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Ultraviolet Radiation and Its Role in Wound Pattern Documentation

REFERENCE: West, M., Barsley, R. E., Frair, J., and Stewart, W., **"Ultraviolet Radiation and Its Role in Wound Pattern Documentation,"** *Journal of Forensic Sciences*, JFSCA, Vol. 37, No. 6, November 1992, pp. 1466–1479.

ABSTRACT: The history of ultraviolet illumination in photography is discussed. Particular attention is devoted to the forensic aspects of ultraviolet photography as it relates to patterned injury on human skin. The authors discuss the theory underlying ultraviolet illumination of wounds on skin as well as the equipment required for this type of imaging.

KEYWORDS: forensic science, ultraviolet radiation, wound patterns

Over 3500 years ago, the physician to the emperor of China noticed that wounds sustained by soldiers had a different appearance when observed under sunlight filtering through his yellow silk tent, than when viewed in direct sunlight [*1*]. From this humble beginning springs the forensic study of wound pattern imaging.

As early as 1801, Ritter noticed that a band of invisible radiation, beyond the spectral color of violet, would blacken certain silver salts that were exposed to it. That marked the recognition of the ultraviolet (UV) region of the spectrum, commonly acknowledged to range from 10 to 100 nm (nanometers) [*2*].

During World War I an American physicist, R. W. Wood, at Johns Hopkins University conducted research in the field of ultraviolet "light." He was attempting to manufacture beacons of this invisible light for use as secret signaling devices for the war effort. After the Armistice was signed ending the conflict, a disclosure of his experiments was published in 1919 in France. The ultraviolet radiation was referred to as "black light" and the illuminating device became known as a Woods lamp. In an article, Wood is quoted as saying, "The question would be worthwhile to be studied by physiologists and pathologists" when questioned about the effects of ultraviolet radiation on humans [*3*].

In 1926 at a dermatological conference in Bruxelles, Vignes discussed photographs exposed with ultraviolet light [*4*]. In 1928, Dr. Herman Gooden of New York was the first to publish an article discussing the hidden potential of Wood's strange light in relation

Received for publication 2 October 1991; revised manuscript received 18 February 1992; accepted for publication 24 February 1992.
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to dermatology [5]. The first photographs of skin taken with ultraviolet light were published in 1935 [6].

Earlier, in 1930, Bachen and Reed used combinations of filters to split the spectrum into 10 to 20 nanometer bands of light. They illuminated cut sections of human skin with the varying frequencies to measure the reflectance, absorption, and penetration of each band of light upon varying thicknesses and types of skin sections. Figures 1 through 4 are drawn from their early work. Among their conclusions they stated:

> "While successive readings on the same specimens agree closely, it cannot be expected that readings on two different specimens of the same subject, will agree so closely when one considers that differences in chemical composition, particular pigment content and retained hemoglobin, relative thickness of the various layers, physical structure, and artifacts due to handling and treatment all play a part in determining the transmission of rays" [7].

These early researchers were quick to realize that the reflectance, absorption, transmission, and penetration of electromagnetic energy through human skin would vary depending on many minute variables. To this day one can still only quote average values for these phenomena, not provide constant ones.

In 1950 Edwards noted that the absorption of electromagnetic energy or light by melanin pigment gradually increased from the red end of the spectrum as the violet end was reached. The absorption continued to increase even into the ultraviolet range. He reported that melanin and its breakdown products actually masked other materials that would have absorbed both visible and ultraviolet radiation. In addition, he plotted the absorption curves for hemoglobin, oxyhemoglobin, α-carotene, and β-carotene. He thought that "the method seems promising for the ultimate identification and quantitative determination of additional substances in the living skin" [8].

Also beginning in the 1950s, Lunnon published the first of many articles that would span three decades discussing ultraviolet photography. Dr. Lunnon conducted his research in England at the Institute of Dermatology, London.

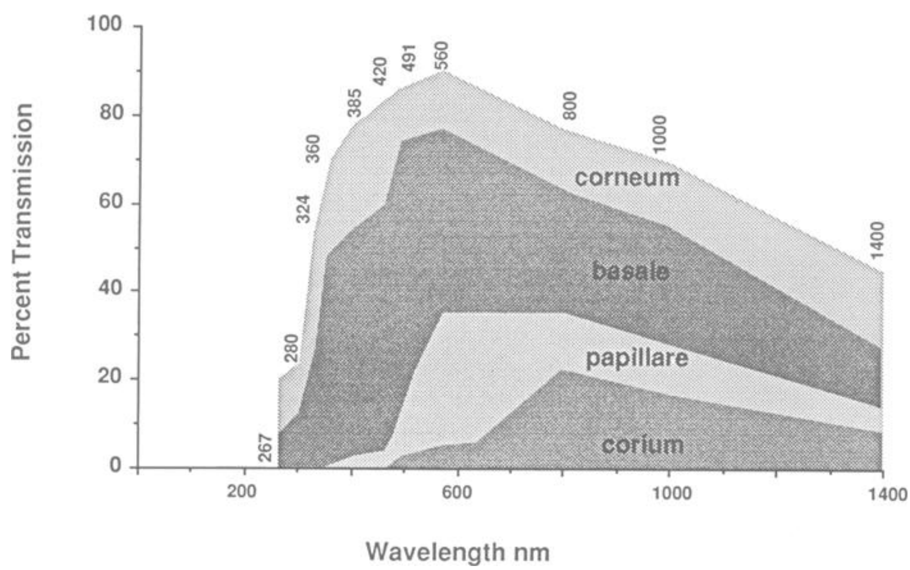

FIG. 1—*Percent transmission through various strata of human skin at selected wavelengths.*

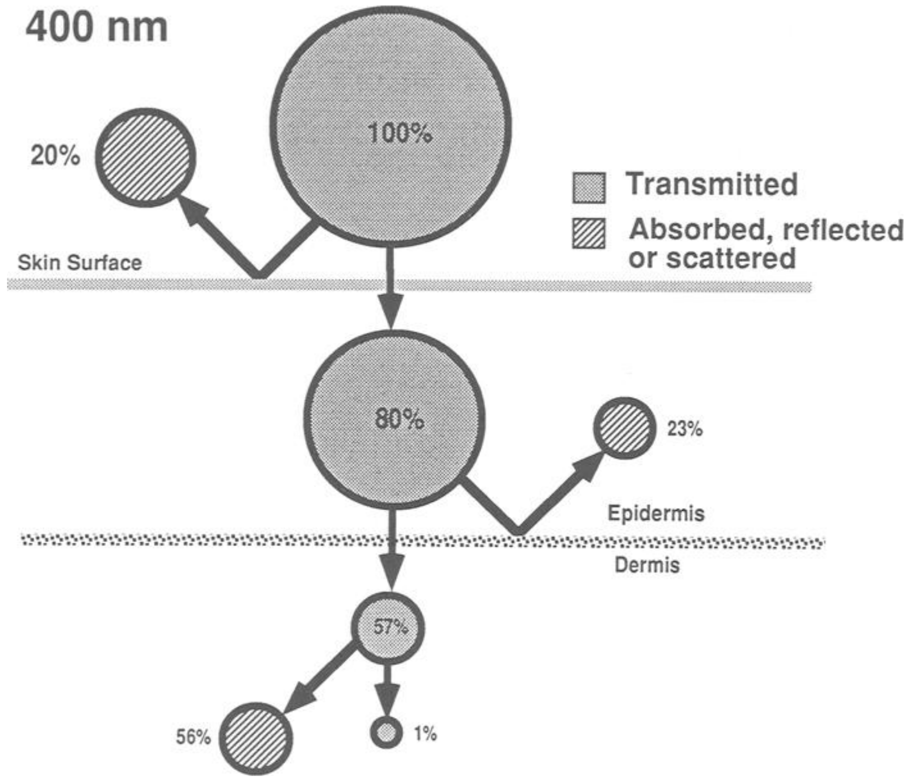

FIG. 2—*Energy dissipation of light at 400 nm through human skin. 57% reaches the dermis while only 1% is transmitted to deeper tissues.*

The Ultraviolet Spectrum

Ultraviolet radiation (UVR) can be divided into categories or types based on physical properties. These are UVA, UVB, UVC, and Vacuum UV. UVA or "long UV" encompasses those wavelengths from 400 nm to 320 nm. Commonly referred to as "Black Light," it is not visible to the human eye, but will cause certain substances to emit visible fluorescence. This type of UVR has the least potential for causing biological damage. The UVB or "Short UV" spectrum from 320 nm to 290 nm is produced by the sun, but usually does not penetrate the atmosphere to reach the earth's surface. Within this range, glass no longer transmit wavelengths below 310 nm. UVC extends down the spectrum to 200 nm and includes those wavelengths which are germicidal. This energy poses the greatest threat to human users and is quite effective at killing unicellular organisms. Vacuum UV consists of all wavelengths below 180 nm and is so named because air molecules absorb these wavelengths; therefore, they can only be used within a vacuum chamber [*9*].

Ultraviolet Light and Human Skin

Forensic investigators began to become aware of ultraviolet imaging of wound patterns on skin in the 1970s. In 1974, Ruddick of the London Hospital detailed a case in which ultraviolet illumination was used to record a bite mark [*10*]. Hempling followed with an article detailing ultraviolet photography in forensic medicine in 1981 [*11*].

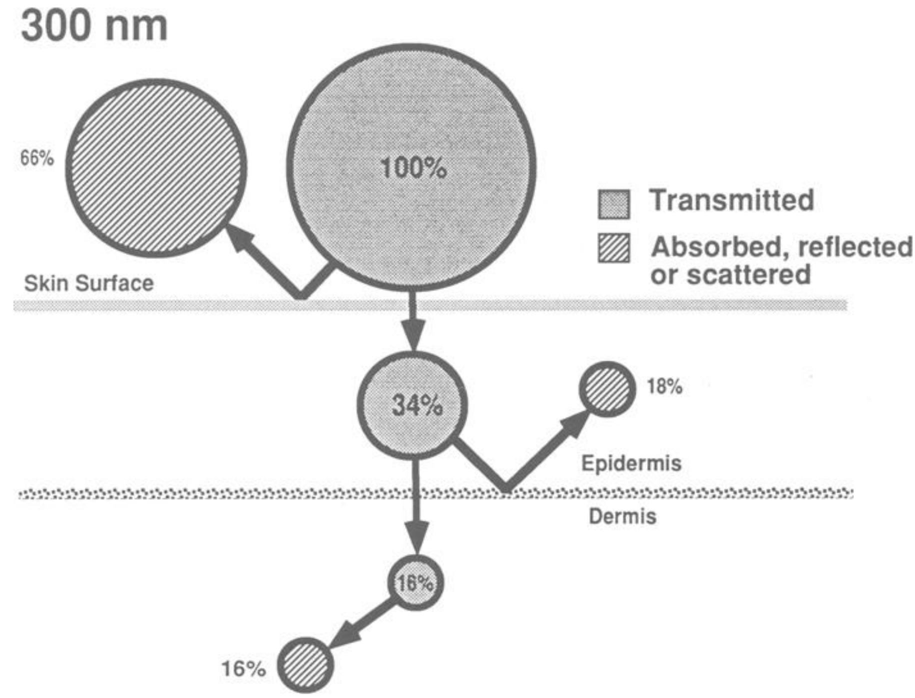

FIG. 3—*At 300 nm only 34% of the light is transmitted into the epidermis and only 16% reaches the dermis.*

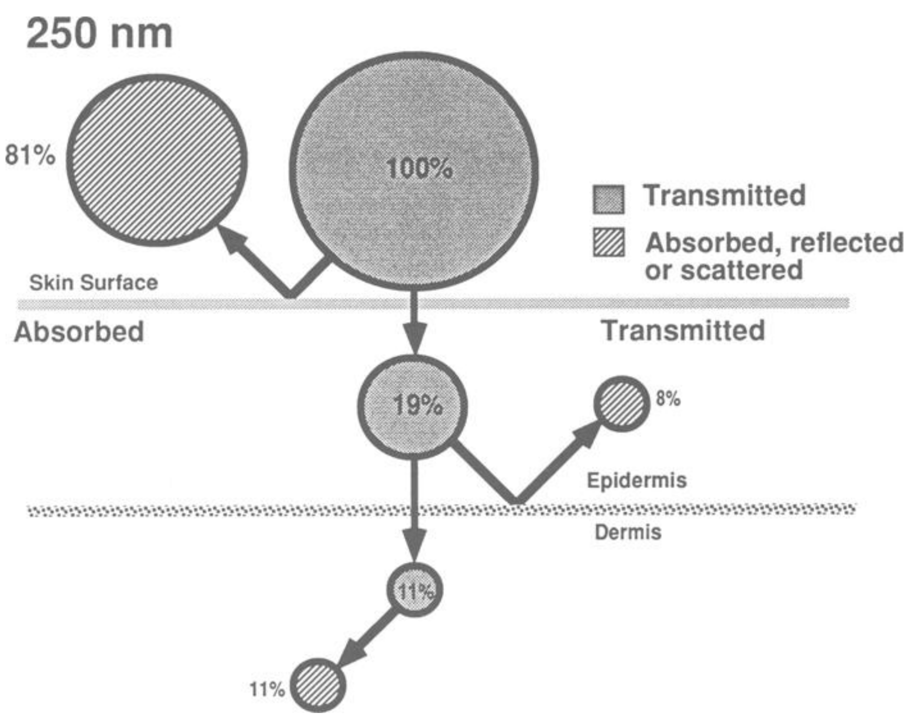

FIG. 4—*Over 80% of short ultraviolet energy is reflected from the skin surface.*

Photographic documentation of patterned injuries on human skin is important to the forensic scientist. Dent in 1951 stated, "[i]n photographing human skin for medical [forensic] records, it is of paramount importance that the visual appearance of the texture and skin lesion present be clearly recorded" [*12*]. The color of healthy skin is largely determined by the quantity and degree of oxygenation of the blood in the dermis and by the presence or absence of the brown/black epidermal pigment melanin [*13*].

Much study has been devoted to the transmission and penetration of light through human skin. The field is known as photobiology, the study of the interaction of biological systems and the wavelengths of selected regions of the electromagnetic spectrum [*9*]. Wide variations in the photographic appearance of skin can be obtained under different lighting conditions. This is because different wavelengths of light vary in their ability to penetrate into human skin. Penetration is dependent upon three factors: reflection, scatter, and absorption. The most important factor is reflection, that is how much illumination is returned to the film. The degree of penetration and scatter is determined by the depth in the skin at which the light is reflected. Light that is not directly reflected or scattered is absorbed by the tissues and for the most part lost. The deeper the penetration the greater the scatter and consequently the greater the loss of detail. UV radiation has the least penetration and infrared the most, with visible light falling in between in a linear fashion. The wavelength of the light also effects the rendition of detail, the shorter the wavelength the greater the resolution. Also the angle of illumination must be taken into account as a poorly positioned light source may flood the minute hills and dales of the skin surface yielding a flattened, washed-out image [*12*].

UV Photography

The author was first exposed to ultraviolet imaging in 1983 in a presentation by Dr. Thomas Krauss. In a review of photographic techniques of interest to the forensic dentist, he said, "Special procedures such as ultraviolet photography are often briefly mentioned, but the practical application is not defined" [*14*]. The author was challenged to search for those practical applications. In a series of experimental bites using sedated volunteers, the resulting wound patterns were followed photographically for several months. This led to the discovery that ultraviolet imaging of the wound site disclosed a patterned injury long after all visible traces were gone. These findings were published in 1987 [*15*].

Illumination via UVR satisfies the needs of photographic documentation of wound patterns on skin. Reflective ultraviolet photography has the added benefit of bringing forth an image of a wound that previously could not be seen unaided by the human eye. In addition, this type of photography can record and document the wound healing process and can oftentimes reveal old, healed wounds [*16*]. Therefore, photographic documentation of a wound pattern can not be considered complete unless UV photography has been employed.

As with any light, the strength or volume of UV radiation striking a given area also affects the penetration. Overlighting the subject causes increased penetration which results in excess scatter [*12*]. However, UV radiation will penetrate a material to only a certain depth no matter how great the intensity (volume). That depth is dependent upon the composition of the material and the wavelength of the energy. Longer wavelengths such as infrared penetrate more deeply than do visible wavelengths. Long UV (365 nm) in turn penetrates more deeply than does short UV (250 nm). In human skin the penetration varies according to wavelength from as little as 1% at 250 nm to as much as 44% at 320 nm [*17*].

Despite the fact that other papers dealing with film selection [*18*] and refining the technique for ultraviolet photography of wounds on skin [*19*] were published, investigators encountered difficulty with the process. Using conventional cameras, it was impossible to visualize with the eye the injury pattern in the ultraviolet spectrum. Therefore, one could not compose the picture or position the ultraviolet source for maximum clarity. This led to occasional cases of disappointment with the technique.

The author had already used a video camera to document some injury patterns and attempted to interest an electronics manufacturer in building a video device sensitive only to the ultraviolet spectrum. A discussion with Ed German of the Army Crime Lab revealed that such a device had already been built for fingerprint detection. A light intensifier, sensitive into the ultraviolet spectrum was available from a Japanese company (Hamamatsu Corp., Bridgefield, NJ). The system, referred to as RUVIS for *R*eflective *U*ltra*v*iolet *I*maging *S*ystem, made possible real-time viewing of a reflected ultraviolet image. With this advance the proper ultraviolet lighting could be gained and the resulting image captured on video tape. In addition, one then could position the 35 mm camera equipment and the UV illumination while remaining confident that the ultraviolet images transferred to film would be of the best possible quality. An even greater benefit was that a reflected image in the short ultraviolet spectrum (below 320 nm) could be visualized through the intensifier.

This breakthrough was responsible for a greatly improved understanding of the ultraviolet imaging process overall. Several articles followed detailing both the process and the advances [*16,20,21*].

This work has lead to the brink of imaging wounds with selected bands of light, termed alternative light, using light sources such as the Omnichrome Omniprint 1000 light source. By using the Stokes Shift, forensic science has come full circle so that fluorescent images of wound patterns, unseen by the naked eye are made visible, just as in that silk tent in China in 1500 B.C.

Photographic Properties of Ultraviolet Radiation

Photography, or its result—a photograph is a product of the visible light spectrum, approximately 400 nm to 700 nm. The basic advantage that illumination by ultraviolet radiation brings to forensic imaging is its ability to provide a visible interpretation of a previously unseen state. Ultraviolet radiation is often improperly referred to as a type of light. It is not (no more than gamma rays are a type of light) [*22*]. Luminography is the production of a picture without the use of visible light. The picture is properly termed a luminograph [*23*].

The contrast of the luminograph is an important aspect of luminography. Just as in conventional photography, there is a gamma/lambda effect yielding a lesser degree of contrast when shorter wavelengths are used to illuminate the subject. In order to compensate and achieve a satisfactory contrast index, one must increase the development of the negatives [*24*]. Even though the resulting negatives may appear quite thin, full detail can be captured [*25*]. Ultraviolet radiation penetrates the skin layers less deeply than visible light and much less deeply than infrared radiation, therefore, there is much less scatter of the reflected rays. This results in a greater degree of definition of surface detail. Variation in underlying pigmentation of the skin will also be preferentially recorded [*26*]. A final benefit of ultraviolet illumination is that the shorter wavelength yields excellent resolution [*2*].

Safety and UVR

When working with the 365 nm wavelength of ultraviolet radiation, also called variously UVA, Black Light, near UV, and Long UV; the biological hazard is quite small. Figure

5 illustrates that the erythemal effects of UVR only occur at wavelengths of 320 nm and below. Visual effects are nonexistent because the retina is insensitive to wavelengths below 400 nm.

However, it is important to note that when dealing with Short UV, the erythemal effects on skin and the conjunctiva can be severe and only appear some four or more hours after exposure. Care must be taken to shield the photographer's and the subject's eyes from overexposure when working with continuous UVR sources. UVR blocking glasses should be worn. If only electronic flash gun illumination is used, there is no danger under normal conditions because of the extremely short duration of the flash [2].

The Optical Society of America has voiced some concern in this area, "growing evidence suggests that retinal degradation may occur . . . possibly from the trace amount of UV-A that reaches the retina. A key factor to remember is that UVR effects are linearly additive over a period of about a day" [27].

Penetration, Reflection, and Absorption of UVR in Human Skin

The optics of human tissue determine how deeply the radiation penetrates [9]. Figure 6 shows the layers of human skin in a cut section along with average measurements. Figure 7 depicts the average penetration of ultraviolet radiation into the skin. Ultraviolet radiation is strongly absorbed in the epidermis, specifically in the stratum basale and by the skin pigment melanin. Very little, if any UVR, reaches the dermis. In fact, virtually none of the incident ultraviolet radiation shorter than 320 nm passes through human epidermis to reach the dermis [28]. This is unlike visible light that has strong absorption in the stratum corium and deeper subcutaneous layers. There is some absorption of UVR

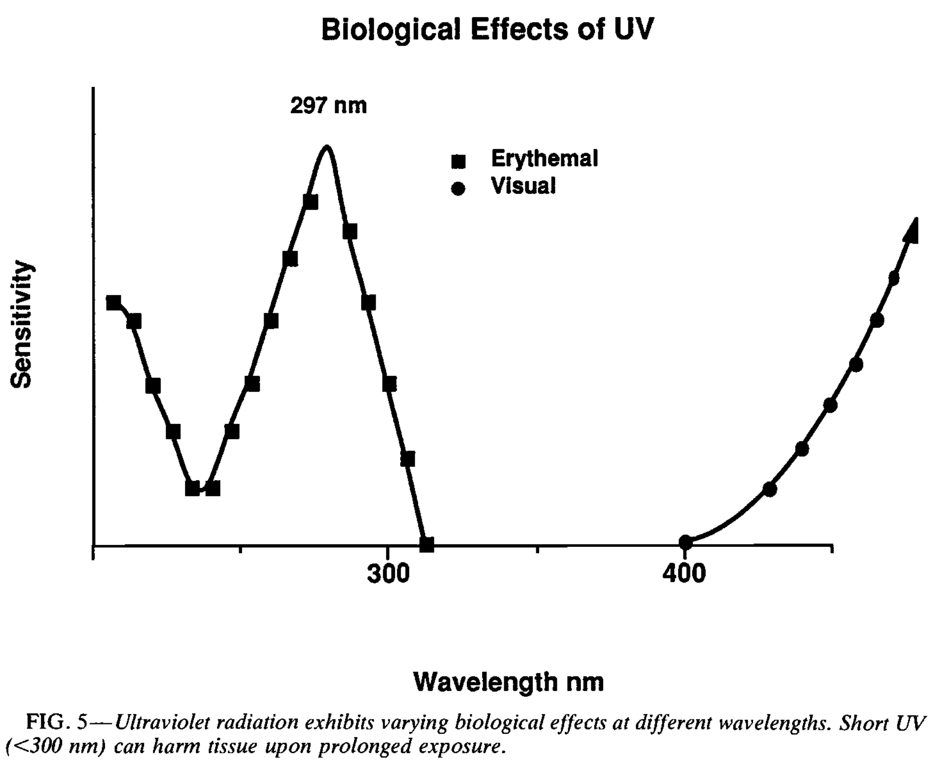

FIG. 5—*Ultraviolet radiation exhibits varying biological effects at different wavelengths. Short UV (<300 nm) can harm tissue upon prolonged exposure.*

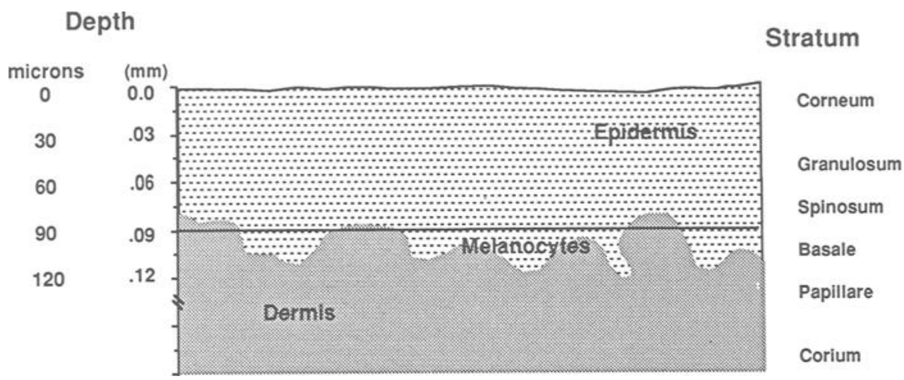

FIG. 6—*Strata and average measurements for sections through human skin.*

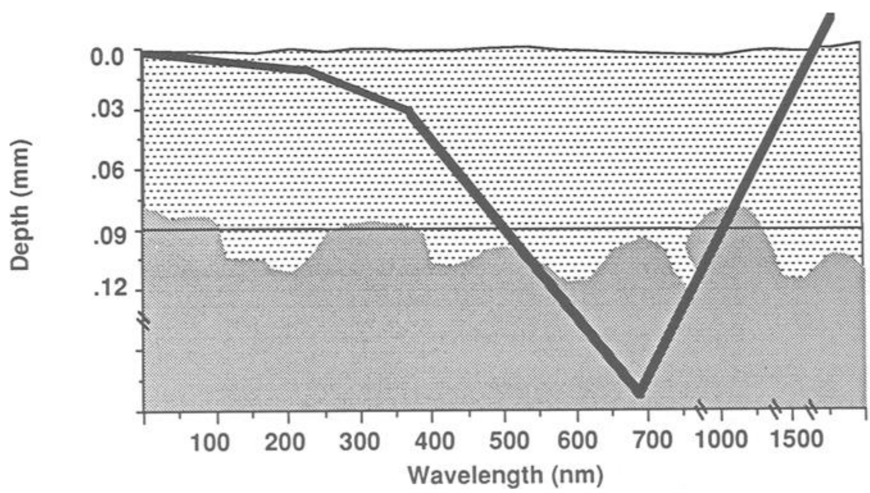

FIG. 7—*Average depth of penetration of radiant energy into thin human skin at various wavelengths.*

in the stratum corneum but this is highly dependent upon the protein content. There is much less scattering of UVR within the tissues when compared to visible light [*29*].

Lens and Camera

A 35 single lens reflex camera with manual exposure capability is required. The authors use a Canon AE-1. A macro lens is also necessary. The authors use a Canon 50 mm macro set at 1 to 1.5 magnification. Other lenses or even bellows systems can be used; however, a longer focal length lens may position the light source, if mounted on the camera or lens, too far from the subject.

Just as visible light can be split into the familiar spectrum of colors by a prism, so can ultraviolet radiation. This property is known as dispersion (or refraction) [*29*]. Photographically speaking, the ultraviolet spectrum is commonly divided into two bands. As previously discussed, Long UV encompasses 320 to 380 nm, also known as UVA. Short UV or UVB is that below 320 nm. Most of the imaging studies using ultraviolet energy have centered on Long UV at 365 nm for several reasons. The Wood's filter, a special barium-sodium-silicate glass that incorporates about 9% nickel oxide has a peak transmission of about 365 nm [22]. The Woods Lamp, the common "blacklight," and the high pressure mercury vapor lamp all have a peak spectral emission at 365 nm. The spectral sensitivity of panchromatic film extends well into the ultraviolet range at 300 to 400 nm. The common xenon electronic flash tube emits ultraviolet radiation well down into the short UV range [24]. Figures 8 and 9 help to illustrate this.

Many standard photographic lenses have considerable transmission at 365 nm. However, one must be careful because often lenses and flashes are designed to reduce or block out ultraviolet radiation because in color landscape photography it can impart a bluish tinge to the image. The lens must be checked for UVR blocking coatings; and of course no haze, UV, or Skylight filters should ever be used in reflective luminography.

Focus Shift

Close-up ultraviolet luminography will require an additional compensatory measure—the focus shift. Because visible light and ultraviolet radiation are dispersed or refracted to differing degrees by the elements of the lens, once focused for visible light the lens must be defocused for proper ultraviolet imaging. A general rule would be to defocus in the opposite direction and in a similar amount as for infrared if the lens is so marked. Most lenses have a red dot just to the right of the focusing line to enable the lens to be refocused for infrared photography. Since the ultraviolet spectrum is on the other side of the visible spectrum from infrared, one must usually refocus the lens for UV a similar amount but in the opposite direction. However, the composition and placement of the

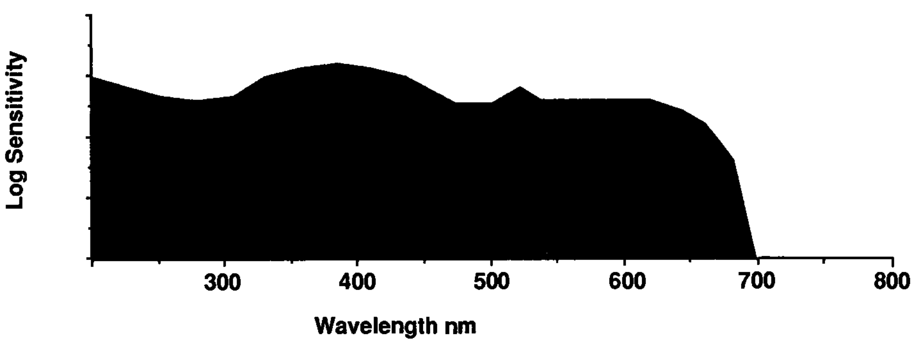

FIG. 8—*Spectral sensitivity of panchromatic film.*

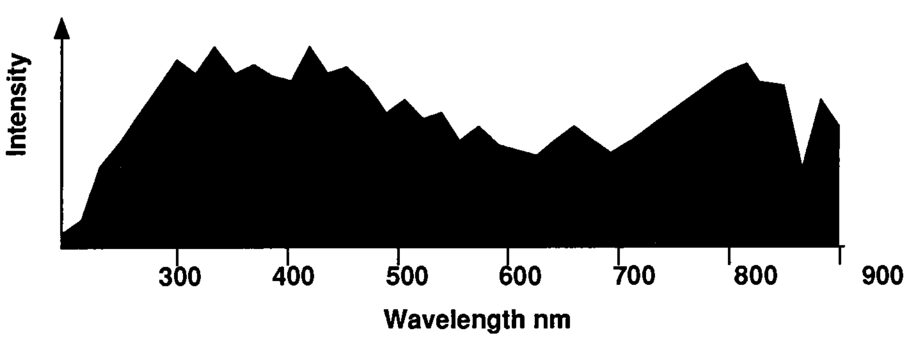

FIG. 9—*Approximate spectral output of the common electronic xenon flash tube.*

elements in a modern compound lens dictate individual experimentation for the best results. Figure 10 points out that different glass compositions result in differing amounts and orientation of refraction at specific wavelengths [*24*]. As in conventional photography, the ability to shoot at large (16 to 22) f-stops yields a greater depth of field and a wider latitude of focus. In other words, each photographic system must be fine tuned for proper exposure indices.

Once you have found the amount of correction necessary for your lens through trial and error, you may decide to scratch a small line on your focus ring as an indicator for later use. Not all lens require correction, and the use of larger amounts of UV illumination will enable the photographer to select an f-stop of 16 or higher to increase the depth of field. The use of more illumination can increase scatter and blur the wound image however.

The Nikon® UV-Micro-Nikkor® 105 mm F/4.5 lens is well suited to all phases of ultraviolet photography. Since it is made of a quartz, not glass, wavelengths as low as 300 nm can pass through it, making it ideal for short UV photography as well. No focus shift is required as the optics are calibrated for UV light. A dedicated band-pass filter is also available. This lens is relatively expensive and only mates to Nikon brand 35 mm SLR cameras.

Film

The choice of proper film is important in the documentation of patterned injuries on human skin. Black and white is usually preferred because a reflective ultraviolet photograph is a noncolor image. Although both black and white as well as color photographic emulsions are equally sensitive to the range of UV wavelengths, color films exposed under only UV radiation, will produce a monochromatic image. Standard color films record UV as blue on the film. In addition, black and white films yield better resolution of detail than color because only a single emulsion layer is present in these films. Color

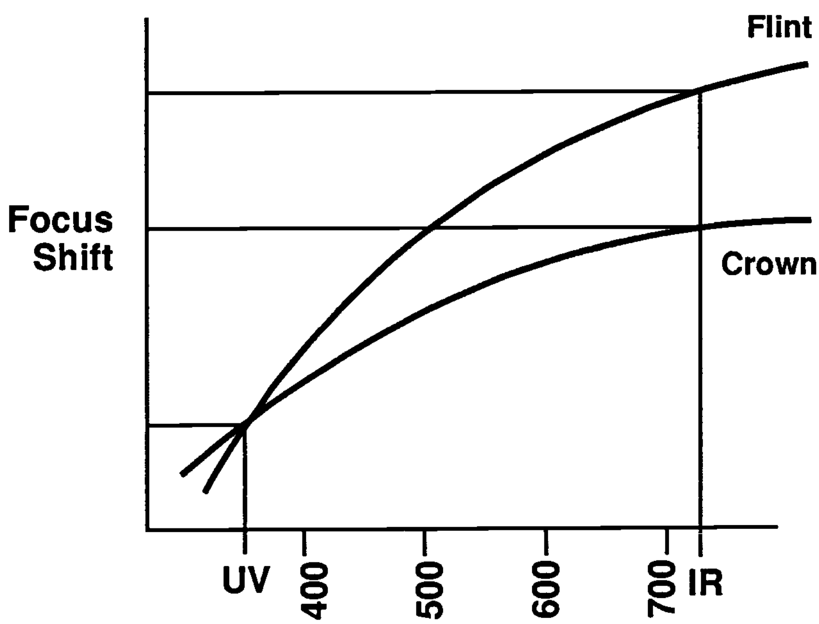

FIG. 10—*Focus shift varies with wavelength and type of lens.*

films are composed of several emulsion layers sandwiched together, one to reproduce red light, one to reproduce green, and one to reproduce blue. There is an additional separate emulsion layer designed to act as a filter to absorb blue wavelengths and UV wavelengths in order to prevent them from penetrating into the red and green emulsions. All photographic emulsions have a natural sensitivity to the blue and UV spectrums, therefore a filter is necessary to prevent spectral degradation. The resulting color emulsion, is much thicker than for black and white. In the case of a thicker emulsion, any light passing through it for projection or photographic printing would be scattered, degrading the detail of the final photograph. Additionally, color emulsions must have three layers of silver grains present to record the tricolor images and therefore produce a "grainier" result. A negative with greatest number of silver grains of the smallest possible size is capable of the greatest degree of resolution.

Under certain circumstances color emulsion films have an advantage over black and white emulsions. Whenever there is a need to show the discoloration or difference in the color of a wound in relationship to surrounding tissue. For example, color photography would be useful in documenting a bruise or other pattern that is present in tissues below the surface of the skin. These types of wounds cannot be recorded using UV reflective photography. The documentation of a tattoo would be another example [*30*].

We prefer to use Kodak T-MAX® 3200 ISO rated at 1600 ISO that can be "push" processed if necessary. Kodak T-MAX® 3200 Professional Film is a continuous tone panchromatic black and white negative film especially useful for dimly lighted or fast action shots. The extremely fine grain of this film allows for high sharpness and high resolving power resulting in excellent quality enlargements. The blue sensitivity of this emulsion is slightly less than other black and white films, enabling a response close to that of the human eye [*15*]. The response of this film drops precipitously beyond the red spectrum; therefore, it is not sensitive to the infrared light wavelengths that can pass by the 18-A filter [*18*].

Lighting

There are three methods of controlling the quality of the light used for in photography [*20*].

1. The use of a band-pass filter placed between the light source and the film.
2. The use of a light source that is rich or deficient in certain wavelengths.
3. The use of a film that is sensitive only to certain wavelengths.

The authors use a combination of these factors to expose reflective ultraviolet photographs.

Many conventional electronic flash units produce large amounts of ultraviolet light when fired. Electronic flash tubes are filled with xenon gas. When ionized, this gas emits a color spectrum that approximates daylight from the ultraviolet range to the infrared range. Many objects, especially fabrics that contain optical brighteners, fluoresce when excited by ultraviolet light producing a bluish tinge which consumers find undesirable in their photographs. Therefore, many manufacturers now apply an ultraviolet absorption coating directly to the flash tube helix or to the protective window of the flash gun, lowering the color temperature by about 500 degrees Kelvin and yielding a slightly warmer photographic result. Although film companies have taken great strides to prevent color film from reacting to ultraviolet radiation, the fluorescent return cannot be blocked in the visible range, therefore these coatings have been applied. Only test exposures can demonstrate for certain that there is no UV-blocking coating on the surface of the flash tube or housing. Newer units are more likely to be coated than older ones [*12*].

The author uses a Sunpack Auto 333 rated at a guide number of 88. The guide number is a measure of the strength of the flash. In order to approximate the guide number if it is unknown, set the flash to 100 ISO and read the suggested f-stop for 10 feet. Multiply that number by ten, the result is the guide number [31]. This formula is:

$$\text{Guide Number (at ISO 100)} = \text{f-stop} \times \text{distance (in feet)} \times 10$$

The guide number can be used to help approximate the position of the flash for the first test photographs. The author's flash with a guide number of 88 is positioned just off the lens face by an adjustable flash mounting bracket that attaches to the filter threads of the lens. This yields flash-to-subject distances of about one foot. The orientation of the flash unit can be adjusted by rotation of the bracket so that light is reflected off the subject at a 45 degree angle from any direction. The angle at which the UV illumination strikes the subject is often critical. The UV image will often appear, peak, and disappear depending on this angle. The authors refer to this phenomena as light painting [32]. A suitable flash bracket can be ordered from Lester A. Dine, Inc. (407) 624-9100 or Adolph Gasser, Inc. (415) 751-0145.

The Kodak Wratten Ultraviolet Filter No.18-A, is made of glass and appears opaque to the human eye. It is a band-pass type filter, allowing only UV and infrared wavelengths to pass through it. Visible or "white" light cannot be transmitted through this filter. This 2 or 3 inch square filter must be used with a filter holder. Since the photographer must compose the photograph without the filter in place in order to see through the lens, the authors have modified Cokin® filter holders for the job. The filter can only be ordered through Kodak Part Services-CES in Rochester, New York (716) 724-7278. The cost is approximately $145.00:

2 inch square, part no. 840447   3 inch square, part no. 840449

Kodak also markets a gelatin filter frame and holder for 75 mm (3 inch) filters.

Frame 75 mm, Cat. No. 148 6638   Holder, Cat. No 148 6661

Method

Because the 18-A filter does not allow visible light to pass, a tripod or focusing bracket must be used. The shot is composed and the camera is aligned to the proper area of the subject. The lens is focused, the focus shift is made if required, the 18-A filter is dropped into place, and the shutter tripped using the proper synchronization for the flash. In some cases multiple flash firings may be necessary to yield sufficient illumination. If ultraviolet lamps are used, long exposure times may be needed.

An accurate scale is always necessary in evidentiary photographs. The ABFO No. 2 Photomacrographic Reference Scale is the ruler of choice in documenting bite marks and other wounds on the skin. Not only is it a reference scale but can be used to compensate for distortion which can result from oblique camera angles [21]. The scale is only available from Lighting Powder Co. (800) 852-0300. As always, at least one photograph must depict the areas covered by the scale in order to rule out the possibility of purposely hidden evidence.

How does one find these "invisible" wounds in order to align the camera and expose the UV photographs? First, examine the suspect or victim in a darkened room with a Wood's Lamp, i.e. a blacklight. Do not look directly into the light. When skin is examined closely under this illumination old wounds or injury patterns may appear. These are weal and erythema reactions, but they most often look like red scratches or bug bites. The Concentrated High Intensity Longwave Lamp D-130, is a 100 watt blacklight lamp that costs approximately $290.00 is available from ODV, Inc. (207) 743-7712. With an ink pen or other marker, draw a bracket widely around any suspicious areas to facilitate accurate positioning with the reflective ultraviolet camera system. Numerous exposures may be required in order to fine tune the technique. Remember, compared to lost evidence, film is cheap. To determine the best position of the flash, the amount and degree of focus shift, and exposure times, run a test roll of film or two and bracket, bracket, bracket! This will assist in fine tuning the camera system and familiarizing the photographer with its operation.

Conclusion

Photographers have long recognized that ultraviolet illumination can alter the final results of their work. Forensic investigators have only recently begun to appreciate the research conducted by pioneering medical and biological photographers. The application of this early work, particularly as it applies to human skin, coupled with new studies in reflective and fluorescent luminography of patterned wounds should prove beneficial to all forensic scientists, not just forensic odontologists.

Kodak Publications of Interest

B-3 Kodak Filters for Scientific and Technical Uses; L-10 Scientific Imaging Products; KW-13 Using Filters; F-32 Kodak T-MAX Professional Films.

Acknowledgments

The authors would like to thank the following departments of the LSU School of Dentistry for assistance in the preparation of the manuscript: Word Processing Department; and Learning Resources, especially Mr. Raymond Calvert for the illustrations.

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