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TECHNICAL NOTE

A. G. Dyer,[1] Ph.D.; L. L. Muir,[2] Ph.D.; and W. R. A. Muntz,[3] Ph.D.

A Calibrated Gray Scale for Forensic Ultraviolet Photography

ABSTRACT: The human eye is an important tool for observing evidence, and visual evidence in turn may be documented onto a photographic medium. The human eye is generally sensitive only to a narrow band of the electromagnetic spectrum from about 700 nm (red) to about 400 nm (violet/blue). It is possible to extend the range of radiations over which evidence may be documented by using the natural ultraviolet sensitivity of photographic films. However, photographing evidence with ultraviolet radiation ultimately involves presenting the information to subjects who may have no prior experience at viewing these wavelengths. This study shows that it is necessary to use a calibrated ultraviolet reflecting gray scale to allow meaningful interpretation of results.

KEYWORDS: forensic science, ultraviolet photography, skin reflectance, gray scale, ultraviolet radiation (UVA)

The imaging of invisible ultraviolet radiations allows the analysis of information not normally visible to humans. Visible light extends from about 700 nm at the red end of the spectrum to about 400 nm at the violet-blue end of the spectrum. Wavelengths of radiation shorter than 400 nm are prevented for reaching the human retina by ocular filters (1,2). Many photographic films are sensitive to both visible light and near ultraviolet (320–400 nm) (UVA) radiation. By using a filter that blocks visible light, it is possible to photographically record ultraviolet reflections and subsequently represent these images so that they can be viewed in the visible spectrum (3). This technique has been used for over 80 years to document UVA reflections in nature (4), and more recently in medical and forensic science applications (3).

For forensic purposes reflected UVA photography has been used to document damage to skin tissue that has occurred as a result of a physical blow (5) or a bite (6). This technique is potentially useful because there is evidence that wounds or bruises can be photographically recorded with reflected ultraviolet techniques many months after evidence of an injury has disappeared in the visible spectrum (3,5,7). When skin tissue is physically damaged, there is a slow migration of melanin in the epidermis layer. This can be recorded with reflected UVA photography because the penetration of short wavelength radiation is restricted to the epidermis layer (8). The migration of melanin appears to occur over time and it has been shown to be possible to record bruises or bite marks inflicted on a victim that have healed to such an extent that there is no visible evidence of the event (3,5,6,8). Photographically recording the invisible UVA radiation reflected from skin can therefore allow the collection of evidence not otherwise available (3,8).

[1] School of Orthoptics, Faculty of Health Sciences, La Trobe University, Bundoora Vic. 3086, Australia.
[2] CSIRO Publishing, PO Box 1139, Collingwood, Vic. 3066, Australia.
[3] Biological Sciences, Monash University, Clayton, Vic. 3168, Australia.
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A problem of recording UVA reflections, however, is that humans do not normally perceive UVA radiation. Photographs made using UVA may be misleading if there is no frame of reference to our normal visual environment. When a photographic exposure is made onto black and white film with visible light a viewer has a reasonable idea about whether a photograph is too dark, light, or contrasty, as viewers have extensive experience with viewing normal visual scenes. However, it cannot be assumed that the appearance of a specimen in the UVA should resemble the appearance of that specimen in the visible spectrum. While this aspect of using UVA imaging techniques has long been appreciated for documenting evidence from biological specimens (4,9,10), current investigation techniques using reflected UVA photography for forensic purposes have ignored this potential problem (e.g., 5–8,11, see 3 for review). For example, one online forensic photography tutorial (11) shows images taken in both the visible and UVA parts of the spectrum, but it is not clear whether dark sections on the skin in these images are actually bruises or possibly artifacts of lighting and poorly controlled contrast. In this current study the spectral reflectance of human skin in both the visible and UVA regions of the spectrum is recorded to determine appropriate appearance for reflected UVA images. A method for making a calibrated gray scale is also provided.

Materials and Methods

The spectral reflectance functions of human skin were measured in a Varian DMS100 reflectance spectrophotometer calibrated against a Varian pressed polytetrafluoroethylene powder standard. The wavelength range considered was 330 to 700 nm. Wavelengths shorter than 330 nm were not measured because of the increasing danger posed to biological matter by high energy, short wavelength radiation (3,8,12). The skin samples were the left-hand index fingers of the three authors of this study, which were scanned in a darkened room to avoid contamination of the signals by external radiations.

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TABLE 1—*Materials used to make a gray scale that can be used for reflected UVA photography. Patch 1 is the lightest patch shown in Fig. 2. The gray scale reflects similar levels of UVA and visible light, see Fig. 1A.*

Patch	MgO (%)	Plaster (%)	Carbon (%)
1	70	26	4
2	60	33	7
3	60	31	9
4	40	30	30
5	20	30	50

Commercially available gray scales reflect UVA radiation poorly, and are unsuitable for reflected UVA photography (10,13). A series of gray scales that can be used as a reference scale were constructed by mixing different ratios of magnesium oxide, plaster, and carbon (13) (Table 1). In addition, black velvet was used as a reference patch of very low reflectance. The resulting gray patches were measured in the Varian spectrophotometer. The gray scale was included in photographs made with UVA and visible light.

Bruises on the arm of one of the authors (LM) were photographed over a period of 94 days, starting one day after a sporting incident, and then being photographed at approximately 3 week intervals. Photographs were made using a Nikon F3 camera onto Ilford HP5 film processed as described by (3) to enable good sensitivity to UVA radiation. To enable transmission of UVA radiation, an 80 mm El-Nikkor enlarging lens was mounted to the Nikon camera using focusing rings. This type of lens was designed to maximize ultraviolet transmission of glass optics and allows for transmission of electromagnetic radiation down to 320 nm, with 50% of peak transmission possible at 335 nm. The lens is chromatically corrected for visible and ultraviolet radiation and does not require a focus shift. Illumination was provided by a Metz 404 ring-flash that had the UVA absorbing front diffusion screen removed. For reflected ultraviolet photographs, a Schott UG11 filter was attached to the lens to block visible radiation. For reflected visible spectrum photographs, a Kodak 2B Wratten filter (14) was attached to the lens. Correct exposures for the lens, filter, and film combinations were determined from test photographs of the constructed gray scale. Reflection prints were made from the processed negatives so that the calibrated gray scale gave an acceptable visual representation. This was possible because the individual gray patches each have a similar reflectance in both the UVA and visible regions of the spectrum, and the human eye can thus be used to make a relative judgement of how the scale should appear in the UVA region of the spectrum.

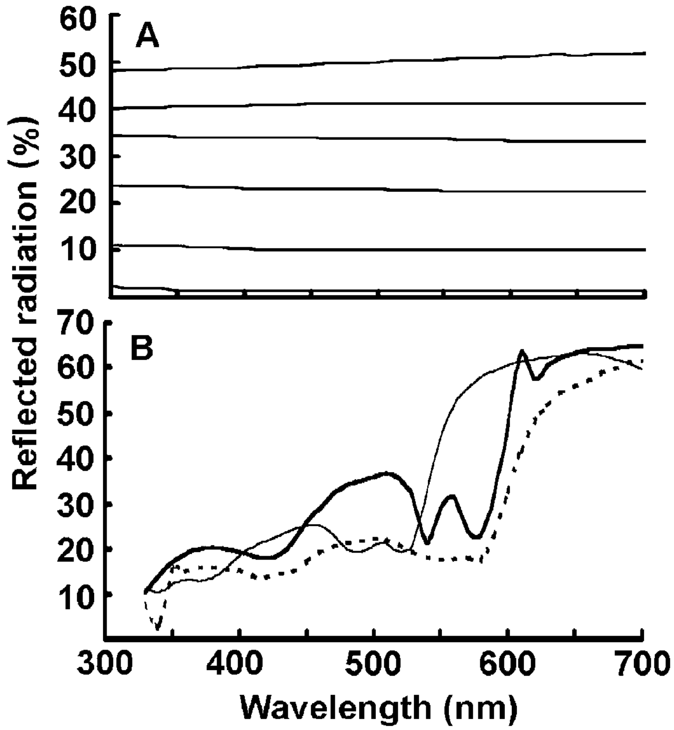

FIG. 1—*Spectral reflectance of materials. (A) Gray scale elements. (B) Caucasian skin.*

Results

Figure 1*A* shows the spectral reflectance of the individual gray elements that make up the gray scale. Each element has a similar reflectance in both the visible and UVA regions of the spectrum, and thus the gray scale serves a good control for determining subject brightness and contrast when reflected UVA images are to be represented as images in the visible spectrum.

The spectral reflectance of the three examples of Caucasian skin are shown in Fig. 1*B*. In the visible spectrum, the reflectance properties are consistent with the mean reflectance of Caucasian skin of 78 subjects reported previously (15). In the current study, the mean reflectance of the skin from 400–700 nm was 37.2%, and the mean reflectance from 330–400 nm was 14.2%. Thus the reflectivity of Caucasian skin in the ultraviolet range of the electromagnetic spectrum is approximately 38% of that in the visible spectrum.

Using the gray scale as a control, it can be seen that the photographs representing the reflectance of Caucasian skin should be rendered much darker for UVA photography (Fig. 2*C*, *D*) compared with photography with visible light (Fig. 2*A*, *B*). The gray scale demonstrated here uses six separate patches to control carefully for image brightness and contrast, although it would be possible to use fewer patches and still retain sufficient control over image contrast and brightness. The use of a gray scale is necessary to ensure that brightness and/or contrast of the image are not artificially enhanced, which could lead to the evaluation of photographic lighting artifacts as possible evidence. This is a particularly important point, as humans do not normally perceive images from the UVA region of the spectrum, and thus have no experience at judging correct image brightness or contrast in this region of the spectrum.

When the bruises on the arm of LM were photographed over a period of 94 days using the calibrated gray scale, there was no evidence of the bruise re-appearing with reflected UVA photography after it had faded in the visible spectrum. The result questions the validity of documenting potential bruises when a calibrated gray scale is not used to control image contrast and brightness.

Discussion

A number of previous studies cited above have evaluated the merits of using reflected UVA photography to document the possible presence of old bruises on subjects. The technique of reflected ultraviolet photography may provide convincing evidence in cases where there is sufficient bite or weapon markings to equate accurately the shape of an implement with the reflected UVA image documenting the bruising (7). However, for documenting subject matter where no specific tooling marks are present, a gray scale must be included to avoid possible errors resulting from artificial increases in image brightness and contrast. Without a fundamental understanding of the reflectance properties of skin in the UVA and visible regions of the electromagnetic spectrum, the use of this technique may lead to inappropriate interpretations about the

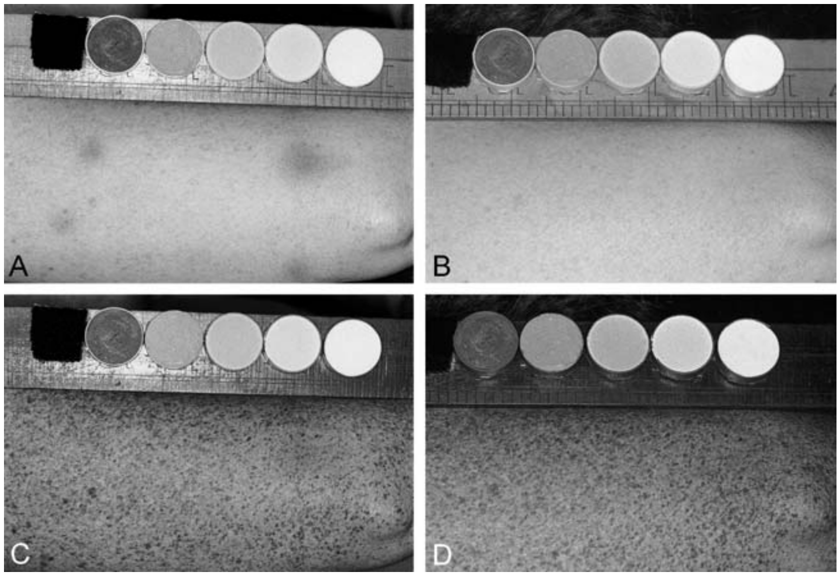

FIG. 2—*Caucasian skin reflects considerably less UVA radiation compared with visible light. Photographs were made using the calibrated gray scale as a reference to control for contrast and brightness. There was no evidence of bruises reappearing in the UVA region of the spectrum: (A) Visible light photograph of bruises one day after incident. (B) Visible light photograph 94 days after incident. (C) UVA radiation photograph one day after incident. (D) UVA radiation photograph 94 days after incident.*

documentation of possible bruising. To avoid such difficulties, it is important to use a calibrated reflectance scale to control subject brightness and contrast.

Conclusion

The use of reflected ultraviolet photography to document evidence is subject to interpretation difficulties unless a properly calibrated UVA/visible reflectance scale is included in the photographs.

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Additional information and reprint requests:
Adrian Dyer, Ph.D.
School of Orthoptics, Faculty of Health Sciences
La Trobe University
Bundoora Vic. 3086, Australia
E-mail: a.dyer@latrobe.edu.au.