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TECHNICAL NOTE

ANTHROPOLOGY

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Investigation into the Merits of Infrared Imaging in the Investigation of Tattoos Postmortem

ABSTRACT: Infrared imaging has a history of use in the forensic examination of artwork and documents and is investigated here for its wider use in the detection of tattoos on the human body postmortem. Infrared photographic and reflectographic techniques were tested on 18 living individuals, displaying a total of 30 tattoos. It was observed that neither age, sex, age of the tattoo, nor, most significantly, skin color affected the ability to image the tattoos using infrared imaging techniques. Second, a piglet carcass was tattooed and the impact of the decomposition process on the visibility of the tattoos assessed. Changes were recorded for 17 days and decomposition included partial mummification and skin discoloration. Crucially, the discoloration was recorded as greatly affecting the image quality using conventional photography, but was insignificant to the infrared recording of these tattoos. It was concluded that infrared reflectography was beneficial in the investigation into tattoos postmortem.

KEYWORDS: forensic science, body modification, tattoos, infrared, imaging

Identification of the deceased is a primary concern for many forensic practitioners. Various methods are employed in the course of this work, including odontology, DNA profiling, and fingerprinting. In Western societies, there must be "identification beyond all doubt" (1) before death can be certified for both humanitarian and legal reasons. Jensen (2) notes that identification techniques, and their results, can be placed into three brackets: (i) "positive or confirmatory" gained by the matching of unique ante- and postmortem data markers such as fingerprints, DNA, or dental records, (ii) "possible, presumptive, or believed-to-be" when multiple factors are considered, such as skeletal and medical traits, which, when combined, can greatly aid the production of a unique individual profile, or (iii) "exclusion" which can occur when a process of elimination is possible. Features occurring on the skin, such as birth marks, scarring, and tattoos are deemed "secondary" characteristics (bracket ii as stated by Jensen above) in that they may not be unique to any one person. Nonetheless, tattoos in particular seem to show great potential as a means of identification because of their increase in popularity (3). Reasons for the uptake of such body modifications are various (e.g., 3–5), but it may be the case that successful recognition and recording of them may speed up the identification of an individual or may allow one to comment upon their life history. Unfortunately, research investigating the potential of tattoos within the forensic context is very limited, despite their reported usefulness in aiding identification of victims in such cases as the London Paddington train crash of 1999 (6) and the South-east Asian Tsunami of 2004 (7).

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Before any identification can be achieved using tattoos, the initial challenge of the forensic investigator is to locate these body modifications, if present. This can be severely hindered by the discoloration of the skin during the decomposition process. Currently, one suggested method employed to detect and emphasize tattoos on the discolored skin of the deceased is the direct application of hydrogen peroxide solution at 3% concentration. While this method has proven successful (8), there are major flaws in its application in modern forensic investigations—it is a destructive technique, there must be initial reason to suspect a tattoo at a specific location, it is a technique limited by time and resources, and it is also constrained by limited repetitive applications.

Infrared imaging shows promise as a technique to significantly aid the process of identification and is practical both home and abroad. Noninvasive techniques must be investigated and employed where possible in forensic investigations into any manner. This paper examines the possible uses of infrared imaging on decomposed, discolored skin samples.

Infrared and ultraviolet imaging applications have long been employed in medical and forensic science investigations. At the crime scene, ultraviolet light can be used to detect the presence of a variety of substances that fluoresce only under these specific wavelengths, such as blood, semen, and certain drugs (9). Infrared investigation into documents and paintings is employed to aid the detection of forgeries and alterations (10,11). Clinically, ultraviolet photography has been used to study skin pigmentation, including that associated with skin cancers, as well as to aid the detection of bruises and surface damage of soft tissues (12,13). In the same context, infrared photography has been employed to investigate alterations in the venous systems of the breasts throughout pregnancy, as well as the detection of various veins and other venous obstructions (14). Ultraviolet imaging is ideal for detecting surface alterations of the skin, surface structure, and melanin content. Infrared wavelengths, however, are able to image superficial layers of the epidermis and deeper skin structures, as melanin is pervious to wavelengths of this frequency.

Two infrared imaging processes can be adopted. Infrared photography illuminates a subject using all wavelengths of light with a filter attached to the camera allowing only the passing of infrared wavelengths to record the image. Reflectography, however, illuminates the subject only by infrared wavelengths which are retrieved, recorded, and interpreted by the camera itself.

Therefore, the aim of this research is to determine whether infrared wavelengths can image the deeper structures of the skin, unaffected by the skin's melanin content, and show the tattoo ink located between the epidermis and the dermis. Once this is established, the effect of skin discoloration during decomposition on the visibility of tattoos will be investigated.

Materials and Methods

Experiment 1

Eighteen individuals, with a total of 30 tattoos, were photographed using two different techniques. A Nikon D50 digital SLR camera (Jessops, Bath, Somerset) with externally attached infrared filter, accompanied by photography flashes, was used first, followed by a Sony 80x digital video camera (Sony Europe, Ltd.) with inbuilt infrared function. All tattoos were photographed by both methods in both visible light and through their respective infrared techniques for comparison and ease. The population consisted of university staff and students, with ages ranging from 19 to 48 years. Varying skin colors and almost equal numbers of men and women (eight and 10, respectively) were represented.

Experiment 2

A piglet carcass was tattooed so that a full body could be used and observed. The piglet was taken to a local tattoo parlor where the artist tattooed blocks of red, green, and black, each accompanied by line work in the form of the words "red," "green," and "black." An adjacent area of skin was left blank to act as a comparative control in this decomposition study. The colors were chosen for the following reasons; red is a common color in tattoos, is photo-sensitive and difficult to remove by laser, and has also been seen in the majority of reported dermatological reaction cases; green is also common, but is also notoriously difficult to remove through laser surgery; black is by far the most commonly used ink—alone, as an outliner, and in shading of all designs. The comparison of line and block work would enable the study to test the ability for infrared to record intricate as well as bold designs. Appropriate measures were taken to ensure sterility of the tattooing environment both before and after the piglet's presence. As a consequence, the viscera of the piglet were removed prior to tattooing. To minimize the effect of this on the subsequent decomposition process, replacement viscera were added following application of the tattoos.

This study adopted a semi-actualistic approach. Once tattooed, the piglet was positioned on a raised surface and was covered by two layers of wire mesh (¼ and ½ inch squared, respectively) to deter rodent activity. Flies were deterred by loosely covering the whole structure with muslin—a tight enough weave to deter insects, but loose enough not to unduly influence the microenvironment. Color and infrared images were captured using the Sony 80x digital video camera, mounted constantly on a tripod. Photographs were taken daily, for a period of 17 days, between 16:30 and 17:30 in order that lighting conditions were as consistent as possible. Weather and temperature were recorded simultaneously, by observation and thermometer, as well as through comparison with local weather records.

Results and Discussion

Experiment 1

The results from the digital SLR camera, when used in its normal color capacity, showed the tattoos, the surrounding skin, and its texture in great detail. While overexposure of images was avoided in most instances, where the skin did appear "shiny," detracting from or interfering with the visibility of the tattoo, the flashes were re-angled and the photograph retaken. Detail of the skin texture, color, blemishes and the tattoos' colors and details were recorded in high quality.

The positioning of the infrared filter (attached to the lens of the camera) blocked the photographer's view of the subject through the camera's viewfinder. The picture, therefore, had to be set up before the filter was attached, and the focus was estimated. This resulted in many blurred images and the repetition of many shots, until useable images were achieved. Each infrared image appeared very dark, with little subject matter, and so the computer's imaging software was used to lighten and sharpen each image, though many still appeared grainy, even after this manipulation. Details of the tattoos and the skin were of far less quality than was seen in the color images.

Many of the volunteers sported solely black tattoos, although those with color showed red more frequently than any other color. However, while the infrared images appear visually in gray tones, all colors are represented in shades of gray, except for red that is sometimes undetectable (Fig. 1*a,b*). Previous medical photographic research, conducted in 1952 by Massopust (15), saw red pigment appearing stark white, not apparently invisible. One explanation for

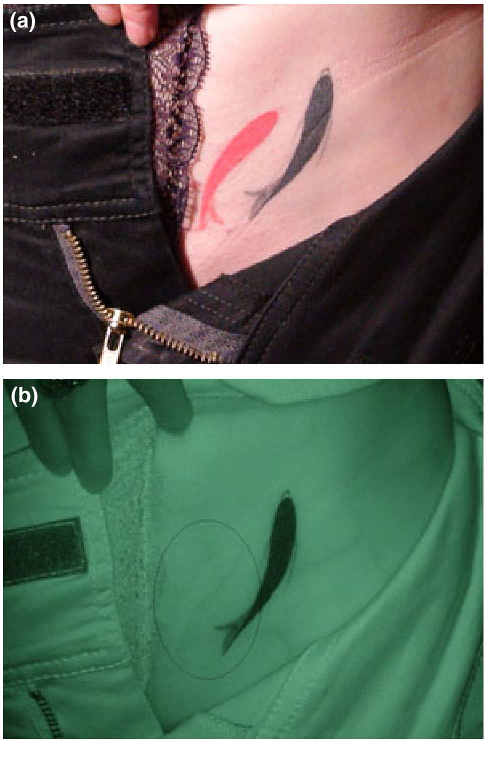

FIG. 1—*(a) Caucasian woman, age 23. (b) Showing "invisibility" of red tattoo in infrared image.*

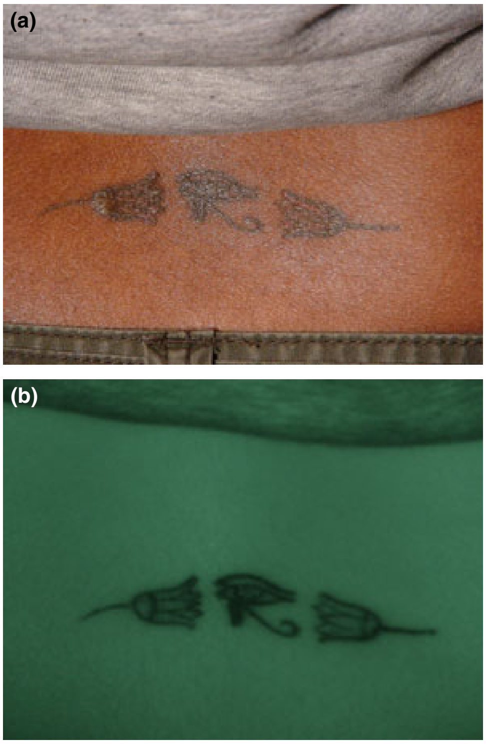

FIG. 2—*(a) Black woman, age 24. (b) Insignificance of darker skin tones to visibility of tattoo in infrared image.*

this may be that whereas Massopust studied the pigment red cinnabar (a mercuric sulfide-based pigment (16)), the red tattoos recorded here were all post-1990 and are more than likely, therefore, to have been napthol red, in accordance with the "phasing out" within the industry of toxic metal–based pigments (17). However, further investigation into the ingredients of tattoo inks and infrared's sensitivity and representation of different pigments should be undertaken before conclusions are drawn.

The variable anticipated to have the most influence on the results was skin color, owing to the contrast between tattoo and skin seen in normal light being less marked in darker skins than lighter skins. However, the results of this experiment show that images taken through an infrared filter are not affected by the skin's melanin content (Fig. 2*a,b*). Melanin is sensitive and responsive to ultraviolet wavelengths while exponentially insensitive to all other wavelengths through to the infrared spectrum (18), and so it is unsurprising that the contrast between tattoo pigment and skin color is more pronounced in infrared photography than in color photography in natural light. Natural light and conventional photographic flashes contain ultraviolet wavelengths that will have been blocked by the infrared filter. It also appears that skin surface blemishes such as pimples and, in one case, a minor burn are not shown by infrared photography (Fig. 3*a,b*). Whether this is because of their physiological position in the epidermis or their pink-red coloration is unclear.

The results from the video camera were in concurrence with those detailed above. The apparent disappearance of red pigment, the eradication of skin surface blemishes (Fig. 3*a,b*), and the inconsequentiality of skin color or pigment unevenness were all observed using the infrared mode of the video camera. However, the infrared images from the video camera were much clearer, and the details of the tattoos were represented as clearly in infrared mode as they were in color, with detail and clarity of image as impressive as the still camera. The ease of use of the video camera (the ability to

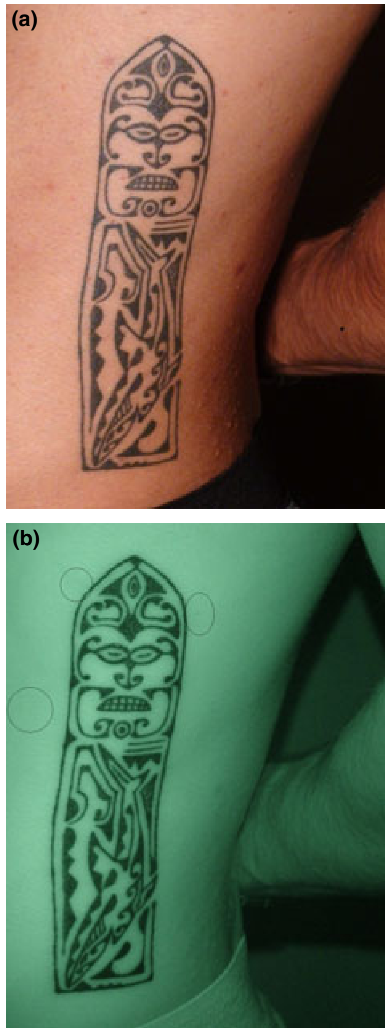

FIG. 3—*(a) Mediterranean man, age 28. (b) Showing "disappearance" of surface skin blemishes in infrared image.*

view the image captured in infrared, the versatility of the positioning and movement of the video camera, and the change from normal to infrared at the flick of a switch) as well as its excellent quality of recording images in both modes emphasized its overall superiority to the still camera technique for investigations of this nature. It was decided, therefore, that experiment 2 should be carried out using only the Sony 80x video camera as the still camera's infrared images were of overall inferior quality and its color images of similar quality to the video camera's, thus rendering it redundant in this study.

The availability of a larger volunteer group would have been of benefit for studying the effect of skin color, age, and application techniques on the visibility of tattoos. Also, all but one were relatively small in size, with limited colors represented, so a larger volunteer group may also have allowed for more detailed study of the behavior of different colors under infrared investigation.

Experiment 2

Pigs are often used as human substitutes within forensic anthropology research because of their comparable fat/muscle body ratio, but for the sake of this study, a piglet was preferential not only for its more practical size, but also its skin most closely emulates

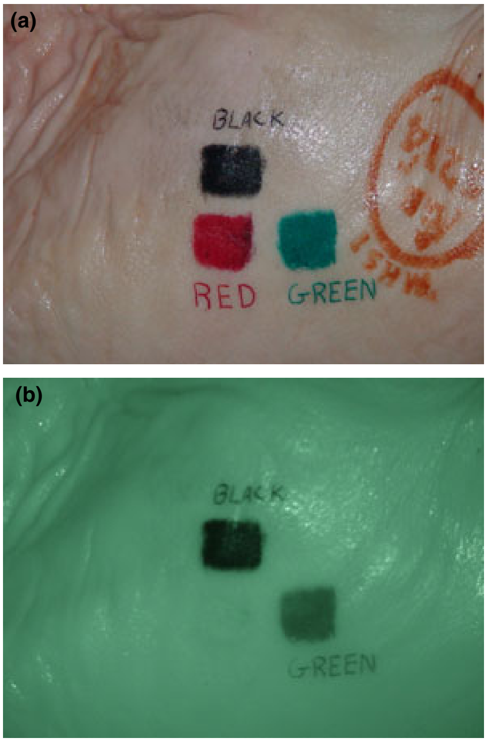

FIG. 4—*(a) Piglet on day 1. (b) Piglet on day 1 showing "disappearance" of red tattoo in infrared image.*

human skin owing to its anatomical structure and lack of formed bristles.

Table 1 displays the time of photograph, temperature and weather conditions, and observations made at the time of image capture. Figure 4*a,b* shows the visible light and infrared image of the freshly tattooed piglet's skin. Negligible bacterial action was observed, and the process of decomposition was dictated almost entirely by larva infestation, despite the measures taken to prevent this, and later through desiccation.

As the mummification progressed, it seemed that the black ink had "run" permeating the surrounding skin, resulting in a blackened appearance and less definition of the word "BLACK" when photographed under normal light in color (Fig. 5*a*). However, the tattoo appears much clearer and better defined when viewed in the corresponding infrared image (Fig. 5*b*), and the surrounding black discoloration is muted. The skin's own discoloration owing to mummification is pronounced when viewed and compared in the color photographs (Figs 4*a* and 5*a*) but is not observed so extensively in the infrared images (Figs 4*b* and 5*b*).

The presence of maggots was prolific throughout this study, despite the preventative measures put in place (namely the double layer of muslin). Fly eggs were observed on day 2. These eggs and maggots were removed until day 7 when the numbers of larvae were extensive.

Conclusion

The aim of this experiment was to assess the suitability and sensitivity of infrared imaging to record modern tattoos on skin. Infrared reflectography was useful in visualizing green and black tattoo colors; however, red ink was less successfully visualized. The red pigment can be detected on some images, and computer manipulation may help with this. Green and black pigments are very responsive

TABLE 1—*Record of daily observations and weather conditions.*

Day	Time	Weather	Observations
1	17:00	Dry 17°C	Piglet's skin pale pink, clammy in appearance, finer texture results in clearer image of tattoos than seen in meat. Through infrared "RED" visible in white tones. Blood around head present from transporting the piglet upside down.
2	16:50	Dry 18°C	Orange tinge to skin already apparent. Skin less shiny as a result. Tattoos clearly visible with no discernable difference from previous day.
3	16:45	Patchy rain 16°C	Fluid seepage more extensive. Wire mesh used to discourage rodent activity too close to piglet resulting in marked depressions on skin. Reformed to avoid repeated occurrence. No change to tattoos evident.
4	16:55	Dry 19°C	Fly eggs present in fluid, majority removed painstakingly using forceps and scalpel, some remained unavoidably. Tattoos appear darker in color themselves.
5	17:00	Dry 21°C	Orange discoloration much more acute with clear areas of epidermal loss visible. Larvae of small size among unhatched eggs present. Again, majority removed.
6	16:50	Patchy rain 17°C	More fluid present. Progression in alignment with previous 2 days. Tattoos showing minor progress of decomposition.
7	16:45	Dry 20°C	Head, neck, and shoulder showing obvious bloating area and more fluid loss. Larva presence more extensive than before, no removal attempted. Epidermal loss in hip and groin area more widespread. "RED" clear in infrared close-up in white tones, though distant still invisible.
8	17:05	Dry 19°C	Larvae prevalent in stomach cavity. Excretory fluids visible and pungent. Head also a focal point for maggot activity. Rear third of piglet continues to show epidermal loss. Tattoos showing stable condition, little change.
9	17:00	Dry 18°C	Stomach cavity still main focus of larva activity, along with head now showing wider neck aperture. Orange discoloration becoming pinker and more noticeable. Again, tattoos showing no change in themselves, but appearing fainter.
10	16:55	Patchy rain 19°C	Lighter image at time of photography. Larvae proliferate still in area of stomach, neck, and now migrated to anal region. Mouth more open than previously as a result of larva action. Tattoos show little change, though fly eggs laid on tattooed area.
11	16:50	Dry 21°C	Tattoos now main focus for larva activity. Photographs taken with larvae *in situ* then moved carefully (avoiding contact with skin) to unveil effects this may have had on the skin. Epidermal loss observed.
12	17:15	Dry 20°C	Heat above head and neck noted prior to unwrapping—main area for larva activity. Area of skin below "BLACK" showing severe discoloration, possibly resulting from ink spread? Detail clearly seen still through infrared photography though and skin discoloration eradicated. Skin appears drier, more "tan" colored indicating process of mummification.
13	16:55	Patchy rain 18°C	Progression in accordance with previous days. "BLACK" more disturbed, though still showing clearer under infrared imaging. "RED" lost even in infrared images. Larvae still active on the head-eyes now lost.

TABLE 1—*Continued.*

Day	Time	Weather	Observations
14	17:00	Patchy rain 19°C	Larvae extensive. Area underneath "BLACK" showing deeper discoloration, writing indiscernible in color image, but still clear in infrared image. Leathery appearance of skin seen particularly on front two-thirds of carcass. Tattoos appear duller in their coloring.
15	16:45	Patchy rain 19°C	Adipocere positioned posterior to the ear suddenly visible. Mummified nature of tattooed area more clear than previously. Mummified nature of head very clear, still focus of much larva activity. "GREEN" and "BLACK" detail still very clear through infrared.
16	16:50	Dry 21°C	Overall "shriveled" appearance very marked. "RED" apparent again under infrared. Skin discoloration still eludes the infrared images. Mummified nature of tattooed skin has halted decay of area. Mummified areas of skin darkening in color still. Mummification of other areas following. Adipocere behind the ear has spread. Larvae primarily focused upon neck and groin.
17	17:10	Dry 19°C	Larvae now almost entirely covering rear portion of carcass. Mummified skin shriveled with no underlying soft tissue remaining. Tattoos show little change from last 6 days. Red letters are not as clear against background as previously, though no clearer on infrared images. "BLACK" still lost in color images, but still visible in infrared. Block colors remained obvious throughout. Unchanged condition of mummified tattooed skin for 6 days, decided to finish the experiment as results regarding skin discoloration and infrared recording collected.

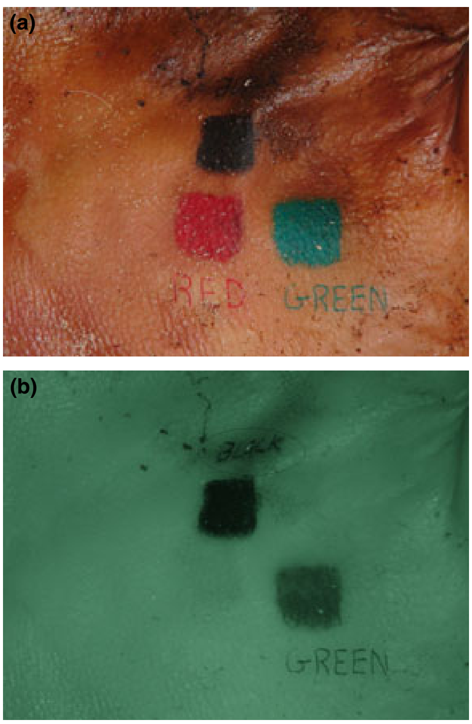

FIG. 5—*(a) Piglet on day 15, showing mummification skin discoloration. (b) Piglet on day 15 showing clarity of the word "BLACK" in the infrared image, and less distinction between skin color and tattoos.*

to infrared photography, and their clarity is emphasized through recording at this wavelength. The block colors show up clearly throughout the experiment, but it is the detail of each word that shows particular promise for this photographic technique.

The long history of infrared photography and the technological development it has enjoyed make it an almost perfect technique for the investigation into victim identity worldwide. Tattoos have received little focus within the field of human identification, despite their popularity and increased occurrence. This investigation has demonstrated, to some extent, their usefulness in the identification of individuals, though much more work is needed into the tattoos themselves and the implications of laser removal for infrared investigation.

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