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Alternate Light Source Findings of Common Topical Products

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Abstract

Background—One of the important roles of a forensic clinician is to perform examinations of patients who are victims and suspects of crime. Alternate light source (ALS) is a tool that can improve evidence collection and enhance visualization of injuries. The purpose of this study was to examine if commonly used topical products fluoresce or absorb when examined with an ALS. Secondly, we aim to identify patient and exam variables that may impact findings.

Methods—A convenience sample of 81 subjects was used. Following the application of 14 over-the-counter products, researchers observed the participants' skin with an ALS under 18 combinations of wavelengths and colored filters.

Results—Of the 14 products viewed (n=1458 observations per product), six were found to fluoresce under alternate light in more than 40% of observations, 5 fluoresced in 1–10% of observations and 3 fluoresced less than 1% of the time. One product (a make-up product) absorbed ALS light consistently (81%), a second (a sunscreen product) absorbed in 7%, while the remaining 12 products produced absorption findings in less than1% of observations. In generalized mixed linear models, absorption findings were more commonly identified in participants with light or medium skin tones when compared to those with dark skin tones.

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Discussion—These results suggest the presence of topical products may impact ALS findings. A thorough forensic clinical assessment should include a documented history, including assessment of potential sources of findings to aid in interpretation.

Introduction

Patients who report interpersonal and sexual violence present for care with a variety of psychological, physical and emotional needs. To help meet those needs, forensic clinicians have a responsibility to provide a quality, evidence-based medico-legal exam (Eldredge, Huggins, & Pugh, 2012). Injury assessment, documentation, and evidence collection are key components of every forensic clinical examination. A widely distributed national forensic examination protocol by the Department of Justice recommends medical forensic clinicians use an alternate light source (ALS) to "aid in examining patients' bodies, hair, and clothing. …for evidence, such as dried or moist secretions,…and subtle injury."(Littel, 2013) Alternate light is light of a specific wavelength, which includes wavelengths within short or narrow-band visible (NBV) spectrum and the ultraviolet (UV) spectrum (Hughes, Ellis, & Langlois, 2006).

Alternate light has been used to assess patients since the mid-20th century when a Wood's Lamp, which produces ultraviolet (UV) light by blocking wavelengths above 365nm, was used by physicians to detect certain skin conditions (Caplan, 1967). Since the mid-1970s, forensic examiners have used the Wood's Lamp to help visualize and collect trace evidence that fluoresces when UV light is passed over the skin in a darkened room. In the early 1990s, UV light was found helpful in identifying bruises on the skin (West, Barsley, Frair, & Stewart, 1992; West, Barsley, Hall, Hayne, & Cimrmancic, 1992). Biological and non-biological evidence, such as lubricants, creams, and oils used to facilitate sexual assault, may be identified with alternate light (Wawryk & Odell, 2005). Sources of trace evidence can corroborate the patient's history (Santucci, Nelson, McQuillen, Duffy, & Linakis, 1999), even when a perpetrator intentionally uses a condom to avoid transfer of biological evidence (Maynard, Allwell, Roux, Dawson, & Royds, 2001).

Depending on its wavelength, light can penetrate the skin and has the potential to detect bruises, which are primarily located below the level of the epidermis (>15μm) within the vascular dermis (Hughes, Ellis, Burt, & Langlois, 2004; Langlois & Gresham, 1991; Sandby-Moller, Poulsen, & Wulf, 2003; Wright & Golden, 2010). At this point, light most commonly interacts with the tissues in three ways: reflection, absorption or fluorescence (Marin & Buszka, 2013). The amount of reflection and absorption allow for viewing of differences in color. Wavelengths of light that are reflected become the visible color of the skin's surface, while absorbed light appears as a darker color (i.e.; the color white reflects all visible wavelengths and the color black absorbs all visible wavelengths). Light that is re-emitted at a longer wavelength through the process of fluorescence appears brighter, or "glowing" compared to the surrounding reflected light (Marin & Buszka, 2013). Historically, fluorescence of potential semen was the purpose of using a Wood's lamp in sexual assault forensic exams. When light penetrates the skin, the degree of reflection is influenced by the presence of any blood in the skin that has resulted from injury or disease processes. Thus, the pattern and wavelength (color) of the fluoresced and absorbed light may

demonstrate the presence of bruising or other injury (as darker absorbed areas). Colored filters (e.g., colored goggles, colored camera lenses) used to block the reflected light allow the fluorescent light to be seen as brighter while absorbed light appears dark in comparison.

Alternate light and its ability to aid in visualization of sub-dermal bruises, visible and invisible to the naked eye has been examined in a small number of previous studies (Holbrook & Jackson, 2013; Limmen et al., 2013; Lombardi, Canter, Patrick, & Altman, 2015). None of these examined whether commonly used topical products absorb under various wavelengths of light. This may have significant practice implications for forensic clinicians. The validity of a positive alternate light finding has been challenged in court as nothing more than artifact from a topically applied product (Maryland v. Augins, 2014; Maryland v. Clifford, 2013).

Review of Literature

Studies of ALS fluorescence of biological and non-biological substances have found that topical agents can possibly confound forensic findings (Vandenberg & van Oorschot, 2006). Nelson and Santucci found only 25% of medical forensic providers not trained in the use of ALS could differentiate known semen stains on cotton fabric from stains from hand cream, bacitracin or Castille soap (Nelson & Santucci, 2002). Maynard and colleagues examined fluorescence of 48 condom and non-condom personal lubricants using ALS and found the 350nm wavelength produced fluorescence in six lubricants (Maynard et al., 2001). Petroleum-based lubricants were observed to fluoresce at 415nm and 450nm wavelengths. Only one study was found, which tested for fluorescence of body fluids, and various lubricants and moisturizers on human skin using ALS (Wawryk & Odell, 2005). None of the topical agents tested fluoresced under any of the tested light-emitting diode (LED) and halogen lamp light sources. Lincoln and colleagues reported semen on the forearm and a variety of other surfaces fluoresced at a wavelength of 450nm viewed using orange filters (Lincoln, McBride, Turbett, Garbin, & MacDonald, 2006). This combined literature indicates the existence of several topical products that fluoresce when viewed under different types of alternate light, however further research is needed to determine if there are similar common topical products that absorb alternate light and result in positive absorption findings in the absence of injury or other physiologic process.

During the forensic exam, when ALS demonstrates absorption, it is often assessed as “injury” or “bruising.” A recent randomized, single-blind study improved upon previous ALS research by examining the effectiveness of narrow-band visible and UV alternate light to detect latent bruises intentionally created when a four ounce weight was dropped down a five foot tube onto subjects’ ventral forearms (Lombardi et al., 2015). Two weeks post trauma, ALS detected almost twice as many subjects with positive ALS findings versus white light. The authors reported over half of these findings were something other than the inflicted bruise (“false-positives”), and did not provide further information regarding other potential causes of positive findings (i.e.; topical products, other injuries, dermatologic conditions). Notably, they did not exclude individuals with pre-existing injuries or assess for baseline artifact observed via ALS. They also did not report if they assessed for possible accidental forearm trauma between visits. Such limitations may have contributed to their

reported false-positives. Lastly, the investigators in that study did not differentiate if ALS findings were darker (consistent with absorption) or brighter (consistent with fluorescence) than the adjacent skin, further complicating interpretation of their findings (Lombardi et al., 2015; Marin & Buszka, 2013).

The purpose of this study was to determine whether alternate light within the NBV and UV spectrums causes fluorescence or absorption of 14 commonly used topical products. In addition, the study will examine which specific wavelengths, filters and skin colors may predict whether absorption and fluorescence is observed.

Methods

This study recruited a convenience sample of 81 adult participants at an urban medical center. Human subjects research approval was obtained from the medical center's Institutional Review Board. Written informed consent was collected for all participants after completing a brief screening to determine eligibility. Inclusion criteria were being at least 18 years of age and able to provide written informed consent in English. Exclusion criteria was as follows: (a) history of a known allergy to the products being tested, (b) observable skin conditions or lesions to the forearms (c) visible discoloration to either forearm from injury (d) injection, venipuncture or intravenous line insertion to either forearm in the last 30 days, (e) application of self-tanner, spray tan, or tanning bed session affecting either forearm in the past 30 days, and (f) pretesting absorption or florescence to forearms that could not be washed off.

Data Collection

Data collection included a brief demographic survey and health-screening questionnaire. Using a handheld Konica Minolta® CM-700d spectrophotometer, skin color was assessed using the Individual Typology Angle (ITA). It was calculated based on luminosity (L*) and blue-yellow (b*) colorimetry measurements of the skin (Del Bino, Sok, Bessac, & Bernerd, 2006). Participants were categorized into one of six skin color categories previously established by the cosmetic and dermatology industries (very light, light, intermediate, tan, brown, and dark) (COLIPA, 2007; Del Bino et al., 2006). This objective method of categorizing skin color based on ITA has been effectively used in previous bruise research (Scafide, Sheridan, Campbell, Deleon, & Hayat, 2013) and within the dermatologic and cosmetic industries (Uhoda, Pierard-Franchimont, Petit, & Pierard, 2003). Colorimetry technology has demonstrated excellent inter and intra-instrument reliability with skin color measurement (Lee et al., 2008), and intra and inter-examiner reliability in bruise color measurement (Scafide et al., 2013).

A rectangular, pre-cut cardstock grid with seven holes was affixed with tape to each forearm. Each hole on each arm was dabbed with a cotton-tipped applicator containing a designated topical product (see Supplemental Content 1 for complete list of the 14 products, manufacturers and ingredients). The 14 topical products were selected based on reported use by the patient population of the study site. Each product was applied with a new cotton-tipped applicator to a designated hole on the participants' forearms. After product application, participants were escorted to an exam room and donned a pair of UV filter

goggles for safety. The room lights were turned off and florescence or absorption was assessed using the SPEX Forensics portable HandScope® Xenon HSX 5000 alternate light source. This device uses a xenon arc lamp with six manually selectable filters on a dial that determine the bandwidth of emitted light. Each product was examined using all wavelengths (UV – 310–390 nm, 415nm, 455nm, 515nm, 535nm and CSS - visible wavelengths shorter than 530nm) in combination with three filters (yellow, orange, and red). The adjacent skin was used for comparison. Data points for each wavelength and filter combination were collected by trained forensic nurse examiners.

Data Analysis

Data were hand-entered into SPSS 22.0™ for statistical analysis.(IBM, 2013) Frequency distributions were examined for coding or entry errors. Demographic characteristics were examined using frequencies and means. Overall frequency of absorption and fluorescence were examined for each product. Additional bivariate descriptive analysis included examining absorption and fluorescence outcomes across skin color, wavelength and filter color group.

In order to examine how wavelength, filter, and skin color predict absorption and fluorescence of topical products, generalized linear mixed models (GzLMM) were performed using a binomial distribution and logit link function. As an extension of classical logistic regression, this type of analysis was appropriate because it accounts for within-subject correlation of repeated measures on the same subject (Diggle, Heagerty, Liang, & Zeger, 2002; Hayat & Hedlin, 2012). Based on the results of the descriptive analyses, observations were included in the GzLMM analyses from those products with the most frequent positive findings.

GzLMM includes fixed effects and random effects. The fixed effects under consideration in this analysis included topical products, wavelengths, filters, skin color and relevant interaction terms. Random effects included the participants. The selection of fixed effects for the final model was based on theoretical assumptions of intrinsic relationships between independent and dependent variables. Results of the fixed effects analysis are presented as odds ratios (ORs).

Results

All interested participants met the eligibility requirements and were included in the study (n=81). The mean age was 39 years (range 18–70) and 83% of the participants were female. The sample self-identified within two main racial categories (53% white/Caucasian and 33% black/African American). We obtained representation from all six ITA skin color groups (very light: 5%; light: 23%; intermediate: 21%; tan: 14%; brown: 32%; dark: 4%). Since the extreme skin colors (very light and dark) were underrepresented in our sample, skin color was collapsed into three broader categories for additional analysis (very light/light, intermediate/tan, and brown/dark).

Of the 14 topical products tested, two (#12 and #3) absorbed alternate light more consistently than the others (see Table 1). Absorption was observed most frequently with the

make-up product (#12, 80.9%), while sunscreen (#3) absorbed 6.5% of the time. The remainder of the products absorbed light in less than 1% of the observations. The make-up product absorbed light across various wavelengths (e.g. from 62% of observations with UV to 98% using the 450nm wavelength). When the sunscreen product absorbed light it was most often in the UV wavelength (36% of observations at the UV wavelength). The other five wavelengths had less than 1% positive absorption findings.

When analyzing the observations of topical product #12 (make-up) using GzLMM analysis (n=1458), wavelength, filter, and skin color each significantly predicted whether absorption was observed. The results of the analysis are presented in Table 2. After controlling for filter and skin color, ALS wavelengths within the visible spectrum and below 530nm were significantly more likely to predict absorption than UV. Red or orange filters were also significantly more likely to predict absorption compared to using a yellow filter. After adjusting for filter and wavelength, absorption was significantly more likely to be observed on individuals with very light/light and intermediate/tan skin color as compared to those with brown/dark skin color (see Table 2).

Six of the topical products tested fluoresced more than 40% of the time (#'s 1, 2, 8, 10, 13, & 14), while an additional five products fluorescence in between 1–10% of observations (#'s 5, 6, 7, 9, & 11), the remaining three products fluoresced in less than 1% of observations (#'s 3, 4, & 12) (see Table 1). Only products with greater than 40% positive fluorescence were included in the GzLMM analysis (n=8748). The wavelengths and filters each contributed significantly to the prediction of fluorescence (see Table 2). Wavelengths of UV, 415nm, and 450nm were significantly more likely to predict fluorescence compared to CSS after controlling for filter. Wavelengths of 515nm and 535nm were either less likely or similar in performance to CSS. As demonstrated in Table 2, orange and red filters were also more likely to improve prediction of fluorescence over yellow filters. Skin color did not predict whether fluorescence was observed.

Discussion

Consistent with prior research, our findings demonstrate positive ALS fluorescence does not mean bodily fluids are present on the skin (Lincoln et al., 2006; Maynard et al., 2001; Nelson & Santucci, 2002). Prior research reported specifically that petroleum-based products tended to fluoresce with ALS. Our results were consistent with these findings; of the six most frequently fluorescing products listed above and in Table 1, only #10 (a bronzer product) was not petroleum-based. Likewise, absence of fluorescence does not indicate an absence of bodily fluids. Therefore, forensic clinicians should base evidence collection on both the patient history and exam findings. The products that fluoresced in our study can be added to the variety of other substances found in prior research that fluoresce under alternate light.

When compared to the UV wavelength, 415nm, 450nm, 515nm, and CSS wavelengths were associated with increased odds of positive fluorescence. This suggests a range of wavelengths will allow visualization of fluorescence from topical products with less consistent visualizations at the lower and upper ends of light wavelength spectrum. Darker

colored filter lenses (orange and red) were also predictive of seeing positive fluorescence. This was not an unexpected finding since they are designed to allow visualization of shorter, brighter wavelengths such as those seen as fluorescence.

One product (#12, a make-up product) consistently absorbed alternate light with ALS, while a second (#3, a sunscreen) absorbed less frequently, primarily when using UV light. As sunscreen is designed provide skin protection from UV light, it was not unexpected that it behaved differently than other topical products. The findings from this study support using ALS in clinical practice to assist in identifying foreign substances on the skin that fluoresce or absorb alternate light.

Implications for Forensic Nursing

During the forensic exam, all positive findings (fluorescence or absorption) should be swabbed for crime lab analysis whether or not the patient reported use of topical products. We also recommend asking all patients if they could have topical products on their skin at the time of the exam, either self applied or applied by the reported perpetrator(s) may also help in interpretation of positive findings by the clinician and in appropriate laboratory analysis. Only laboratory analysis, in conjunction with a police investigation, can determine if positive findings on ALS have evidentiary value. The locations of positive ALS findings need to be documented in the exam narrative, on body maps and, if possible, photographed.

After all the ALS positive sites have been swabbed, and only then, our research findings suggest the sites be gently cleaned, dried and reassessed with ALS at the same wavelengths and the same color filters used originally. It is especially important for sites positive for absorption to be cleaned then reassessed. If absorption is still present post-cleansing, this would be consistent with a positive finding, especially if supported by history or other examination findings such as pain with palpation or induration. However, we agree with the caution previously stated in the literature, that positive ALS findings alone are not definitive of the presence of a bruise or other injury (Lombardi et al., 2015).

Our results indicate the 415nm and 450nm wavelengths with orange filters are most likely to have some positive findings (absorption or fluorescence). Thus, these wavelengths could take priority in the event an extended exam with multiple wavelengths and filters cannot be completed. Additionally, if there are a limited selection of filters, orange would be recommended as it consistently identified fluorescence and absorption in most wavelengths. However, yellow filters were more likely to identify positive absorption and red filters more likely to identify fluorescence. This suggests forensic examinations using multiple wavelength and filter combinations should be conducted to provide the most comprehensive assessment for possible sources of evidence.

Our findings demonstrated having darker skin color is associated with being less likely to identify absorption of a topical product. This may be important in its relation to possible disparities in evidence collection and injury identification among darker skinned individuals. Since the product most consistently producing absorption in our study was a make-up marketed to medium skin toned individuals, it was not possible to differentiate whether our

findings related to skin color are related to the degree of difference in color (lighter or darker) between the product and the participants' skin tones.

Research Implications

While our findings support the importance of inquiring about the application of topical products during a medico-legal exam utilizing ALS, additional research is still needed. Our research examined only 14 of hundreds of topical products readily available in the market. Additional research is needed on other common topical products, especially products more commonly used in a forensic program's geographic catchment region. This should include self-tanning products, which we intentionally excluded. Follow-up studies are needed to test various make-up and sunscreen products for absorption of alternate light, including documenting and assessing for variation in findings related to sun protection factor (SPF) which are increasingly common in make-up products. Ideally, such studies would also test the effectiveness of readily accessible cleansing products that could be used in a clinical setting to remove topical products producing positive absorption results. A key limitation of this study and others that have evaluated ALS use is the lack of pre-testing to determine if participants have preexisting absorption or fluorescence prior to carrying out study procedures designed to create ALS findings, including this step in future studies will add to the validity of subsequent findings.

Skin color's effect on identification of absorption is another area requiring additional study. Because of the nature of our convenience sampling method, we were unable to recruit sufficient numbers of subjects from all six skin colors. Future research should include larger participant samples with a focus on recruiting equal numbers of subjects across all six ITA skin color groups and assessing make-up shades that are similar to and different from the skin tone of the participants.

Limitations

This study, while adding to the evidence base of ALS findings in clinical forensic patients, was limited in scope to one research site, one visit per participant, and only one primary data collector making observations of each participant. Because of the pilot study nature of our design, we did not formally assess for inter-rater or intra-rater reliability of the ALS findings.

However, a second examiner was present when the ALS examinations were done and verbally verified the findings on each subject. Because there was no prior research using our methodology, a power analysis was not conducted to determine an a priori sample size. Blinding to product was not feasible since the data collectors were also the study investigators.

Strengths

While we were not able to recruit equal numbers of subjects in all six skin color groups, care was taken to objectively quantify skin color. We were able to recruit subjects from all skin color categories via their ITA measurement, a method successfully utilized in previous research. This was one of the first studies to specifically examine ALS technology on topical

products in a clinical practice setting on human subjects. All members of the research team are experienced forensic nurses and also experienced in the use of ALS in clinical practice.

Conclusions

Examining differences in ALS patterns between known injury findings and known topical products may in the future help to identify clinical markers of injury. The use of ALS technology is becoming more common in clinical forensic programs. While there is a growing body of evidence on its usefulness in detecting body fluids and other substances during the investigations, there has yet to be a rigorous randomized control trial that has examined longitudinally if purposively caused injuries can be seen using ALS. Positive ALS findings, especially absorption, have been correlated to body sites reportedly injured from accidental and intentional injury; however, ALS alone should not be used diagnostically. This study provides additional guidance to clinicians using ALS technology in practice and in interpreting findings for clinical and legal purposes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

List of Products Examined and ALS Findings

No.	Product Name	% of ALS Observations with + Fluorescence*	% of ALS Observations with + Absorption*
1	A + D® First Aid Ointment	**51.5**	0.5
2	Bag Balm®	**67.6**	0.1
3	Banana Boat® Ultra Defense ®SPF 30 Lotion Sunscreen	0.9	6.5
4	JOHNSONS® Baby Oil	0.4	0
5	K-Y® Brand Jelly	2.3	0
6	Neosporin® + Pain Relief Ointment & Cream	7.9	0.1
7	Palmer's Cocoa Butter Formula Body Lotion	3.9	0
8	Preparation H® Ointment	**66.0**	0.6
9	Secret® Original Invisible Solid	3.2	0
10	Sublime Bronze™ Luminous Bronzer	**66.3**	0.3
11	Trojan® MAGNUM® Lubricated Condoms	1.9	0
12	True Match™ Super Blendable Makeup	0.3	**80.9**
13	Vaseline® Original 100% Pure Petroleum Jelly	**42.1**	0.1
14	Murray's Original Pomade	**55.5**	0.1

Bolded items observations were used in generalized linear mixed models

*n=1458 observations per product

Table 2

Generalized Linear Mixed Model for Absorption* and Fluorescence**

Fixed Effect	Odds Ratio	95% Confidence Interval	p-value
Absorption (n=1458)			
Wavelengths			
UV	–	–	–
415nm	**9.01**	**5.01–16.21**	<**0.001**
450nm	**81.62**	**22.00–302.72**	<**0.001**
515nm	**7.03**	**3.99–12.38**	<**0.001**
CSS	**5.62**	**3.18–9.98**	<**0.001**
535	1.38	0.78–2.43	0.272
Filters			
Yellow	**3.76**	**2.46–5.76**	<**0.001**
Orange	**6.75**	**4.35–10.48**	<**0.001**
Red	–	–	–
Skin Color Groups			
Very Light/Light	**8.94**	**2.88–27.8**	<**0.001**
Intermediate/Tan	**2.52**	**1.30–4.87**	**0.006**
Brown/Dark	–	–	–
Fluorescence (n=8748)			
Wavelengths			
UV	**1.86**	**1.43–2.40**	<**0.001**
415nm	**3.39**	**2.67–4.31**	<**0.001**
450nm	**6.74**	**5.26–8.63**	<**0.001**
515nm	0.93	0.84–1.03	0.185
CSS	–	–	–
535nm	**0.24**	**0.21–0.29**	<**0.001**
Filters			
Yellow	–	–	–
Orange	**4.43**	**3.75–5.23**	<**0.001**
Red	**7.38**	**5.64–9.67**	<**0.001**

* Only observations from product #12 included in analysis

** Only observations from product #s 1, 2, 8, 10, 13, and 14 included in analysis