Final Summary Overview

Analysis of Alternate Light in the Detection and Visibility of Cutaneous Bruises

Research and Development in Forensic Science for Criminal Justice Purposes

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Principal Investigator:
Katherine N. Scafide, PhD, RN
George Mason University
Fairfax, VA

Co-Principal Investigator:
Daniel J. Sheridan, PhD, RN, FAAN
Texas A & M Health Sciences Center (retired)
Bryan, TX

Co-Investigators:
Nancy Downing, PhD, RN, SANE-A, SANE-P, FAAN
Texas A & M Health Sciences Center
Bryan, TX

Matthew J. Hayat, PhD
Georgia State University
Atlanta, GA

PI Contact Information:
George Mason University
College of Health and Human Services
4400 University Drive, Mail Stop Number 3C4
Fairfax, VA 22030
(703) 993-3595
kscafide@gmu.edu

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Introduction

Each year, over 6 million violent victimizations occur to men, women, and children across the United States, but only 43% of these victimizations are reported to law enforcement.[1] The accurate forensic identification and documentation of injuries suffered by victims are essential, not only for their medical treatment, but also as vital evidence for the criminal justice system. Research has found documenting injuries may also improve victim engagement with the criminal justice process.[2] Failure to effectively detect injuries from criminal assaults may have negative outcomes, including: lack of criminal prosecution, under-charging, and fewer successful prosecutions of perpetrators since evidence of visible injury is not available to the trier of fact.

Bruising is one of the most common types of soft tissue injury noted on victims of violence. Also termed contusions, these injuries are caused by blunt, compressive, or squeezing force mechanisms. The discoloration observed in bruising results from blood escaping from damaged blood vessels along with associated inflammatory processes.[3–5] However, bruises can vary widely in their clinical presentation.[4,6] Factors, such as the subject's skin color[7] and the bruise's age[7,8] and depth,[9,10] can affect how bruises appear during physical assessment. New bruises are often painful and firm to the touch and, when visible, have distinct margins. Yet, it is also common to observe no discoloration on individuals with darker skin. Older injuries may offer no palpable or visible indication of their presence. Deeper bruises may take days to be visible to travel close enough to the skin's surface to be seen on forensic examination.[11] As a result, unidentified bruises may contribute to a disparity in the medical care and forensic investigation of victims, including those with darker skin color[12] or who delay treatment resulting in older injuries.

In 2013, a widely distributed national protocol published by the Department of Justice (DOJ) recommended medical forensic examiners use an emerging technology – **alternate light** – to aid the naked eye in visualizing patients' bodies and clothing for trace evidence and "subtle injury."[13(p68)] While typical white lighting used in forensic clinical practice contains wavelengths of the entire visible spectrum (400-700nm), alternate light refers to light of specific bandwidths.[14] Commercially available alternate light sources (ALS) include narrow-band visible, ultraviolet (UV), and infrared spectrums.[15] When using an ALS to examine the skin, some of the light is reflected back to the observer, while other wavelengths transmit to deeper layers. The hemoglobin in blood and its associated breakdown products absorb light at certain wavelengths appearing dark against the surrounding tissue. Clinical research suggests an ALS with wavelength peaks of 365nm (UV) or 400-450nm (violet and blue) may improve the detection and visibility of bruises.[16–21] However, existing studies lack diversity in skin color and/or a prospective, systematically controlled design.

Study Purpose

Given melanin, the primary pigment contributing to skin color, absorbs light at all wavelengths, its impact on the ability of alternate light to detect bruises needed investigating.[22] Furthermore, it remained unclear how visualization of bruises under alternate light was influenced by bruise depth, size, and color and the subject's localized fat, age, and sex. Therefore, the *purpose* of this study was to determine if alternate light effectively detected and improved visibility of cutaneous bruises on individuals with different skin colors through bruise resolution. More specifically, we wanted to identify which ALS wavelengths and filters were most effective and the potential impact of bruise and subject factors.

Methods

This study was a multisite, longitudinal, randomized controlled trial with a crossover design. The following is a summary of our methods, with further detail provided in the appendices and in our published work.[23,24]

The study population included healthy adults, ages 18-65, conveniently recruited from two study sites: George Mason University (GMU) and Texas A&M University (TAMU). We used a quota sampling strategy similar to our previous research[25,26] to obtain equal representation of six skin color categories, ranging from dark to very light. Skin color was determined by colorimetry measurements taken on the right lateral deltoid using a spectrophotometer (Minolta® CM-600D; Konica Minolta, Osaka, Japan; see Appendix A). For safety purposes, participants were excluded if they used medications and/or had health conditions that affected coagulation and/or inflammation; had a history of prolonged or unusual healing; or had an upper arm circumference less than 24cm. Participants were also screened and excluded if they had existing injuries, lesions, or artifacts visible under white light or an ALS at the bruise induction sites (left and right lateral deltoids, left and right anterior forearms). A power analysis (power = .8, $\alpha = .05$) estimated 156 participants were required to achieve a 10% improvement[16] in the area under the curve while anticipating a 20% sample attrition.

Each participant received two bruises created using different published methods to examine whether variation in trauma may have an effect on visualization with an ALS. A randomly selected upper arm positioned behind a 20mil rubber barrier received a bruise to the deltoid region by firing a paintball pellet from 20ft.[7] On a randomly selected forearm, a second bruise was created by dropping a 6oz ball bearing through a 5ft vertical pipe.[16] The resulting bruises were examined at 21 time points over a 4-week period (see Appendix B for details) using an ALS (Handscope® Xenon HSX-5000; Horiba, Edison, NJ) and a white light source

(SpectroLED Essential 240 Daylight, Genaray, New York, NY). Using a crossover design, the order of treatment (the two different light sources) was randomized for each bruise assessment, thus minimizing carryover effect from one light source to other. Under ALS, assessments were conducted using ultraviolet (350nm) and narrow-band visible wavelengths between 415nm-535nm. To filter reflected light, observers viewed bruises through colored goggles. Details regarding specific wavelength/filter combinations are presented in Appendix A.

During bruise assessment visits, the two injuries were assessed for detection and visibility. *Bruise visibility* refers to the degree of clarity in which an injury is perceived.[24] Two instruments, the Bruise Visibility Scale (BVS) and Absorption Visibility Scale (AVS) (previously developed by Dr. Scafide) were used to measure visibility under white light and ALS, respectively (see Appendix B).[24] During the study, inter-observer reliability of the outcome measures was assessed. Additional injury measurements included the bruises' age, size, and overall color difference from surrounding skin (see Appendix A for details). Participant sex, age, arm circumference, and skinfold thickness were also obtained.

Our study was reviewed and approved by institutional review boards at both study sites to ensure human subjects protection (GMU IRB# 728978, TAMU IRB# 2016-0742F). Informed consent was obtained from all research volunteers. Additionally, an independent data safety monitoring board provided study oversight regarding participant safety.

The data collected in this study was complex due to its multilevel structure. Specifically, each participant had two bruises which were both assessed at multiple time points using multiple wavelength/filter combinations. This resulting outcome data set had the potential to be both very large (156 subjects x 2 bruises x 21 visits x 11 white light/ALS wavelength/filter observations = 72,072 data points) and highly correlated. To address this issue, we used advanced statistical

techniques to account for the multilevel data structure: marginal models with generalized estimating equations and general linear mixed modeling.

Study Findings

Sample Description[i]

Between June 2017 – March 2019, a total of 238 subjects consented to participate in our study (see Appendix D). After excluding 81 subjects based on screening criteria and successful bruise induction, a final sample of 157 was reached. The retention rate was 95% with all participant data included in the analysis. The sample was generally young (mean 24.2 years), female (73%), and of healthy weight (mean body mass index 26.3 kg/m^2) (see *Table 1*). Quota sampling resulted in nearly equal distribution across the six skin color categories (see *Figure 1*).

Table 1. Sample Description (n=157)

Characteristic	Frequency (%)
Study Site	
GMU	81 (52%)
TAMU	76 (48%)
Sex	
Female	114 (73%)
Male	43 (27%)
Race/ethnicity	
Asian	24 (15%)
Black	36 (23%)
White	76 (48%)
Hispanic	14 (9%)
Native American	5 (3%)
Other	2 (1%)
Age	
Under 25 years	119 (76%)
25 and older	38 (24%)
Body Mass Index	
Underweight	2 (1%)
Normal	84 (54%)
Overweight/obese	71 (45%)

GMU=George Mason; TAMU=Texas A&M

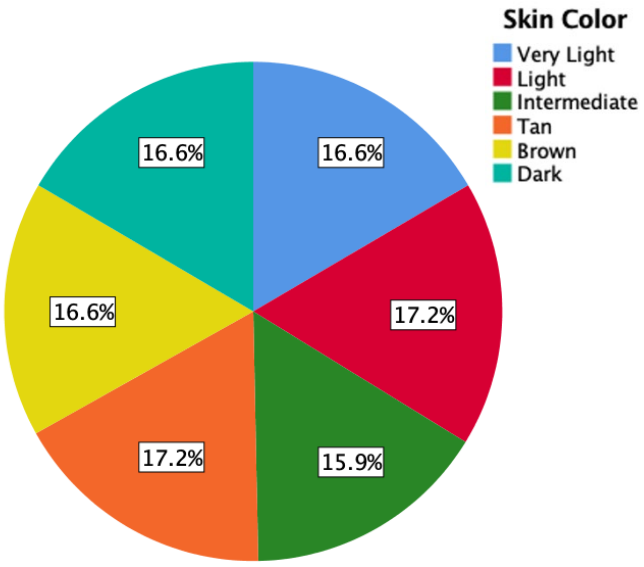

Figure 1. Sample distribution by skin color category determined by colorimetry.

[i] For more details regarding the sample, see Scafide et al. (2020).[23]

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Bruises induced to the upper arm with the paintball projectile were immediately visible under white light on all participants. Trauma to the lower arm using the dropped weight only created a visible bruise on 86.6% of subjects. Randomization of arm selection was effective for the upper arm (left: *n*=79; 50.3%), but less so for the lower arm (left: *n*=95; 60.5%). A total of 2,903 bruise assessment visits were completed, averaging 19 visits per subject. During the study, the aggregate number of bruise observations across the different wavelength and filter combinations was 63,130 (upper arm: 31,621; lower arm: 31,509).

Bruise Detection[ii]

Using ALS, bruises were identified as areas of absorption at the trauma site more frequently than when viewed under white light (see *Table 2*). Similar findings were noted after 4 weeks and in our subsample at 8 weeks. Fewer bruises were detected on the lower arm by either light source. Using either yellow or orange goggles, wavelengths 415nm and 450nm resulted in the most frequent detections of both upper arm and lower arm bruises across visits (see *Table 3*).

Table 2. Number of Participant Visits with Bruise Detection

	Upper Arm	**Lower Arm**
Visits 1-21 (aggregated)		
White (n=2903)	2490 (85.8%)	516 (17.8%)
ALS (n=2903)	2810 (96.8%)	922 (31.8%)
Visit 21 (4 weeks post induction)		
White (n=126)	64 (50.8%)	2 (1.6%)
ALS (n=126)	103 (81.8%)	10 (7.9%)
Visit 25 (8 weeks post induction)		
White (n=25)	15 (60%)	0 (0)
ALS (n=25)	17 (68%)	0 (0)

ALS=alternate light source

To examine the effectiveness of ALS compared to white light while controlling for subject characteristics, separate multivariable marginal models were created for the paintball

[ii] For more details regarding bruise detection findings, see Scafide et al. (2020).[23]

injury and dropped weight injury observations. We determined wavelengths 415nm and 450nm were more effective than white light at detecting bruises after controlling for subject characteristics (see *Table 3*). The remaining wavelengths (UV, 475-535nm) were less effective than white light. When considering both types of trauma (projectile, dropped weight), a yellow filter (goggles) improved odds of detection on both upper and lower arms over orange.

Table 3. Bruise Detection Comparison between Select ALS Wavelengths and White Light

Wavelength	Filter	Upper Arm Model			Lower Arm Model		
		Visits detected n(%)	Odds Ratio	95% CI	Visits detected n(%)	Odds Ratio	95% CI
415nm	Yellow	2781 (95.8)	5.34	(4.35, 6.56)	721 (24.8)	1.69	(1.50, 1.90)
	Orange	2576 (88.7)	1.42	(1.20, 1.68)	389 (13.4)	0.66	(0.58, 0.76)
450nm	Yellow	2751 (94.8)	4.08	(3.36, 4.96)	849 (29.3)	2.25	(2.01, 2.53)
	Orange	2623 (90.4)	1.77	(1.50, 2.10)	372 (12.8)	0.63	(0.55, 0.72)
White light	None	2490 (85.5)	Ref	-	516 (17.8)	Ref	-

Note: Generalized estimating equations with white light as reference. Other variables controlled in models: observer, bruise age, skin color (ITA°), sex, subject age, and local fat (arm fat index upper arm model, skinfold thickness and arm circumference in lower arm model). CI=Confidence Interval. For complete results, see Scafide et al. (2020).[23]

Bruise Visibility

When aggregated across visits, the mean BVS and AVS scores showed little variation across light sources (see Table 4 and Appendix F). Bruises on the lower arm were less visible than the upper arm. For bruises that were detected, we examined whether an ALS was more effective at enhancing bruise visibility than white light using general linear mixed models. We determined 415nm using a yellow filter increased bruise visibility over white light after controlling for subject characteristics on both types of trauma (see Table 4). Based on the upper arm model results, visibility increased by nearly a half point on the visibility scale under this wavelength ($\widehat{\beta}$ = 0.46; 95% CI: [0.43, 0.48]), an arguably clinically meaningful improvement.

Factors Associated with Bruise Visualization

In our statistical modeling presented in Tables 3 and 4, we controlled for several bruise and subject factors that could impact bruise visualization. We further explored whether certain characteristics contributed to detection or visibility of bruises under ALS as compared to white

light using tests of moderation. We found odds of detection and bruise visibility increased with increasing skin lightness across all ALS wavelengths/filters compared to white light (p<.0001). The odds of detection and bruise visibility also increased with increasing arm fat across most ALS wavelengths/filters compared to white light (p<.0001). Moderation of detection and visibility by bruise age was more complex. Increasing bruise age improved odds of detection and visibility using UV light over white light (p<.0001), with 415nm (with an orange filter) and 450nm (with a yellow filter) also being more effective on the projectile injury. Further work is in progress to determine which specific ALS wavelength/filter combinations may improve detection based on specific skin tones and time frames since injury.

Table 4. Enhanced Bruise Visibility Comparison between Select ALS Wavelengths and White Light

Wavelength	**Filter**	**Upper Arm Model**			**Lower Arm Model**		
		Aggregate Mean (SD)	*Beta*	95% CI	Aggregate Mean (SD)	*Beta*	95% CI
415nm	Yellow	3.0 (1.1)	0.46	(0.43, 0.48)	1.6 (0.5)	0.06	(0.01, 0.11)
	Orange	2.7 (1.1)	0.16	(0.13, 0.19)	1.5 (0.5)	-0.12	(-0.18, -0.06)
450nm	Yellow	2.8 (1.1)	0.30	(0.27, 0.32)	1.5 (0.5)	0.002	(-0.05, 0.05)
	Orange	2.7 (1.1)	0.14	(0.11, 0.16)	1.5 (0.4)	-0.16	(-0.22, -0.10)
White light	None	2.5 (1.0)	Ref		1.5 (0.6)	Ref	

Note: General linear mixed models with white light as reference. Other variables controlled in models: observer, bruise age, skin color (ITA°), sex, subject age, local fat (arm fat index upper arm model, skinfold thickness and arm circumference in lower arm model), ΔE, and bruise size. CI=Confidence Interval. For complete results, see Appendix E.

Instrument Reliability[iii]

Interrater checks were conducted during the study to assure calibration of observers and determine interrater agreement in bruise detection and visibility measurements. A total of 14 observers completed 120 interrater checks (mean 17 per observer) during which two observers completed a bruise assessment blinded to one another's findings. Agreement in bruise detection was greater than 90% for all but two ALS wavelength/filter combinations (515nm and 535nm with a red filter). Kappa values under white light (K=0.76) and an ALS (K=0.78) demonstrated

[iii] For more details regarding reliability and validity analyses, see Scafide et al. (in press)[24]

good agreement between observers. Interrater reliability of the BVS and AVS instruments analyzed by intraclass correlation coefficients (ICC) were also satisfactory (BVS: ICC=0.91, 95% CI [0.90-0.95]; AVS: ICC=0.93, 95% CI [0.89-0.94]).

Implications

Findings from our study suggest alternate light is more effective at detecting bruises than white light across diverse skin tones. Specifically, using 415nm (violet) or 450nm (blue) wavelengths with a yellow or orange filter significantly increased odds of detection. Results are consistent with previous clinical research[16,17,27] and a cadaver study with histological confirmed bruises.[28] We found the improvement in bruise detection was sustained up to 4 weeks post injury. Additionally, we noted clinically meaningful improvement in enhanced bruise visibility using ALS at 415nm with a yellow filter, confirming the findings of Limmen et al. (2013)[19] and Nijs et al. (2019).[20] Finally, we identified several bruise and subject factors (i.e., bruise age, skin color, subcutaneous fat) that contributed significantly towards detection of bruises under ALS. Further research is warranted to understand what effects variations in these characteristics may have on the ability of specific wavelength and filter combinations to detect bruises.

Study Limitations

Our study had several limitations. Given our intent was not to create latent bruises, the observers could not be blinded to where arms were injured. We mitigated this problem by randomizing the order of the two light source assessments to minimize the effect of comparing one observation to the next. Additionally, we did not control for variations in the speed of the projectile and dropped weight. However, because each injury served as its own control, our investigation was focused on whether light source affected visibility, not the force of trauma. Variation in modeling results based on the two trauma mechanisms may have been confounded

by differences in trauma location. Finally, our sample included mostly young, healthy adults, which may limit generalizability of the findings beyond this population.

Forensic Clinical Practice

Previously published concerns regarding low specificity of ALS in detection of bruises are valid, particularly if the assessment is limited to only visual cues.[16] An ALS' positive findings are not diagnostic of bruising because other skin lesions (e.g., scars, hyperpigmentation, tattoos) can also absorb light.[15,27] Thus, forensic clinicians should be cautious not to interpret alternate light observations without history of trauma and a thorough physical assessment. For example, tactile qualities such as presence of induration or tenderness may provide support of ALS interpretation of possible bruising. Additionally, topical products (e.g., make-up, sunscreen) can also absorb light similar to bruising and should be removed after being swabbed for evidence (if applicable) and prior to ALS assessment.[29,30]

Criminal Justice Policy

Our research provides evidentiary support for the DOJ's recommendations to use ALS as a tool for enhancing visualization of injuries.[13] Even without visible signs of injury, victims of violence should be encouraged to receive a medicolegal examination that includes an ALS. Clinical forensic departments may find a single-wavelength ALS (specifically 415nm or 450nm) more cost-effective for purposes of bruise assessments. However, other ALS equipment factors, such as lumens, should also be considered.[31]

Few forensic medical units currently use ALS to examine bruises due to limited available research supporting protocols on its application. An inter-disciplinary approach is needed to develop and evaluate evidence-based guidelines for broader implementation of ALS into forensic practice. Future research could then focus on how use of ALS affects documentation of injuries, police and prosecutorial decision-making and, ultimately, legal outcomes.

Deliverables

To support dissemination of the research findings to a broader audience, the following scholarly, work products were created (as of 12/31/2020):

Publications

1. Scafide KN, Sheridan DJ, Downing NR, Hayat MJ. Detection of inflicted bruises by alternate light: Results of a randomized controlled trial. *J Forensic Sci.* 2020*;65*(4): 1191-1198. doi.org/10.1111/1556-4029.14294

2. Scafide, K. N., Downing, N. R., Kutahyalioglu, N., Sebeh, Y., Sheridan, D. J., Hayat, M. J. Quantifying the degree of bruise visibility observed under white light and an alternate light source. *J Forensic Nurs*. 2020; Epub ahead of print. doi: 10.1097/JFN.0000000000000304

Presentations

1. Scafide KN, Downing NR, Hayat MJ, Sheridan DJ, Kutahyalioglu N. (2021, February). *Predicting alternate light absorption in areas of trauma based on skin color: Not all wavelengths are equal.* Podium session co-presented at 73rd Annual Scientific Meeting of American Academy of Forensic Sciences, virtual.

2. Scafide KN, Downing NR, Hayat MJ, Sheridan DJ, Kutahyalioglu, N. (2021, February). *How skin color affects bruise assessments by alternate light: The results of a randomized controlled trial.* Poster session co-presented at the National Institute of Justice Forensic Science Research and Development Symposium held at 73rd Annual Scientific Meeting of American Academy of Forensic Sciences, virtual.

3. Scafide KN, Sheridan DJ, Downing NR, Hayat MJ. (2020, February). *Detection of cutaneous bruises using alternate light: A multi-site, randomized controlled trial.* Podium session presented at 35th Annual Conference of Southern Nursing Research Society, New Orleans, LA. (rescheduled from 2020)

4. Scafide KN, Sheridan, DJ. (2021, April). *Detection and visibility of bruises using alternate light: From science to practice*. Podium session presented at annual International Conference on Sexual Assault, Domestic Violence, and Violence Across the Lifespan by End Violence Against Women International*,* virtual. (rescheduled from 2020)

5. Sebeh Y, Scafide KN, Hayat, MJ. (2020, March). *Lessons learned in developing an interdisciplinary collaboration between biostatistics and forensic nursing.* Poster session presented at Spring Meeting of Eastern North American Region International Biometric Society, Nashville, TN. (session cancelled)

6. Scafide KN, Sheridan DJ, Downing NR, Hayat MJ. (2020, February). *Alternate light wavelength and filter detection of inflicted cutaneous bruise.* Podium session presented at

72nd Annual Scientific Meeting of American Academy of Forensic Sciences, Anaheim, CA.

7. Sheridan DJ, Scafide KN, Downing NR. (2020, February). *Clinical implications of using alternate light to assess bruises*. Podium session presented at 72nd Annual Scientific Meeting of American Academy of Forensic Sciences, Anaheim, CA.

8. Scafide KN, Sheridan DJ, Downing NR, Hayat MJ. (2019, September). *Detection and visibility of cutaneous bruises using alternate light: A multisite randomized controlled trial.* Podium session co-presented at annual International Conference on Forensic Nursing Science and Practice by International Association of Forensic Nurses, New Orleans, LA.

9. Scafide KN, Sheridan DJ. (2019, February). *Analysis of alternative light in the detection of cutaneous bruises: A multisite randomized controlled trial.* Podium session co-presented at the National Institute of Justice Forensic Science Research and Development Symposium held at 71st Annual Scientific Meeting of American Academy of Forensic Sciences, Baltimore, MD.

10. Moyer L, Downing NR, Scafide KN, Sheridan DJ. (2019, February). *Let there be light! Using alternate light sources to detect and improve cutaneous bruise visibility.* Poster session presented at Creating Healthy Work Environments conference of Sigma Theta Tau International, New Orleans, LA.

Webinar

1. Scafide KN, Sheridan DJ. (2019, October 30). *Detection and visibility of bruises using alternate light: from science to practice.* Forensic Technology Center of Excellence. https://forensiccoe.org/webinar/detection-and-visibility-of-bruises-using-alternate-light-from-science-to-practice/

Podcast

1. Mangum, L. (producer). (2019, May 14). *Just skin deep (Guests: Dr. Katherine Scafide and Dr. Daniel Sheridan).* Just Science Podcasts. RTI International Center for Forensic Sciences. https://forensiccoe.org/2019rd-e1/

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Appendix A – Study Variables

Time Point	*Variable*	*How Measured*
Screening Visit	Skin Color	6 skin color categories based on Individual Typology Angle (ITA°) calculated from luminosity (L*) and blue-yellow (b*) colorimetry measurements of the superolateral upper arm[25]: • ITA° = $[\tan^{-1}((L^*-50)\div b^*)]x180\div\pi$ • Final ITA° value will be an average of both arms Category values: Very light > 55° ≥ Light > 41° ≥ Intermediate > 28° ≥ Tan > 10° ≥ Brown > -30° ≥ Dark
	Sex	Self-reported male or female
	Mid-arm Circumference (AC)	Using a cloth tape measure. Upper arm AC measured halfway between shoulder and elbow. Lower arm AC measured two inches below antecubital fossa.
	Skinfold Thickness (SF)	Using Lange Skinfold Calipers. Upper arm SF measured posteriorly halfway between shoulder and elbow. Lower arm SF measured medially two inches below antecubital fossa.
	Localized fat/muscle ratio	Ratio of localized arm fat area to muscle area (AMA) was calculated as an index (Arm Fat Index, AFI): [32,33] • AMA = $((AC - SF\pi)^2/4\pi) - x$, where x is 10 for men and 6.5 for women • AFI = $[(AC^2/4\pi - AMA)/AC^2/4\pi]*100$
	Weight	Digital scale (Seca, Chino, CA)
	Height	Self-report
Bruise Assessment Visits	Trauma Type	Bruise created using paintball (superficial, blunt force impact) and dropped weight (deep, blunt force impact)
	Wavelength	Peak (bandwidth limits): 350nm (310-390nm), 415nm (392-438nm), 450nm (422-478nm), 475nm (452-498nm), 495nm (472-518nm), 515nm (492-538nm), 535nm (512-558nm)
	Filter (Goggles)	Color (50% Transmission): Clear (418nm), Yellow (515nm), Orange (562nm), Red (602nm)
	Wavelength (filter) combinations	350nm (clear), 415nm (yellow and orange), 450nm (yellow and orange), 475nm (orange), 495nm (orange), 515nm (orange and red), and 535nm (red).
	Detection	Whether or not bruise or absorption (if ALS) is perceivable
	Visibility (if detected)	Bruise Visibility Scale (if white light) or Absorption Visibility Scale (if ALS)
	Bruise Age	Hours between time of injury and beginning of examination
	Size of Bruise or Area of Absorption	Measure longest two distances of the bruise at 90 degrees (length and width). Size = area of ellipse = (0.5 x length) (0.5 x width) x π.
	Bruise Color Difference	Colorimetry assessment values (L*, a*, and b*) are obtained of the skin color prior to bruising and bruise center. Overall color difference (ΔE^*_{ab}) is then calculated by formula[25]: $\Delta E^*_{ab} = \sqrt{\left((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right)}$

Appendix B – Data Collection Schedule

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Main Sample (n=157)	Screening Visit – within 30 days of Visit 1						
		Visit 1* Visit 2* Visit 3*	Visit 4* Visit 5* Visit 6*	Visit 7* Visit 8* Visit 9*	Visit 10	Visit 11	
		Visit 12		Visit 13		Visit 14	
		Visit 15		Visit 16		Visit 17	
		Visit 18		Visit 19		Visit 20	
		Visit 21					
Sub-Sample (n=29)		Visit 22					
		Visit 23					
		Visit 24					
		Visit 25					

*At least 4 hours between start of visits

Appendix C – Instruments

Figure C.1. Bruise Visibility Scale

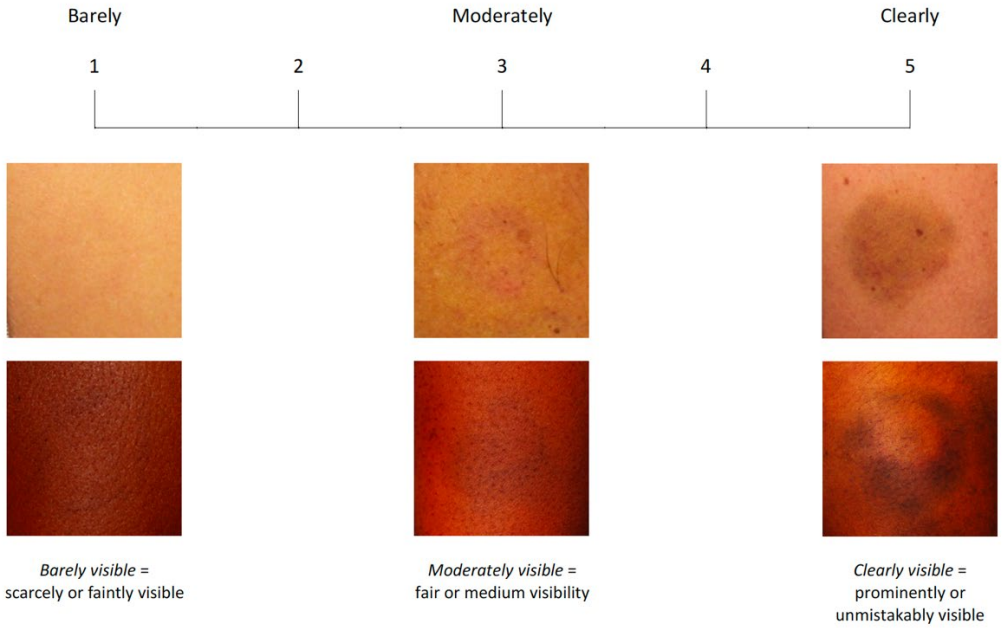
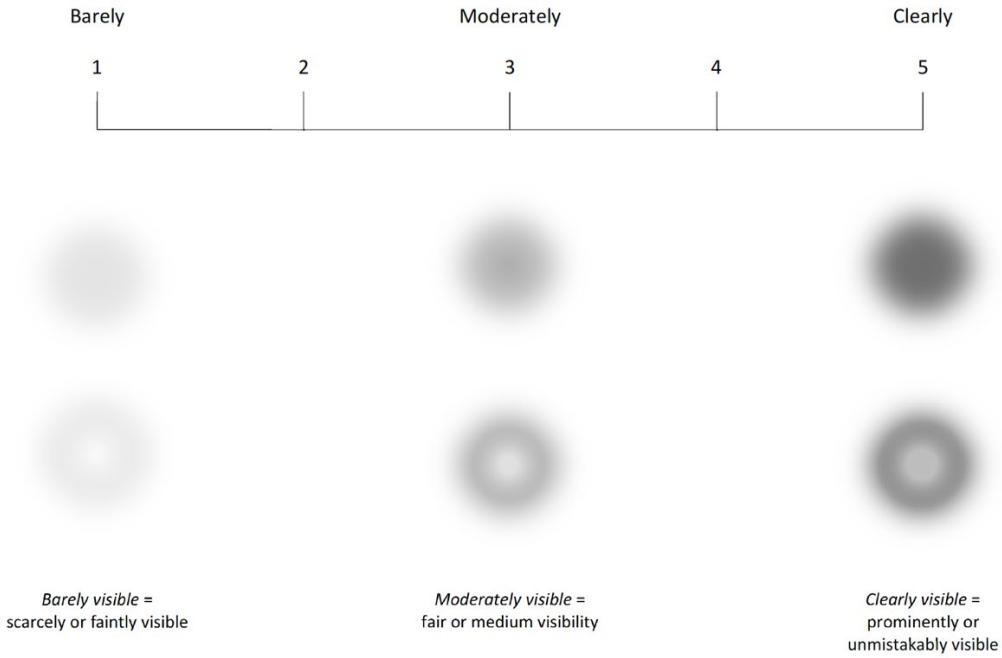


Figure C.2. Absorption Visibility Scale



Appendix D

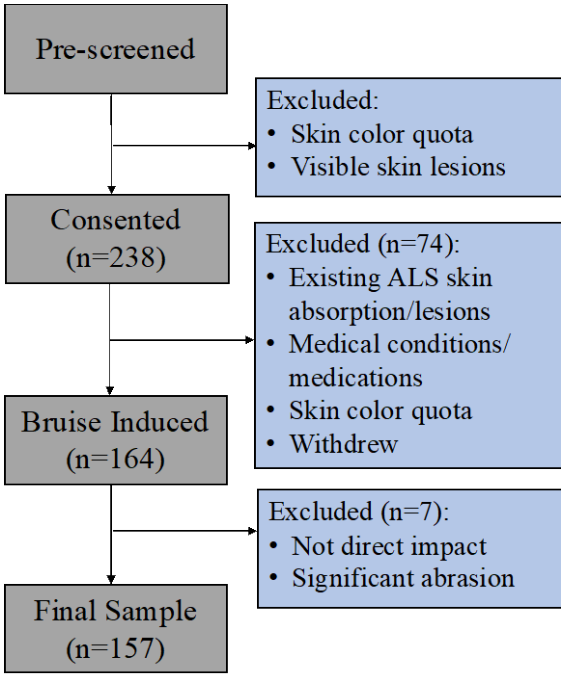


Figure D.1. Flow diagram of sample recruitment

Appendix E

Table E.1. Enhanced Bruise Visibility Comparison between ALS Wavelengths and White Light

Wavelength	**Filter**	**Upper Arm Model**			**Lower Arm Model**		
		Aggregate Mean (SD)	*Beta*	95% CI	Aggregate Mean (SD)	*Beta*	95% CI
Ultraviolet	Clear	2.5 (1.0)	-0.24	(-0.28, -0.21)	1.5 (0.5)	-0.19	(-0.27, -0.12)
415nm	Yellow	3.0 (1.1)	0.46	(0.43, 0.48)	1.6 (0.5)	0.06	(0.01, 0.11)
	Orange	2.7 (1.1)	0.16	(0.13, 0.19)	1.5 (0.5)	-0.12	(-0.18, -0.06)
450nm	Yellow	2.8 (1.1)	0.30	(0.27, 0.32)	1.5 (0.5)	0.002	(-0.05, 0.05)
	Orange	2.7 (1.1)	0.14	(0.11, 0.16)	1.5 (0.4)	-0.16	(-0.22, -0.10)
475nm	Orange	2.6 (1.1)	-0.05	(-0.08, -0.02)	1.4 (0.4)	-0.26	(-0.33, -0.19)
495nm	Orange	2.5 (1.1)	-0.17	(-0.20, -0.14)	1.4 (0.4)	-0.32	(-0.41, -0.24)
515nm	Orange	2.4 (1.4)	-0.34	(-0.37, -0.31)	1.4 (0.4)	-0.48	(-0.59, -0.37)
	Red	2.3 (1.0)	-0.81	(-0.85, -0.77)	1.5 (0.4)	-0.30	(-0.77, 0.16)
535nm	Red	2.3 (1.1)	-0.65	(0.28, 0.21)	1.5 (0.4)	-0.32	(-0.48, -0.16)
White light	None	2.5 (1.0)	Ref		1.5 (0.6)	Ref	

Note: General linear mixed models with white light as reference. Other variables controlled in models: observer, bruise age, skin color (ITA°), sex, subject age, local fat (arm fat index upper arm model, skinfold thickness and arm circumference in lower arm model), ΔE, and bruise size. CI=Confidence Interval.