Because histological examination cannot be obtained in clinical forensic cases, the only way to estimate the age of a bruise is based on color change. Theoretically, red, blue, and purple colors appear in the early period. Then, green and yellow colors appear later around 4 - 7 days. If a bruise becomes yellow, it has been there for longer than 18 hours. [6, 7] However, it is unreliable to estimate the age of a bruise through in-person direct observation. An observation of the color change is a subjective method that can vary depending on how each person perceives color. [3, 8] The accuracy of in-person direct observation of color changes can also be affected by the light source. Some light sources, such as those that are not daylight, may be yellow or orange, can distort color from direct observations. Therefore, forensic experts have sought to use modern technology to estimate the age of bruises. There are studies using devices such as visual scale [8], colorimeter [9 - 11], and trans-cutaneous bilirubinometer [12] to help determine the age of bruises with accuracy and in a quantitative value.

Despite the fact that forensic experts and medical professionals advise the use of color measurement tools to evaluate the age of bruises, [13, 14] this has not yet become a common practice in the majority of forensic practice in Thailand. An earlier study in the Thai population used the standard color chart to track the color changes that occur in bruises after trauma. But this study was limited in that a bruise was only examined at a point in time and had no follow-up. [8] In a previous study, the color of a bruise showed a significant change over four days, which proved the ability to simulate the change of bruise colorimetry over time in healthy adult subjects. [9] Gender and the amount of subcutaneous fat tissue did not substantially explain the bruise color or its change but skin color and bruise size were.[9, 15] However, there was no further analysis after the yellow colorimetry reached its peak on the fourth day. Hence, it was unknown when yellow colorimetry would return to the baseline.

This study aimed to investigate how the colorimetry of bruises changed over time in a healthy Thai population, including numbers of males and females with light and dark skin tones. The result of this study could help clinicians estimate the age of bruises more precisely.

Materials and methods

Study subjects

We obtained consent from the patients with bruises and this study has been approved by the Ethics Committee of the Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand (IRB no.543/2564) on 30th August 2021. From 1st September 2021 to 1st August 2022, Thai patients, ranging between 18 - 50 years, who were admitted to Siriraj Hospital with a history of a bruise were selected for the study. This study chose the age of 18 as the lower cutoff due to the issue of obtaining consent. Individuals under the age of 18 are not be able to give their consent and require parental/guardian permission to participate in the study. The upper eligible age was selected at 50 years in order to reduce an impact of declining estrogen on the inflammatory process. [16 - 17]

The information of all patients such as gender, age, height and weight, underlying disease, the date and time of injury, the position of the bruise, the color of a bruise, and the size of the bruise was recorded. The person with the following findings needs to be excluded from this study: 1) could not remember the time of injury; 2) had a history of bleeding tendency e.g., coagulopathy, taking an anticoagulant drug; 3) had a history of wound healing impairment e.g., liver cirrhosis, diabetes; and 4) had a severe trauma at the site of a bruise e.g., bone fracture and laceration. The location of the bruise was recorded and classified depending on underlying soft tissue thickness.

Colorimetric measurement

Bruises were examined from the following anatomical locations: ankle, calf, elbow, foot, forearm, upper arm, knee, shin, and thigh. The affected area is classified into two groups: namely: soft tissue area and non-soft tissue area. The soft tissue area refers to the area with a subcutaneous fat layer beneath the skin, whereas non-soft tissue area refers to the area with a thinner subcutaneous fat layer. The amount of subcutaneous fat beneath a bruise can affect the area of hemorrhage. The more soft tissue there is, the greater the space for blood to accumulate and bleed, unlike bony prominences, which have less subcutaneous fat and tend to bleed less.

A portable FRU® colorimeter WR - 18 was used for this study. The instrument was set including the standard light source of D_{65}, illumination mode 8/d, light mode SCI, Color space CIE1976 LAB, observer = CIE 10º, and the 8 mm diameter caliber. Before the examination, the instrument was daily calibrated by a black-and-white calibrator.

Colorimeter measurements were taken by gently pressing the probe on the area of the bruise at a right angle. The area of interest was the center of the bruise measured by marking its four widest corners and simply approximating the point where two imaginary diagonal lines from the opposite corners cross. By using this technique, we were able to examine the color of the bruise at the same point until the study ended. The control colorimetry was determined by measuring the normal skin close to the bruise. The average value of the three scans was used at each bruise to create each record. Daily colorimetric measurements were carried out by the same examiner until the subjects were discharged from the hospital or the bruise visually disappeared. There was no inter-observer variability in this study due to the measurement taking place in the in-patient ward, which is necessary to keep the privacy of the patients.

Color analysis

The color of a bruise was quantitatively assessed in a three-dimensional space and represented by the Commission Internationale de l'Eclairage (CIE: International Commission on Illumination) L*a*b* system. The L* value represents brightness in the range 0 to 100, where 0 is black and 100 is white. The chroma coordinates with the a* and b* represent the proportions of different colors. The positive value of a* indicates redness, while the negative value indicates a greenish hue. The positive value of b* indicates a yellow color, whereas the negative value indicates a blue hue. In this study, the bruise colorimetry was evaluated over time in all three values by noting changes in L*, a*, and b* and comparing those changes to the colorimetry of the control region. The bruise value was subtracted from the control value to obtain the ΔL*, Δa*, and Δb* values.

The Individual typology angle (ITA°) system, which is based on L* and b* measurements (ITA° = $[\tan^{-1}(L^*-50)/b^*)]$ *180/π), was used to categorize normal skin color.The healthy skin near the bruise was measured for the baseline colorimetry. The result is an angle with a value between + 90° and - 90°, which is used to classify the subjects into one of six categories of skin color, namely: light, very light, intermediate, tan, brown, and dark. [18 - 19] Lighter skin color is seen when ITA° increases. However, in our study, there were few extreme skin types, so we divided the study population into two main groups appropriate for Thai people using a cut-off value of 28. Light skin color included the groups of light, very light, and intermediate, while dark skin color included the groups of tan, brown, and dark. Therefore, the subjects' skin color was categorized into two types: dark (< 28°) and light (> 28°).

In this study, the delta E (or ΔE*) was evaluated by comparing the color of the controlled region and the bruise region. The ΔE* represented the quantitative distinction between two colors. The equation is $\Delta E^* = [(\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)2\ ]^{1/2}$. The ΔE* scale ranges from 0 to 100, with 0 indicating minimal color change and 100 indicating total distortion. The lesser ΔE*, the more challenging it will be to distinguish colors. The greater ΔE*, the more dissimilar two colors are. The typical perceptual ranges are provided if 1: not noticeable to the human eye, 1 - 2: perceptible with close examination, 2 - 10: perceptible at a glance, 11 - 49: colors are more similar than opposite, and 100: colors are the absolute opposite. [20]

Statistical analysis

Due to the prospective cohort nature of this study, the outcomes in each bruise were repeatedly observed at different days to assess its change over time. All statistical data analyses were performed using IBM SPSS Statistics 28.0 (IBM Corp., Armonk, N.Y., USA). Descriptive data such as the mean ± standard deviation (SD) or percentage are presented. Normal probability plots were used to verify the normality of the model's residuals. A one-way analysis of variance (ANOVA) was used to analyze the differences in bruise colors between each period in hours. A $P < 0.05$ was considered as statistical significance.

Results

Sample characteristics

In this study, there were 41 consecutive patients, including 31 females (75.6%) and 10 males (24.3%). The mean age of the subjects was 32.9 ± 6.4 years with the range between 23 and 47 years. The average body mass index (BMI) of all subjects was 23.2 ± 3.5 kg/m^2. A total of 343 measurements were taken after daily measurements of the skin color with and without bruises (mean number of measurements per patient = 8.4, range 4 - 19). Using the ITA° approach, the patients were separated into two types of skin colors: dark and light. There were 21 subjects (51.2%) with light skin color and 20 subjects (48.8%) with dark skin color.

Bruise characteristics (Figure 1)

Forty-one bruises were examined in this study. In total, 24 bruises were studied until complete healing, and 17 bruises were evaluated until the appearance of brown or yellow color was noticed. The traumatic event that caused the bruise in all cases was blunt trauma. The surface area of the bruises in this study ranged between 1.2 and 25 cm^2 (mean 9.8). The average bruise age of the first colorimetric measurement was 45.8 ± 33.1 hours after injury, with bruise ages ranging from 1 to 127 hours after injury. The average duration of the measurement of bruises in this study was 248.0 ± 102.3 hours, according to colorimetric data collected across a period of 91 to 479 hours post-trauma.

After injuries, red and purple colors were first displayed. Yellow color is an easy color to detect by an observer. The purple color remained at the center of some bruises even more than one week later. Yellow color could appear within the first day after injuries. This color was initially presented at a bruise's edge and then spreads gradually across the entire area of the bruise. The average time of the peak of yellow color presented at the period of 119.5 hours or around five days after injury in this study. About 70.0% of all bruises showed a peak of yellow color to the naked eye between 72 and 168 hours. The data showed a symmetrical distribution mostly situated around the mean. Using a one-way ANOVA test, the appearance of ΔL*, Δa*, and Δb* in contusion sites was significantly correlated with the period after injuries between each period ($P < 0.0001$). Also, this study found that the location of bruises and the type of normal skin color were not statistically significant factors affecting the change of bruise colors ($P = 0.09$ and 0.22, respectively).

Bruise colorimetric measurement (Figure 2)

Change in ΔL Colorimetry (black - white)*

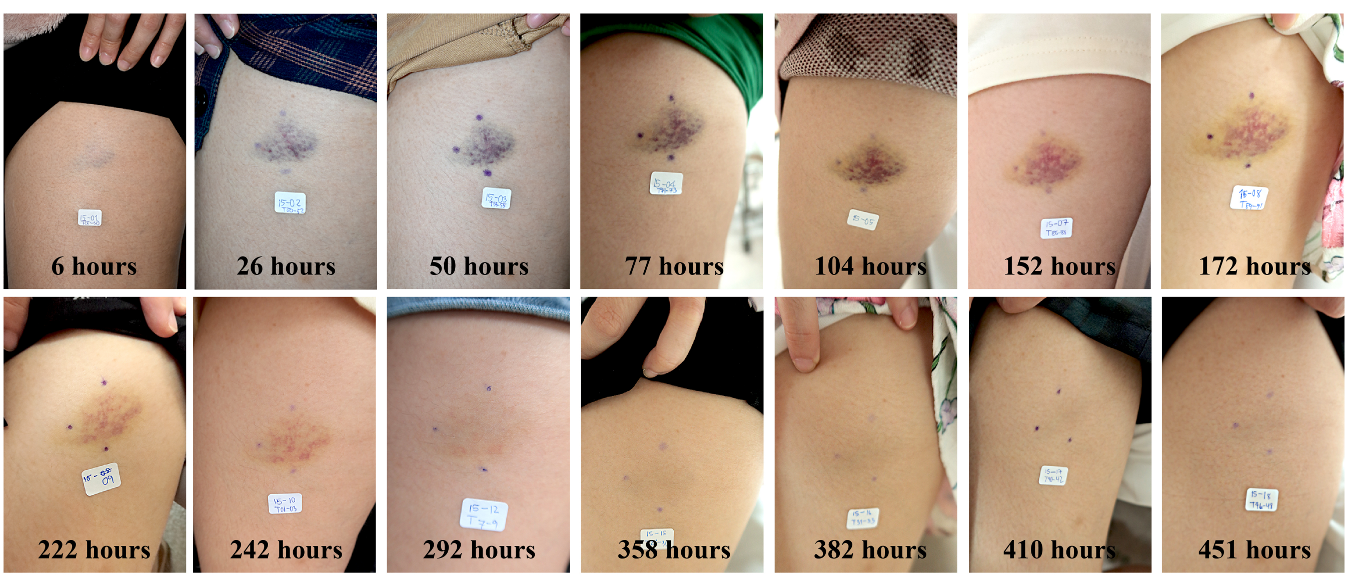

Figure 1. Samples of the contusion color assessment.

(A)

(B)

(C)

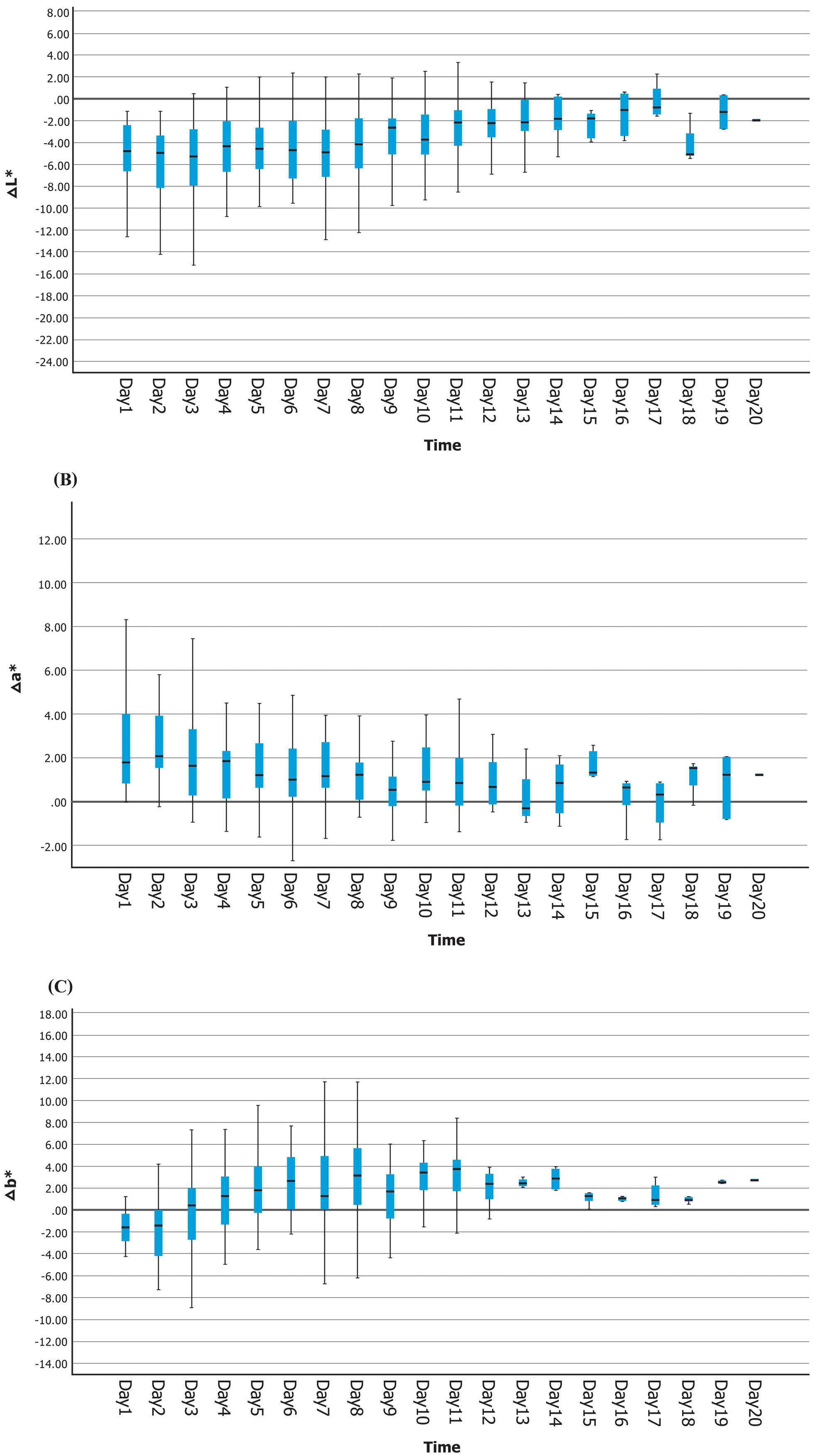

Figure 2. Changes of the average ΔL*(**A**), Δa*(**B**), and Δb*(**C**) values of bruises during two weeks post-trauma.

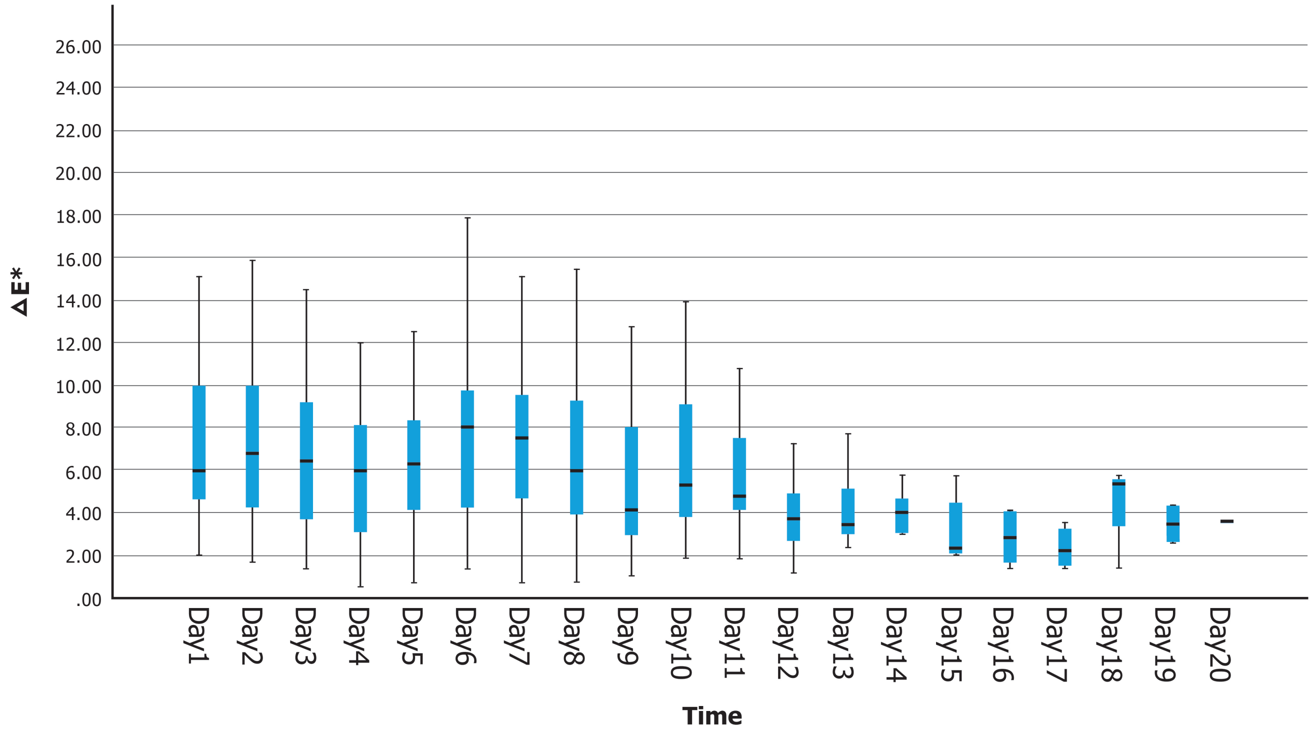

Figure 3. The daily DE* values in this study.

Almost all subjects exhibited negative quantities during the course of discoloration. The majority of the bruise reach the negative peak for ΔL* within the first week. Most bruises became darker (-L*) during the first three days and then gradually return to baseline L* colorimetry. The baseline represents the normal skin color. The mean time to the negative peak for ΔL* (the maximum darkness) was 96.1 hours post - trauma. It was generally observed that 48.8% of bruises showed the highest negative peak within the first three days.

Change in Δa Colorimetry (red-green) and Δb* colorimetry (yellow-blue)*

The Δa* showed plus values immediately after the traumatic event. During the first three days post-trauma, a substantial increase in the amount of red color (a*) was observed. The Δa* value showed the highest peak (the maximum redness) at an average time of 99.4 hours after the trauma event and then gradually decrease to the baseline. The positive peak was frequently seen in 58.5% of bruises observed within the first three days. The Δa* continued to maintain plus characteristics while the bruises aged.

A more complex model with two different patterns was noted in Δb* colorimetric measurement. After the traumatic event, the Δb* varied from minus to plus values over 3 days and then displayed a positive peak after 4 - 5 days. A considerable decrease in Δb* to the negative peak (the maximum blue) was observed during the first few days followed by a steady rise toward the baseline. Afterward, there was an increase in Db* to the positive peak (the maximum yellow) and then it gradually return to the baseline as time went on. The average post-traumatic time to the positive peak for Δb* was 147.41 hours, with 63.7% of bruises exhibiting the highest positive peak between 72 and 168 hours after injury.

*Change in ΔE**

The ΔE* value, which measures how much the colors differ from one another, is likewise produced by the colorimeter. The value of delta E increases from zero to its maximum and then returns to about zero. Each bruise has its own characteristic delta E value. Delta E varies between 0.5 and 24.0, with a mean of 6.6 and a standard deviation of 4.5 (Figure 3).

Discussion

The color of the normal skin is influenced by the amount and distribution of overlying pigmentation, and by the extent of the cutaneous and subcutaneous capillary filling where a greater degree of skin redness or pallor is due to an increase or decrease in the filling. Therefore, the color of the underlying skin affects the bruise color. Even though blood is red, the presence of hemoglobin can modify the bruise's outward appearance, primarily depending on the oxygenation of the blood and the depth of the lesion. The breakdown of hemoglobin results in the formation of biliverdin, the release of carbon monoxide, and the presence of iron atoms in heme. [21] Greenish biliverdin then transforms into bilirubin, which has yellowish pigmentation. In the macrophage, some of the liberated iron from heme is used to form hemosiderin (brownish pigmentation). When the bilirubin and hemosiderin are eliminated, the bruise then gradually fades away. These phenomena explain how the colors of such a lesion change over time and a bruise is typically described as initially reddish, fading to bluish or purplish, then greenish, yellowish, and eventually brownish. However, there is no recognized indicator that can forecast whether the bruise will fade gradually or quickly. The initial colors can differ from case to case, and resorption starting at the edges causes the bruise to disappear in a few days to weeks.

The simplest and most practical way to evaluate bruises is visual assessment. However, it is unreliable even for experienced forensic pathologists to date bruises directly from naked eye observation or through a photograph. [4, 13, 22 - 25] Different people perceive color differently, with extreme cases being color blindness. [26] The perception of yellow decreases with age and it was best in late adolescence. [13] Additionally, perceptions of visual color can alter in different lighting conditions. Therefore, visual assessment is imprecise and should not be used as evidence in court. [3, 14, 23] The L*a*b* system has the benefit that it simulates the physiology of sight, and it seems to be particularly useful for determining skin color. [26]

A colorimetric method for dating bruises has been discussed in previous literature. [9 - 11] Because it is portable, simple to use, easily accessible on the equipment market, non-invasive, safe, painless, and reasonably priced, a colorimeter was employed in this study. Also, a colorimeter would be easy to use in routine forensic casework to help in dating bruises. This technique relies on using a colorimeter to describe a color into its three primary RGB colors (red, green, and blue) and quantifies their hue, saturation, and luminosity. Although colorimetric examination has some limitations, the pressure applied to the skin during measurement can affect colorimetry results. Additionally, in this study, which examined bruises on the following day, it was impossible to measure the exact same point. Nonetheless, we attempted to minimize discrepancies by using surgical pens as boundaries and taking the average of three measurements. It would be feasible to identify whether the bruise corresponds to the increase or decrease phase of colorimetric measurement by examining the patient again on the following day and collecting the same measurement. Our findings indicate that when a bruise displays increasing Δb^* values from one day to the next, the trauma must have occurred at least two days before the first measurement. Additional research should aim to validate this assumption, which is constrained by the limits of our study and confounding variables.

Generally, a mixture of different colors was observed in each bruise. The yellow color of a bruise is the easiest color to distinguish from other colors. Even in the purple/blue-colored bruises, a yellow color could be visible in this study. According to previous literature [7 - 9] the yellow color became apparent 18 - 24 hours or more after injuries. This study started to detect yellow color within the first day, and this color was generally peaked on day 3 - 7 after injuries (mean = 119.5 hours). These results are consistent with the analysis of bruises by Mesli V*, et al.* [12] and Kim O*, et al.* [27], where a peak of yellow discoloration from subcutaneous bilirubin concentration was discovered 4 - 5 days following the traumatic event. This study showed that the recognition of the yellow color, especially around the edge of the bruise, might be helpful in the evaluation of the age of the bruise.

The previous study showed that the colorimetric examination of the color of a bruise might be useful for the dating of a bruise in patients with dark skin. [10] Though this method enables accurate color description, the color of underlying skin is too much of a complicating variable to allow for the determination of a bruise's age. Comparisons between Caucasian and South Asian subjects were made, and the b* showed the most significant difference among both groups. In addition, this study revealed that the yellow color of a bruise could not be recognized with a colorimeter on dark-skinned subjects because of the skin pigmentation. [10] In this study, there was no statistically significant relationship existed between the color of the underlying skin (light and dark) and the color of the bruise. This finding could be explained by the lighter skin color of the Thai people compared with South Asian people.

In this study, the location of the bruises had no statistically significant impact on how the colors of the bruises changed. These results showed that different locations of bruises may tend to affect how the color of the bruise changed throughout the injury. Different body areas have different tissue characteristics, such as varying blood vessel distribution, connective tissue density, and tissue reaction after traumas, and these variables may have an influence on the rate of the breakdown of hemoglobin and its by-products. [7] To ascertain the effect of the body area of bruises, further research with a larger sample size and different locations of bruises should be undertaken.

This study has recently started a pilot study to determine whether a colorimeter can be used to evaluate the aging of bruises in the Thai population. However, several limitations should be considered in this study. The current study cohort is not representative of the Thai population because it included patients with younger ages and more women. The previous study reported that normal skin blood flow dramatically declines with increasing age and identified significant age-related changes in the skin's blood flow at specific anatomical regions. [7] This is mostly the result of recruitment bias because only patients who admitted to Siriraj Hospital service were involved. Also, there was no patient with very light skin color in this study due to the weather in Thailand, which is very sunny all year round. Further study should be conducted using a larger sample size and a wider diversity of skin characteristics. It was impossible to measure the same point during each colorimetric examination even though we attempted to minimize discrepancies by identifying the area of interest by a surgical pen and taking the average value from three measurements.

Conclusions

In this study, the range of bruise colorimetry was carefully investigated. Some individual factors, such as the type of normal skin color and the location of the bruises, has no statistically significant effect on the change of bruise color. Our research results showed that colorimetry is a precise and accurate tool for determining the color of bruises. Examining changes in bruise color using colorimetry during the increasing or decreasing phases on the following day can help estimate the age of the bruise. Nonetheless, this study still recognizes the importance of visual observation of bruise color because it is the easiest method for a forensic pathologist to estimate the age of the bruise. It is hoped that the colorimetric method will provide a more objective assessment of the color and color changes related to the bruise, and perhaps make it possible to estimate the time since injury in a more objective way.

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Conflicts of interest statement

The authors have each completed an ICMJE disclosure form. None of the authors declare any potential or actual relationship, activity, or interest related to the content of this article.

Data sharing statement

The present review is based on the references cited. Further details, opinions, and interpretation are available from the corresponding authors on reasonable request.

References

1. DiMaio VJM, Molina DK. DiMaio's Forensic Pathology. 3rd ed. Boca Raton: CRC Press; 2021.
2. Vanezis P. Bruising: concepts of ageing and interpretation. In: Rutty GN, editor. Essentials of autopsy practice. London: Springer; 2001. p. 221-40.
3. Bariciak ED, Plint AC, Gaboury I, Bennet S. Dating of bruises in children: an assessment of physician accuracy. Pediatrics 2003;112: 804-7.
4. Grossman SE, Johnston A, Vanezis P, Perrett D. Can we assess the age of bruises? An attempt to develop an objective technique. Med Sci Law 2011;51: 170-6.
5. Ross CG, Langlois NEI, Heath K, Byard RW. Further evidence for a lack of reliability in the histologic ageing of bruises-an autopsy study. Aust J Forensic Sci 2015;47:224-9.
6. Langlois NE, Gresham GA. The ageing of bruises: a review and study of the colour changes with time. Forensic Sci Int 1991;50:227-38

7. Langlois NE. The science behind the quest to determine the age of bruises - a review of the English language literature. Forensic Sci Med Pathol 2007; 3:241–51.
8. Dulabutr D. The correlation between the color changes of contusions and the time period after injuries in Thai populations. Thammasat Med J 2018;18:561-70.
9. Scafide KR, Sheridan DJ, Campbell J, Deleon VB, Hayat MJ. Evaluating change in bruise colorimetry and th effect of subject characteristics over time. Forensic Sci Med Pathol 2013;9: 367-76.
10. Thavarajah D, Vanezis P, Perrett D. Assessment of bruise age on dark-skinned individuals using tristimulus colorimetry. Med Sci Law 2012;52:6-11.
11. Yajima Y, Funayama M. Spectrophotometric and tristimulus analysis of the colors of subcutaneous bleeding in living persons. Forensic Sci Int 2006; 156:131-7.
12. Mesli V, Le Garff E, Marchand E, Labreuche J, Ramdane N, Maynou C, et al. Determination of the age of bruises using a bilirubinometer. Forensic Sci Int 2019;302:109831.
13. Hughes VK, Ellis PS, Langlois NE. The perception of yellow in bruises. J Clin Forensic Med 2004;11:257-9.
14. Munang LA, Leonard PA, Mok JY. Lack of agreement on colour description between clinicians examining childhood bruising. J Clin Forensic Med 2002;9:171-4.
15. Mimasaka S, Ohtani M, Kuroda N, Tsunenari S. Spectrophotometric evaluation of the age of bruises in children: measuring changes in bruise color as an indicator of child physical abuse. Tohuko J Exp Med 2010; 220:171-5.
16. Ashcroft GS, Ashworth JJ. Potential role of estrogens in wound healing. Am J Clin Dermatol 2003;4:737-43.
17. Ashcroft GS, Mills SJ, Lei K, Gibbons L, Jeong MJ, Taniguchi M, et al. Estrogen modulates cutaneous wound healing by downregulating macrophage migration inhibitory factors. J Clin Invest 2003;111: 1309-18.
18. Osto M, Hamzavi IH, Lim HW, Kohli I. Individual typology angle and Fitzpatrick skin phototypes are not equivalent in photodermatology. Photochem photobiol 2022;98:127-9.
19. Wu Y, Tanaka T, Akimoto M. Utilization of individual typology angle (ITA) and hue angle in the measurement of skin color on images. Bioimages 2020;28:1-8.
20. Mokrzycki W, Tatol M. Color difference Delta E-A survey. Mach Graph Vis 2011;20:383-411.
21. Pimstone NR, Tenhunen R, Seitz PT, Marver HS, Schmid R. The enzymatic degradation of hemoglobin to bile pigments by macrophages. J Exp Med 1971;133:1264-81.
22. Pilling ML, Vanezis P, Perrett D, Johnston A. Visual assessment of the timing of bruising by forensic experts. J Forensic Leg Med 2010;17:143-49.
23. Stephenson T, Bialas Y. Estimation of the age of bruising. Arch Dis Child 1996;74:53-5.
24. Hughes VK, Ellis PS, Langlois NE. Alternative light source (polilight) illumination with digital image analysis does not assist in determining the age of bruises. Forensic Sci Int 2006;158:104-7.
25. Lecomte MM, Holmes T, Kay DP, Simons JL, Vintiner SK. The use of photographs to record variation in bruising response in humans. Forensic Sci Int 2013; 231:213-8.
26. Queille-Roussel C, Poncet M, Schaefer H. Quantification of skin colour changes induced by topical corticosteroid preparations using the Minolta Chromameter. Br J Dermatol 1991;124: 264-70.
27. Kim O, McMurdy J, Lines C, Duffy S, Crawford G, Alber M. Reflectance spectrometry of normal and bruised human skins: experiments and modeling. Physiol Meas 2012;33:159-75.