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Investigation of the Aging of Post-Traumatic Bruises Using Traditional and Computerized Digital Color Comparison Methods

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ABSTRACT

Estimating bruise age by color is unreliable due to low accuracy and confounding variables. The aims of the current study were 1) to compare the RGB values, obtained for age determination of post-traumatic bruises, as identified by four methods in sequence: traditional naked eye and photographic color identification, ImageJ analysis, and artificial intelligence (AI)-supported color identification; 2) to statistically determine the accuracy prediction rates of the bruise aging phase using discriminant function analysis (DFA) of these RGB values; and 3) to assess the usability of these methods in forensic medicine and clinical practice.

We examined 407 photographs from 43 patients with traumatic bruises at the University Hospital (2023–2024). One researcher recorded RGB values during patient examination; two researchers used a scale to assess RGB values from photographs; two researchers used ImageJ; and AI analyzed bruise photos. Discriminant function analysis (DFA) assessed bruise-aging group classification using RGB means.

The AI-assisted program demonstrated the highest overall accuracy in bruise age estimation (50.1%). In the yellow-dominant group, the 65-year-old researcher exhibited the lowest accuracy (18.3%), whereas the AI-assisted program achieved perfect accuracy (100.0%). Visual identification by the naked eye was more accurate compared to other non-AI digital methods. These findings indicate that AI-based color analysis, which uses computational techniques to assess bruising, outperforms traditional and digital methods across specific bruise color groups.

Determining bruise age remains unreliable with current methods, but AI-supported programs offer higher prediction rates in some color groups. These results suggest AI may improve accuracy as technology advances.

Keywords: Bruise, Aging, Photograph, RGB, Artificial intelligence

Introduction

A non-elevated skin discoloration larger than 1 cm in diameter, caused by blood leaking from damaged vessels into the dermis and subcutaneous tissue, is generally called ecchymosis (1-4). The term "ecchymosis" is more often used for lesions of pathological origin. "Bruise" describes lesions of traumatic origin. Many physicians use "ecchymosis," "hematoma," "bruise," and "contusion" interchangeably for both pathological and traumatic lesions (1, 3, 5). Although "ecchymosis" is more commonly used for lesions of traumatic origin in forensic medicine practice in Türkiye, these traumatic lesions will now be defined as bruises in the current study.

Judicial authorities may ask forensic medicine specialists or physicians who prepare forensic reports to identify bruise age, particularly in cases of suspected injury under police supervision, or child and women abuse cases, often basing the request on bruise color (2, 6, 7). The comments made can serve as evidence in court and influence the decision to convict or acquit a suspect (8).

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After a certain period, the development of decomposition products causes visible color changes in the bruises (7). Many factors, including the location of the bruises, the presence of underlying bone or vascular tissue, the age and gender of the injured person, skin color, the presence of underlying bleeding disorders, the use of certain medications such as steroids, and whether the bruises are superficial or deep, can cause variations in the timing of color change and even the order of the color change (2, 7). Despite many factors contributing to this difference, one aspect that has been frequently discussed in older forensic literature is the distribution of caries colors and the time required for their appearance and disappearance. Specifically, as quoted in these articles, various authors have defined different time intervals for color changes associated with caries aging (Table 1) (2, 5, 9). Furthermore, a study of observers evaluating bruises found that the ability to perceive yellow decreases with age, potentially affecting color identification (10).

In 1991, Langlois and Gresham conducted a pioneering United Kingdom study based on the idea that estimating the age of bruises is complex, involves many variables, and largely relies on interpretation rather than documentation. They examined 369 color photographs of bruises up to 21 days old, from 89 people aged 10 to 100, taken with a high-resolution color daylight-film camera, a single-lens reflex camera with a lens suitable for close-up photography, and a camera-mounted electronic flash. For each photo, they recorded the observed colors at the time of the photo shoot using a standard color scheme. Their main finding was that it is unlikely to reliably estimate a bruise's age solely from its photographic appearance, because multiple factors can influence how bruises appear (2).

In a 2002 study and a systematic review published in 2005, the authors concluded that the age of a bruise cannot be accurately determined clinically live or from a photograph, and therefore members of the judiciary and the legal profession should stop relying on color when determining the age of a bruise (11, 12).

In 2011, Grossman et al. induced bruises in volunteers using a vacuum pump. They presented 25 photographs of volunteers depicting different bruise ages to 23 forensic specialists, who rated them using a 7-colored scale. In the second phase of their study, the researchers monitored the resulting bruises, taking daily photographs from the moment they appeared. The red, green, and blue (RGB) values for each bruise were compared using Adobe Photoshop. The researchers concluded that visual assessment of photographs is unreliable for estimating bruise age, regardless of assessor experience. They found that while the RGB technique reliably measures color, it does not validly estimate bruise aging (8).

Following these publications, research on aging determination of bruises in forensic medicine declined after 2010. In contrast, colorimetric analysis of photographs for skin discolorations unrelated to bruises, as well as the digital assessment of Red-Green-Blue values within a defined color spectrum, was increasingly adopted in clinical practice (11-13).

The aims of the current study were 1) to compare the RGB values, obtained for age determination of post-traumatic bruises, as identified by four methods in sequence: traditional naked eye and photographic color identification, ImageJ analysis, and artificial intelligence (AI)-supported color identification; 2) to statistically determine the accuracy prediction rates of the bruise aging phase using discriminant function analysis (DFA) of these RGB values; and 3) to assess the usability of these methods in forensic medicine and clinical practice.

Material and Methods

Study Population and Material: The study population comprised 43 patients with traumatic bruises admitted to the Departments of Orthopedics and Traumatology and Neurosurgery at Van Yüzüncü Yıl University Hospital for inpatient care or follow-up between 2023 and 2024. A total of 407 photographs of bruises met the inclusion and exclusion criteria and were included as study material.

Inclusion Criteria: Patients were included if they were conscious and had full cognitive abilities. They or their legal representatives had to give informed consent for bruise photography. Patients also had to agree to photographs during their hospital stay or follow-up. Additional criteria included a history of trauma, bruises less than 24 hours old, and bruises located away from fracture sites in fracture cases.

Exclusion Criteria: Exclusion criteria comprised unconsciousness, impaired cognitive function, absence of consent from the patient or representative, pathological bruises, and systemic trauma effects. Bruises detected more than 24 hours post-injury or were situated in fracture regions were also excluded.

Data Collection: The data collection phase of the study was conducted at the Departments of Orthopedics and Traumatology and Neurosurgery at Dursun Odabaş Medical Centre of Van Yüzüncü Yıl University.

Visual and Colorimetric Assessment: After obtaining informed consent, the study group patients were examined within the first 24 hours. M.A.G., an orthopedics and traumatology specialist, and M.A., a neurosurgery specialist, conducted these initial examinations. Later, the researcher E.K. (37 years old, a forensic medicine specialist) carried out a medical examination as daily as possible. During these examinations, researchers identified bruise colors by naked-eye inspection. They recorded these observations, along with patient information, in an Excel file. The identified colors were later evaluated using a color scale. The RGB values of the detected colors were also determined and added to the Excel file.

Photographing of Lesions: After initial visual and colorimetric assessments were completed, patients were positioned relative to the lesion area using the technique described by Halpern et al. (14). Bruises were then photographed at a right angle to the lesion, with the lesion in the middle third of each frame, at a distance of 90 cm or 30 cm, depending on the lesion size, as described by Bloemen et al (15). During the photographing process, a color scale consisting of 13 primary and 103 secondary colors, each with predetermined RGB values , was placed next to the bruises (Figure 1). Photographs of the bruises were taken every 24 hours when possible (Figure 2). For patients who left the hospital early, follow-up appointments were arranged to capture photographs during return visits.

Photography Technique: The room lighting was controlled, and spotlights (LED number: 144pcs bead light for 3200K color temperature and 144pcs bead light for 5600K color temperature, Brightness control: 0% / 100%, Maximum illuminance: 1100 Lumen / 1m, Color temperature range: 3200K / 5600K adjustable, Color rendering index: CRI>95, Display mode: LCD display) were used if natural white light was not available. The photographs were taken with a camera (DIGIC 7 Image Processor. Multi-Point Full Cross-type AF System. Full HD Video at 60 fps; Digital IS. Native ISO 40000, Expanded ISO 102400. 6.5 fps Shooting; Time-lapse and HDR Movie. Built-in GPS with NFC, Bluetooth, and Wi-Fi.) mounted on a tripod and using a lens (Fast f/1.4 aperture, Standard 46° angle of view, USM focus motor and full-time manual focus override, 45cm shortest focusing distance, Aspherical lens element, 58mm filter size).

The photographs were assigned numbers in a randomized sequence to remove any identifying information, while patient details and the date each bruise was photographed were excluded from the Excel file. Both files, including photos and Excel, were then transmitted electronically to Bahçeşehir University for the second phase of the study, which involved blinded assessments.

Data Processing: Three different blind evaluation methods were applied at this phase. In the first, two researchers (S.U. and G.A., both 25 years old) compared bruise colors to photo colors on a colorimetric chart and recorded the RGB values. In the second, two researchers (C.G. (25 years old) and M.A. (65 years old)) used ImageJ, an open-source Java script (ImageJ is used across many scientific fields to calculate RGB values, Z values, and other digital image features). They automatically calculated and noted the RGB values within the area whose boundaries they drew themselves in the ImageJ program. In the third, an AI-supported program drew bruise boundaries and identified RGB values. RGB values from all three methods were recorded in an Excel file.

Data Assessment: Subsequently, information on bruises was obtained from the first study center, and in accordance with the results of previous studies presented in Table 1, bruises that occurred on the 1st day were included in the first group, bruises that occurred on the 2nd and 3rd days were included in the second group, bruises that occurred between the 4th and 7th days were included in the third group, and bruises that occurred between the 7th and 13th days were included in the fourth group. Since no photographs could be taken after the 13th day, a fifth group could not be created.

Statistical Analysis: Statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation (SD). The significance level was set at α=0.05.

Prior to the analysis, the assumptions of normality and homogeneity of variances were evaluated using the Kolmogorov-Smirnov test and Levene's test, respectively. To compare the mean Red (R), Green (G), and Blue (B) values across the four bruise-age groups (Group 1: 0–24 h; Group 2: 2–3 days; Group 3: 4–7 days; Group 4: 8–13 days), a One-way Analysis of Variance (ANOVA) was

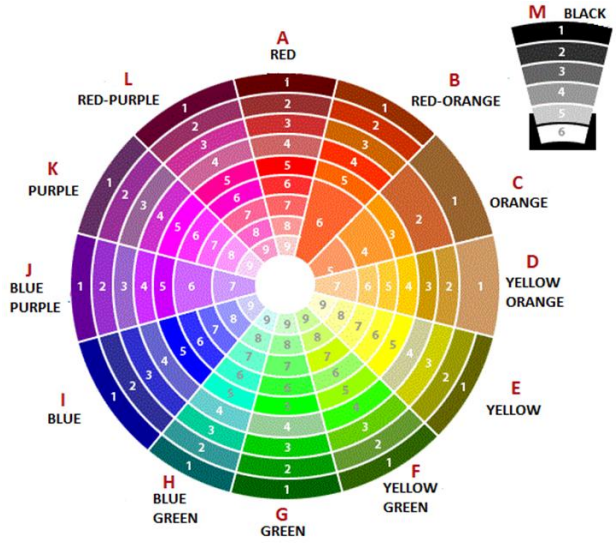

Fig. 1. A color scale consisting of 13 primary and 103 secondary colors

Fig. 2. Daily photo tracking of a patient

conducted. This analysis was applied separately to the data obtained from each method: naked-eye examination, scale-based photography, ImageJ software, and AI-assisted analysis. For the ImageJ and AI methods, the differences between the RGB values of the bruise and the adjacent intact skin (ΔR, ΔG, ΔB) were also analyzed using the same ANOVA framework. Where the ANOVA indicated statistically significant differences, Duncan's Multiple Range Test was utilized as a post-hoc analysis to determine specific pairwise differences between the groups.

Finally, to evaluate the predictive accuracy of color information for classifying bruise ages, Discriminant Function Analysis (DFA) was performed. The standard 'Enter' method was used, where all independent variables (raw RGB means or ΔRGB differences) were entered into the model simultaneously to assess their combined classification ability. To validate the stability of the classification model and minimize bias, leave-

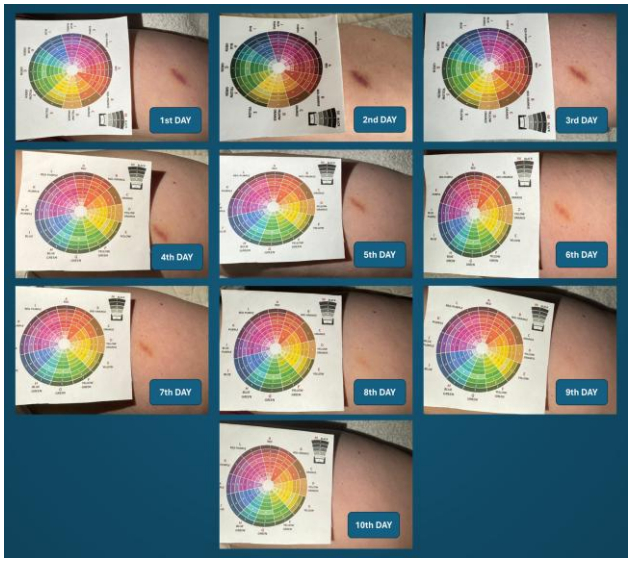

Fig. 3. RGB values of the bruise and skin closest to the lesion using ImageJ

one-out cross-validation was applied. Classification accuracy rates were derived from the resulting confusion matrices for each method.

Inter-observer Error Analysis: To assess the reliability and consistency of the measurements, inter-observer error analysis was conducted for methods involving multiple evaluators. Paired-samples t-tests were used to compare the mean R, G, and B channel values obtained by two independent researchers. This analysis was performed separately for the scale-based photographic assessments and the ImageJ digital measurements. The mean differences and p-values were calculated to determine if there was a statistically significant systematic difference between the observers.

Ethical Approval: The study received ethics approval from Bahçeşehir University on June 22, 2023 (2023-12/03).

Results

A total of 43 patients and 407 corresponding photographs were included in the present study. The mean patient age was 27.8±13.4 years. Of the participants, 19 (44.2%) were male and 24 (55.8%) were female.

The study utilized four techniques: (1) one researcher visually determined bruise RGB values during examination; (2) two researchers assessed RGB values from scale-based photographs; (3) two researchers used ImageJ software to obtain RGB values from bruise photographs; (4) artificial intelligence determined RGB values from bruise

Table 1: Color Change of Bruises According to the Definitions of Different Authors (Quoted from Langlois & Gresham (2), Vanezis (5), and Stephenson & Bialas (9)

Literature (In chronological order)	0-24 h (Immediately)	1-3 Days (Soon After)	4-7 Days	7-14 days	Over 13-14 days
Smith & Fiddes (1955)	Red	Purple / Black	Green	Yellow	Resolution
Glaister (1962)	Violet	Blue	Green	Yellow	Resolution
Rentoule & Smith (1973)	Violet	Dark Blue	Green	Yellow	Resolution
Adelson (1974)	Red, Blue / Purple	Blue / Brown	Yellow / Green	Resolution	Resolution
Spitz and Fisher (1974)	Light Blue / Red	Dark Purple	Dark Purple / Greenish Yellow	Brown	Resolution
Camps (1976)	Red	Dusky Purple / Black	Green	Yellow	Resolution
Polson & Gee (1985)	Red / Dark, Red / Black	-	Greenish (Around 7th Day)	Yellowing (Around 14th Day)	Resolution (Up to 30 Days)

Table 2: The Red, Green, and Blue Color Means Of The Bruises, Which Were Computed Using Various Color Determination Techniques and the RGB Color Model

		Color Determination Technique					
RGB Values		Naked Eyes (Patient Examination)	Photographs Scala (1)	Photographs Scala (2)	Photographs ImageJ (1)	Photographs ImageJ (2)	Photographs AI (Copilot)
RED	Mean	199.6	170.0	141.4	153.4	156.4	119.8
	SD	27.9	57.3	51.8	37.9	38.3	18.4
	Minimum	134.7	0.0	0.0	41.0	57.3	58.0
	Maximum	255.0	255.0	254.0	251.0	251.3	145.0
GREEN	Mean	138.1	132.0	72.7	121.8	124.7	93.7
	SD	39.4	63.5	54.1	34.8	35.7	16.2
	Minimum	64.2	0.0	0.0	37.0	42.6	39.0
	Maximum	220.9	254.0	253.0	204.0	210.3	115.0
BLUE	Mean	106.2	147.5	95.7	110.7	112.8	83.5
	SD	25.8	65.7	71.7	34.5	34.6	8.4
	Minimum	46.7	2.0	1.7	11.0	27.9	54.0
	Maximum	153.4	255.0	255.0	196.0	192.6	104.0

RGB: Red, Green, Blue; SD: Standard Deviation

photographs. The various bruise color detection techniques and the mean red, green, and blue values of bruises, calculated using the RGB color model, are presented in Table 2.

A Paired Sample t-test was used to determine whether there was a difference between two measurements performed with the same methodology. Specifically, there was a statistically significant difference between the mean red, green, and blue (RGB) values of the two researchers who evaluated photos and defined colors on a scale ($p=0.001$ for each color). In addition, there was a significant difference in the mean red and green values, but not in the mean

Table 3: Statistical Relationship Between The Mean Value of Red, Green, and Blue of Bruises Calculated Using The RGB Color Model On 407 Photographs, and The Four Different Stages of Bruises

Color Determination Technique								
RGB Values	Aging Groups of Bruises	n	Naked Eyes (Patient Examination)	Photographs Scala (1)	Photographs Scala (2)	Photographs ImageJ (1)	Photographs ImageJ (2)	Photographs AI (Copilot)
RED	Group 1	43	206.7	180.0b	132.7a	159.3	158.5	130.2b
	Group 2	82	202.8	155.4a	125.7a	153.9	154.7	130.0b
	Group 3	164	195.6	162.2a	140.4a	153.4	156.4	127.3b
	Group 4	118	200.5	187.5b	156.7b	151.1	156.6	98.4a
	P		0.058	0.000	0.000	0.684	0.963	0.000
GREEN	Group 1	43	109.5a	119.0b	75.1	130.3	130.7	102.4b
	Group 2	82	117.9a	107.2a	61.6	121.0	121.8	102.3b
	Group 3	164	145.2b	131.2b	73.3	120.7	124.0	99.9b
	Group 4	118	152.8b	155.1c	78.8	120.5	125.6	76.0a
	P		0.000	0.000	0.168	0.405	0.594	0.000
BLUE	Group 1	43	122.0b	173.1b	147.5d	126.7b	122.7	84.3
	Group 2	82	116.5b	145.4a	124.4c	111.9a	113.8	84.1
	Group 3	164	101.7a	148.0a	94.0b	108.3a	110.2	83.2
	Group 4	118	99.7a	138.8a	59.1a	107.2a	112.0	83.3
	p		0.000	0.033	0.000	0.010	0.202	0.782

RGB: Red, Green, Blue; SD: Standard Deviation; Group 1: 1st day; Group 2: 2nd and 3rd days; Group 3: 4th–7th days; Group 4: 8th–13th days; n=number, AI: Artificial Intelligence.
P values were obtained using a one-way ANOVA test. Superscripts a, b, c and d: Indicate that the difference between the means of R, G or B values in four different stages of bruises in the same column is statistically significant ($p<0.05$) in Duncan Test.

blue value, between the two researchers who measured RGB values directly from photos using ImageJ ($p=0.007$ for red, $p=0.005$ for green and $p=0.051$ for blue). Due to these differences, the results from each researcher were analyzed separately.

Using methods including naked-eye examination definitions and RGB determination, RGB determination after photography and color scale evaluation, and direct RGB value determination with an artificial intelligence-supported program, statistically significant results ($p<0.05$ for each method) were obtained for at least two of the R, G, and B mean values, and between these values and the four different stages of bruises (Table 3). In contrast, when the RGB values were directly determined using the ImageJ method, no statistical significance was found between each RGB color and the bruise aging groups. Assuming that underlying skin color as a confounding factor, the RGB values of the skin closest to the lesion were also measured using ImageJ (Figure 3). The differences between the RGB values of intact skin and the RGB values of bruises were calculated. In

Table 4: Statistical Relationship Between "The Difference Between the RGB Mean Values of Bruises and Intact Skin Tissue" On 407 Photographs, and "Four Different Stages of Bruises".

			Color Determination Technique		
RGB Values	Aging Groups of Bruises	n	Photographs ImageJ (1)	Photographs ImageJ (2)	Photographs AI (Copilot)
RED	Group 1	43	-25.3b	-26.2a	-54.5b
	Group 2	82	-36.9a	-36.0a	-60.7b
	Group 3	164	-27.9ab	-24.8b	-53.9b
	Group 4	118	-22.6a	-17.0b	-75.3a
	P		0.034	0.002	0.000
GREEN	Group 1	43	-24.7a	-24.3b	-52.6b
	Group 2	82	-37.6b	-36.5a	-56.0b
	Group 3	164	-24.7a	-24.3b	-48.4b
	Group 4	118	-22.8a	-17.8b	-67.4a
	P		0.015	0.001	0.000
BLUE	Group 1	43	-8.1b	-12.1b	-50.5
	Group 2	82	-29.4a	-27.4a	-57.2
	Group 3	164	-22.2a	-20.3ab	-47.3
	Group 4	118	-21.0a	-16.2b	-44.9
	P		0.006	0.029	0.115

RGB: Red, Green, Blue; SD: Standard Deviation; Group 1: 1st day; Group 2: 2nd and 3rd days; Group 3: 4th–7th days; Group 4: 8th–13th days; n=number, AI: Artificial Intelligence.
P values P values were obtained using a one-way ANOVA test. Superscripts a, b, and ab: Indicate that the difference between the means of R, G or B differences in four different stages of bruises in the same column is statistically significant ($p<0.05$) in Duncan Test

addition to the RGB values previously determined directly using ImageJ and the artificial intelligence-supported program, calculations were also made based on the differences between the RGB values of bruises and healthy tissue (Table 4). When the RGB value differences between bruised and intact skin were determined directly using ImageJ, statistically significant differences were observed for all three values of red, green and blue ($p=0.034$ for red, $p=0.015$ for green, $p=0.006$, respectively). In AI-assisted RGB calculations, any change was observed between the results obtained with direct RGB values and those obtained by calculating the differences between bruised and intact skin.

The accuracy of bruise age group estimation was evaluated using discriminant function analysis (DFA). This analysis used RGB averages from all methods, and RGB differences between bruises and healthy tissue obtained with ImageJ and AI methods (Table 5). DFA showed mean accuracy rates of 50.2% (minimum 44.2%, maximum 55.8%) for the first group (bruises formed within the first 24 hours). The second group (bruises on the second and third days after formation) had a mean accuracy of 30.7% (range 0.0%-47.6%). The third group (bruises between the fourth and seventh days after formation) showed a mean accuracy of 28.4% (minimum 7.3%, maximum 49.4%). For the fourth group (bruises older than 7 days), mean accuracy was 58.7% (minimum 18.3%, maximum 100.0%). The overall mean accuracy rate across all groups was 37.4% (minimum 29.7%, maximum 50.1%).

Several inferences were drawn from the DFA results. First, the AI-assisted program achieved the highest overall accuracy rate (50.1%) among all methods. Second, the lowest accuracy rate (18.3%) was observed for the 65-year-old researcher in the fourth group, who used ImageJ and identified yellow as the dominant color. Third, the AI-assisted program achieved a 100% accuracy rate in the fourth group, where yellow was dominant. Finaly, naked-eye visual color determination yielded higher accuracy than other methods, except for RGB determination with AI.

Table 5: Comparison of bruise age estimation results from 407 photographs using Discriminant Functional Analysis with all three Red, Green, and Blue values

	Correctly Matched	Incorrectly Matched	Accuracy Rate	Correctly Matched	Incorrectly Matched	Accuracy Rate
Groups	Naked Eyes (Patient Examination) Direct RGB Measurement Results					
Group 1	24	19	55.8%			
Group 2	0	82	0.0%			
Group 3	81	83	49.4%			
Group 4	61	57	51.7%			
Total	166	241	40.8%			
Groups	Photographs/ Scala (1) Direct RGB Measurement Results			Photographs/ Scala (2) Direct RGB Measurement Results		
Group 1	23	20	53.5%	22	21	51.2%
Group 2	39	43	47.6%	20	62	24.4%
Group 3	12	152	7.3%	15	149	9.1%
Group 4	64	54	54.2%	87	31	73.7%
Total	138	269	33.9%	144	263	35.4%
Groups	Photographs/ ImageJ (1) Direct RGB Measurement Results			Photographs/ ImageJ (2) Direct RGB Measurement Results		
Group 1	21	22	48.8%	19	24	44.2%
Group 2	19	63	23.2%	29	53	35.4%
Group 3	29	135	17.7%	60	104	36.6%
Group 4	52	66	44.1%	22	96	18.3%
Total	121	286	29.7%	130	277	31.9%
Groups	Photographs/ ImageJ (1) RGB Difference Results of Bruises from Healthy Tissue			Photographs/ ImageJ Difference RGB (2) RGB Difference Results of Bruises from Healthy Tissue		
Group 1	23	20	53.5%	20	23	46.5%
Group 2	31	51	37.8%	30	52	36.6%
Group 3	16	148	9.8%	22	142	13.4%
Group 4	63	55	53.4%	63	55	53.4%
Total	133	274	32.7%	135	272	33.2%
Groups	Photographs/ AI (Copilot) Direct RGB Measurement Results			Photographs AI (Copilot) / Difference RGB RGB Difference Results of Bruises from Healthy Tissue		
Group 1	23	20	53.5%	19	24	44.2%
Group 2	19	63	23.2%	39	43	47.6%
Group 3	44	120	26.8%	47	117	28.7%
Group 4	118	0	100.0%	94	24	79.7%
Total	204	203	50.1%	199	208	48.9%

Discussion

In the second half of the 1990s and the first decade of the 2000s, research was conducted and published on determining bruise aging from color **(**2, 5-12, 16-18). In one of the most recent publications on this topic, Thavarajah et al. used tristimulus colorimetry to assess bruising age in dark-skinned individuals. They used eighteen subjects of South Indian or Sri Lankan descent and two Caucasian individuals for comparison.

They reported that their measurement method yielded objective and reproducible results (19).

Within this body of research, the subset of studies is notable for relatively few articles specifically addressing the accuracy of bruise-aging estimates, and most of these focus on children.

In 1996, Stephenson and Bialas presented data from 23 children to a 'blind' observer. The observer was asked to identify bruise colors in photographs as red, blue, purple, grey, brown, green, or yellow, and to estimate the injury age as fresh (48 hours or less), moderate (48 hours to seven days), or old (more than seven days). Even in this controlled research setting, estimation accuracy for bruise age from color photographs was low: correct guesses were 7/15 for fresh bruises, 10/17 for moderate bruises, and 7/12 for old bruises (9).

In a 2002 study by Munang et al., 58 bruises at different stages of bruise development were evaluated by three observers in 44 children. The bruises were then photographed, and the same observers re-evaluated the bruises at a later date using the photographs. Complete agreement was achieved between the two observers in 27% of direct identifications and 24% of photo identifications. The agreement rate between two observations for direct and photo identification by the same observer was 31%. It was determined that due to this significant discrepancy, color assessment based on bruise color yields imprecise and unrepeatable results (11).

Similarly, a 2003 study by Bariciak et al. examined fifty children with accidental bruise and found that the accuracy of bruise age estimation within the first 24 hours was 47.6%. Accuracy rates varied widely among individual emergency pediatricians (0% to 100%) and were 29.4% for other physicians and 36.8% for trainees (16).

A 2005 study by Maguire et al. reported that, among children under 18 years, clinicians correctly dated a bruise lesion within the first 24 hours in fewer than 40% of cases. The accuracy for identifying fresh, moderate, or old bruises ranged from 55% to 63%, and both intra- and inter-observer reliability were low (12).

A 2010 study by Pilling et al. involved 16 observers who examined 132 photographs of 25 bruises from 11 subjects in a blind manner. The highest accuracy rate, 52.1%, was achieved for bruises aged 0 to 12 hours. Observer accuracy declined to 18.2% as bruise aged, with an overall accuracy rate of 29.1% across all bruise aging categories (7).

Low accuracy rates and the belief that bruise age cannot be reliably predicted from color have discouraged research in this area.

Building on this context, advancements in photographic techniques and technology motivated this study, which aimed to evaluate whether these methods improve the accuracy of bruise age estimation. Traditional naked-eye and photographic color determination processes were enhanced by incorporating RGB values, which had previously been used once for bruise color assessment (8) and multiple times for other skin lesions (11-13). In contrast to earlier research, RGB values were now directly obtained using ImageJ and AI-supported programs, and accuracy rates were evaluated using discriminant function analysis (DFA).

Results demonstrated that the distribution of red color across aging groups was statistically significant in RGB evaluations of photographs using a 103-color scale and in assessments with the AI-supported program ($p=0.001$). However, RGB evaluations conducted with other methods did not yield significant results ($p>0.05$ for each). For green color, statistical significance was observed in the naked-eye RGB evaluation and in one of the photographic RGB evaluations using the 103-color scale, while other methods remained insignificant ($p>0.05$) (Table 3). Notably, the ImageJ method's inability to distinguish RGB value distributions across bruise-age groups suggested that underlying skin color may act as a confounding variable. To address this limitation, the difference in RGB values between the lesion and adjacent intact skin was calculated in two steps. This approach resulted in statistically significant distributions of red, green, and blue colors across bruise-age groups ($p<0.05$ for each) (Table 4).

When the statistically significant distributions of colors in Table 3 and Table 4 were examined within each bruise aging group, it was observed that the color distributions differed depending on the methodology used, and this change could not be explained by a single assumption.

Analysis of the statistically significant color distributions in Tables 3 and 4 within each bruise aging group revealed that the distributions varied according to the methodology applied. This variation could not be attributed to a single explanatory factor.

The low accuracy rates obtained with DFA, a statistical method initially used for bruise aging estimation (Table 5), were consistent with those

reported in previous studies (7, 9, 11, 12, 16). In contrast, the AI-assisted program, which analyzes RGB color data using machine learning algorithms, demonstrated the highest accuracy (50.1%) among the evaluated methodologies. These findings illustrate differences in performance between traditional statistical methods and AI approaches and suggest that further development and broader implementation of AI-assisted programs may improve accuracy.

The 65-year-old researcher achieved the lowest accuracy (18.3%) in the fourth group, where yellow was the predominant color, using ImageJ. This result supports the thesis by Hughes et al. that the ability to detect yellow in bruises diminishes with age (10). In contrast, the artificial intelligence-supported program achieved a 100% accuracy rate in the same group. This finding indicates AI's greater capacity to perceive yellow in photographs, unlike that of older observers.

Bruise color detection by the naked eye is more accurate than other methods, except for RGB-based artificial intelligence detection. This finding shows that the limits of human visual evaluation with the naked eye are wider than the limits of color perception from photographs. Consequently, clinicians should not rely solely on lesion color when determining bruise age. Additional clinical findings—including edema, swelling, pain, and redness around the wound—should be evaluated. Comprehensive physical examination, detailed injury history, past medical and family history, assessment of risk factors, and appropriate laboratory and radiological tests are also essential (18).

Limitation of Study: The study was limited by the inability to obtain regular daily photographs for each case. In some instances, clinical constraints prevented meeting the photographing conditions specified in the materials and methods section. Additional limitations included the subjective identification of bruise color according to color scala, either by the naked eye or from photographs. Observer-dependent processes differences, such as delineating bruise boundaries in ImageJ, also influenced RGB value measurements.

This study used both traditional methods, like visual identification and photographic analysis. It also employed ImageJ and artificial intelligence-supported programs to determine RGB values. Discriminant function analysis was applied to statistically evaluate the accuracy of bruise aging estimation, reflecting advancements in photography and technology. While the use of AI-supported programs resulted in improved accuracy, the degree of improvement did not meet initial expectations.

The findings confirm that bruise color is influenced by many factors beyond bruise aging. These include bruise location, the presence of underlying bone or vascular tissue, the age and sex of the individual, skin color, underlying bleeding disorders, use of medications such as steroids, and whether the bruise is superficial or deep. Therefore, determining the age of a bruise based solely on its color is not feasible.

AI-supported programs are likely to improve bruise age prediction as they become more common and advanced.

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