CASE REPORT

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Digital Enhancement of Sub-Quality Bitemark Photographs

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ABSTRACT: Digital enhancement software was used to enhance bitemark photographs. This enhancement technique improved the resolution of the bitemark images. *Lucis* was the software program utilized in this study and case applications. First, this technique was applied on known bitemark images to evaluate the potential effectiveness of this digital enhancement method. Subsequently, *Lucis* was utilized on two separate unsolved cases involving enhancement of bitemark evidence. One case involved a severely beaten infant with a bitemark on the upper thigh. The second case involves a bitemark observed on the breast of a female sexual assault strangulation victim. In both cases, bitemark images were significantly improved after digital enhancement.

KEYWORDS: forensic science, forensic odontology, bitemark, digital enhancement, computerized image enhancement, *Lucis*

Only for the past ten years has the use of digital enhancement techniques been embraced for improving poor quality and problematic images associated with forensic evidence. Some earlier successes were limited to the enhancement of fingerprint images. In 1990, a digital enhancement process helped resolve a bloody fingerprint on a pillowcase (1). Recently, digital enhancement is being applied to a greater variety of forensic image needs, e.g., shoeprint, footprint, tire mark, pattern evidence, and bitemark evidence.

In recent years, several researchers have evaluated computer-based programs for use in enhancement of bitemark and other pattern evidence. McGivney and Barsley found that computers can assist in displaying bitemark graphics, calculating the geometric center (centroid) of the tooth or tooth marking, storing information associated with the bitemark in a database, performing necessary calculations, and ranking the likely matches between bitemarks and suspected dentitions (2). In 1998, Sweet et al. utilized a computer-based technique for the production of life-sized bite mark comparison overlays (3). Naru and Dykes reported success in producing a noninteractive method of bitemark comparison using a digital image correlation technique (4).

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Sweet and Bowers conducted a comparison of five common methods to record characteristics of the teeth and to generate overlays. Of the evaluated methods—computer-based, radiographic, xerographic hand-traced from dental casts, and hand-traced from wax impressions—computer-based was reported to be the superior choice mainly due to accuracy (5). Each of the above referenced authors stated that computer-based methods were advantageous in that they helped reduce the degree of subjectivity associated with bitemark comparisons.

Lucis, the software program used in this study, was a differential hysteresis methods (*Lucis* is a patented trademark of Image Content Technology LLC, 185 Main St., Suite 211, New Britain, CT 06051). After successfully testing *Lucis* on a control study of known bite marks, the authors applied this technique in two cases to evaluate the validity and usefulness of *Lucis* for bitemark comparisons. The results of these experiments and the limitations of this technique are presented in this paper.

Enhancement of bitemark photographs was achieved by the use of a commercially available digital enhancement software product. *Lucis* is a Differential Hysteresis Processing technique that has several attributes very amenable for forensic casework. While this specific software program was developed only a few years ago, it has been extensively tested and applied to a variety of applications. Applications include enhancement of medical images, microscopy, manufacturing process control, and general photography and document processing. Recently, it has emerged as a valuable tool for forensic applications.

Generally, *Lucis* enhances digital images by its ability to identify and work with the numerous layers of contrast found within an image. Based on a patented algorithm called Differential Hysteresis Processing, *Lucis* image-processing software extracts and displays contrast patterns based on variations in luminance. While the human eye can only differentiate 32 levels of contrast, images actually contain hundreds if not thousands of levels of contrast. *Lucis* shifts the relative emphasis of contrast in the image, allowing users to see more. The result is an artifact-free image with clarity far beyond that achieved with any exiting image processing method (6).

Lucis analyzes differences in contrast, as detected by intensity differences between neighboring pixels. *Lucis* enhances contrast variations falling within a selected range of contrast differences, and diminishes contrast variations falling outside of the range. A very narrow range of contrast variations can be selected, and will result in enhancing fine contrast variations in the original image.

Utilizing theses ranges, the ability to perceive image detail is greatly increased. By further selecting a contrast range that emphasizes mid-range contrast layers the image is smoothed in appearance. This approach can suppress interfering fine background details and thereby visually enhance the critical portions of the original image. These two functions can be used in tandem to produce excellent results with many different types of images encountered in forensic casework.

Methods

Since the original image was not in a digital format, the photograph had to be converted to a digital image with a flatbed scanner. An Agfa Arcus II 12-bit scanner was used as it has the option of eliminating any enhancement functions associated with a vast majority of flat bed scanners. Any type of image enhancement performed by a peripheral piece of equipment such as a scanner or printer will remove certain portions of the image, thus limiting the optimal enhancement features of an enhancement program like *Lucis.*

Next, the digital image was processed on a computer loaded with *Lucis.* The minimum hardware specifications are as follows.

- 300 MHz Pentium II processor with 512K cache
- 64MB of RAM or more
- 6.4GB Hard Drive
- Video card with 8MB of SDRAM or VRAM
- Microsoft Windows 95, Windows 98 or Windows NT 3.5 or later
- High quality, large monitor set to High Color (16-bit) or higher

Once the image is opened up within the *Lucis* program the enhancement process can begin. The preview mode of *Lucis* allows the examiner to highlight the specific area of the photograph that needs enhancement. While in the preview mode, the user selects a range of contrast variances of interest as defined by a big and small cursor setting. Then Lucis compares each pixel in the image to every other pixel along hundreds of radial lines.

Contrast variations within the selected range are enhanced while contrast variations outside the range are diminished. Decreasing the upper end of the range, or big cursor setting, increases image detail. This is because image detail is represented by small changes in contrast, so the narrower the upper end of the range the more image detail is revealed. Increasing the lower end of the range, or small cursor setting, smooths the image because contrast variations smaller than the small cursor are diminished. For example, if the big cursor is set to 41 and the small cursor is set to 3, contrast variations greater than 41 and less than 3 are diminished, and contrast variations equal or greater than 3 and less than or equal to 41 are enhanced.

The large cursor setting was adjusted to select the range of contrast layers that provided the most image detail associated with the actual bitemark. Then, the lower cursor setting was adjusted to smooth the textured appearance associated with the selected image. Once the optimal settings were located, as determined by visual observations during the preview enhancement mode, the entire photograph was subjected to the selected cursor settings. These cursor settings represent the selected range of contrast layers that provide the most image detail and best contrast and clarity. Typically in scientific imaging applications only the big cursor is varied to reveal image detail. The smoothing or small cursor is use to remove noise or small features from an image, so contrast patterns in an image can be more clearly seen.

This image was then printed and stored on a Zip disc for future reference. It should be noted that if the cursor settings are recorded the exact enhancement process can be duplicated at a later date or on another computer equipped to perform *Lucis* image processing.

At this point the examiner can print a hard copy of the enhanced image. As with the scanner, the proper type of high-end, 600 to 1200 dpi printer must be used to prevent the loss of image data by printer enhancement functions.

Results

Evaluation on Known Bitemark

A set of known bitemarks was prepared by firmly pressing a dental plaster model into the skin of the forearm for approximately one minute. A bitemark pattern was visible and was photographed with a Polaroid Spectra 1:1 camera (Fig. 1). The resulting Polaroid pho-

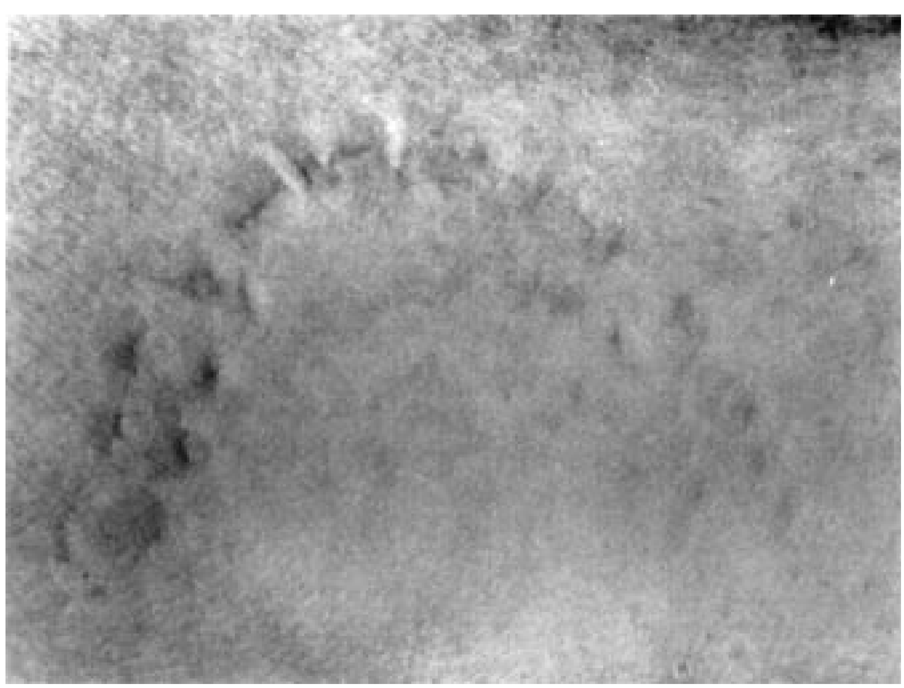

FIG. 1—*A 1:1 Polaroid photograph of a known bite mark prepared by pressing a dental plaster model into skin on the forearm.*

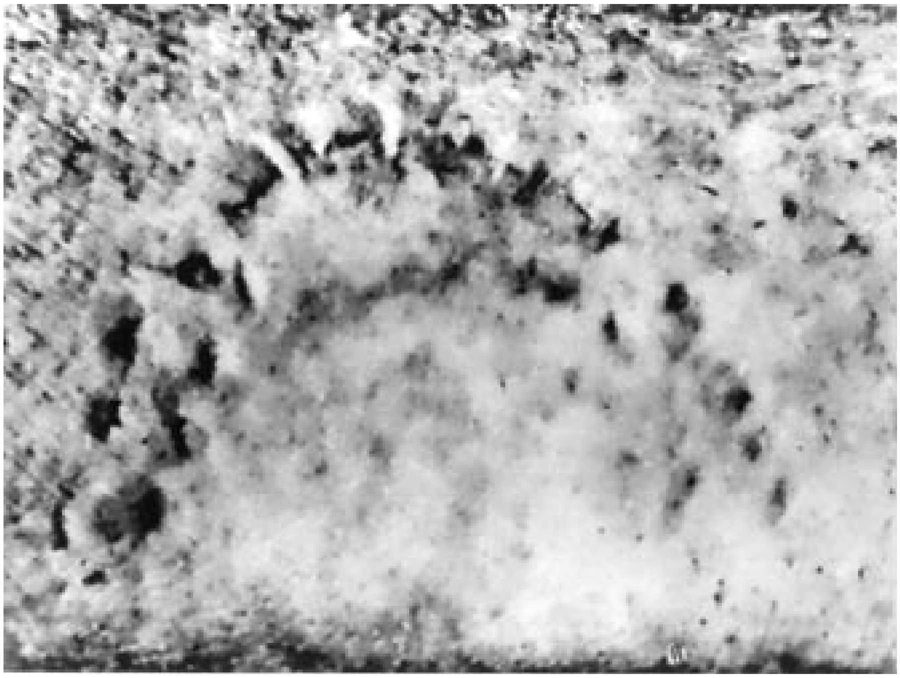

FIG. 2—*The Polaroid bitemark photograph as depicted in Fig. 1 after enhancement with* Lucis.

tograph was transformed into a digital image with a flatbed scanner. This digital image was then enhanced with the *Lucis* program. A variety of different cursor settings were experimented until the enhanced image provided the greatest degree of clear identifiable image detail (Fig. 2).

No distortions or artifacts were observed in the resulting enhanced image, and this enhanced image was much easier to evaluate for bitemark comparison experiments.

Applications of Casework

Case One

This case involved a female victim of sexual assault and homicide. The cause of death was determined to be manual strangulation. Patterns consistent with bitemarks were observed on both breasts, surrounding the nipples. Although a suspect was developed, other than the potential bitemark evidence there was no substantial physical evidence or investigative leads. The case clearly was in the cold case status after having gone unsolved for seven years. The only available photograph of the bitemark was of poor quality and the necessary contrast and resolution were not present (Fig. 3). In addition, the scale was slightly out of plane. *Lucis* is not able to correct for this factor, and the odontologist must determine if the photograph is suitable for comparison. Despite the scale being slightly out of plane, it was determined to be of suitable quality to conduct a comparison to the bitemark in question.

After the color photograph was scanned and transferred to a digital image the area surrounding the nipple, containing at least two distinct bitemarks was highlighted. Experimentation with a broad range of different *Lucis* cursor settings resulted in an excellent enhanced image with a *Lucis* setting of Big cursor—51, Small cursor—11 (Fig. 4).

The enhanced image was printed with a color printer. The enhanced image was of suitable quality for use in bitemark comparison with a known dental plaster model of the suspect. There were

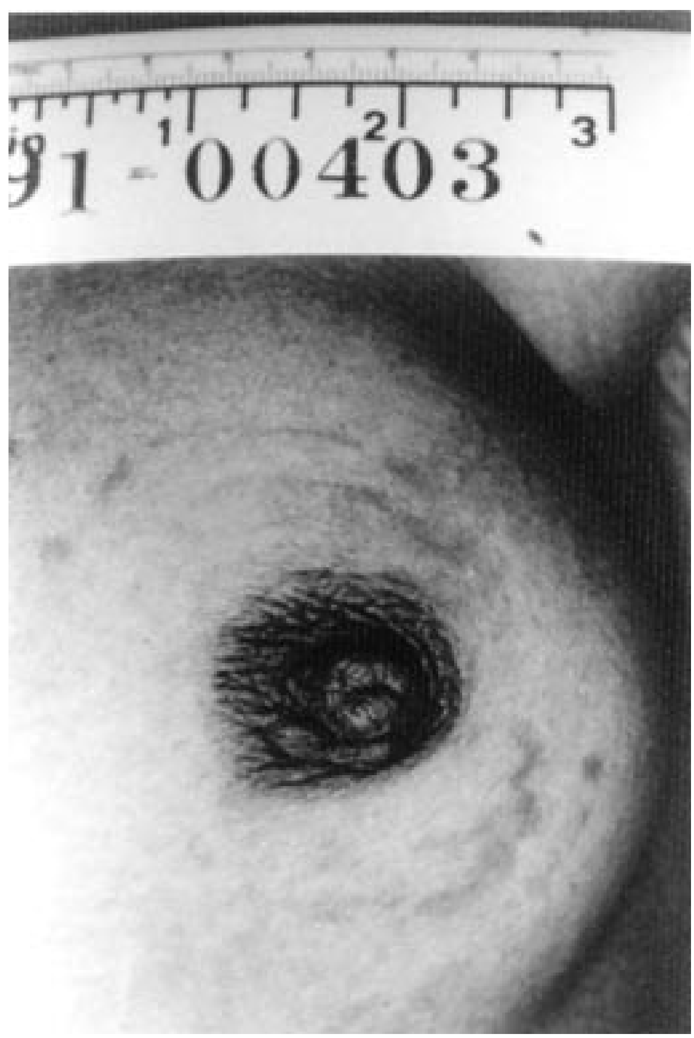

FIG. 3—*Close-up photograph of apparent bitemark on the front left side of breast area of victim.*

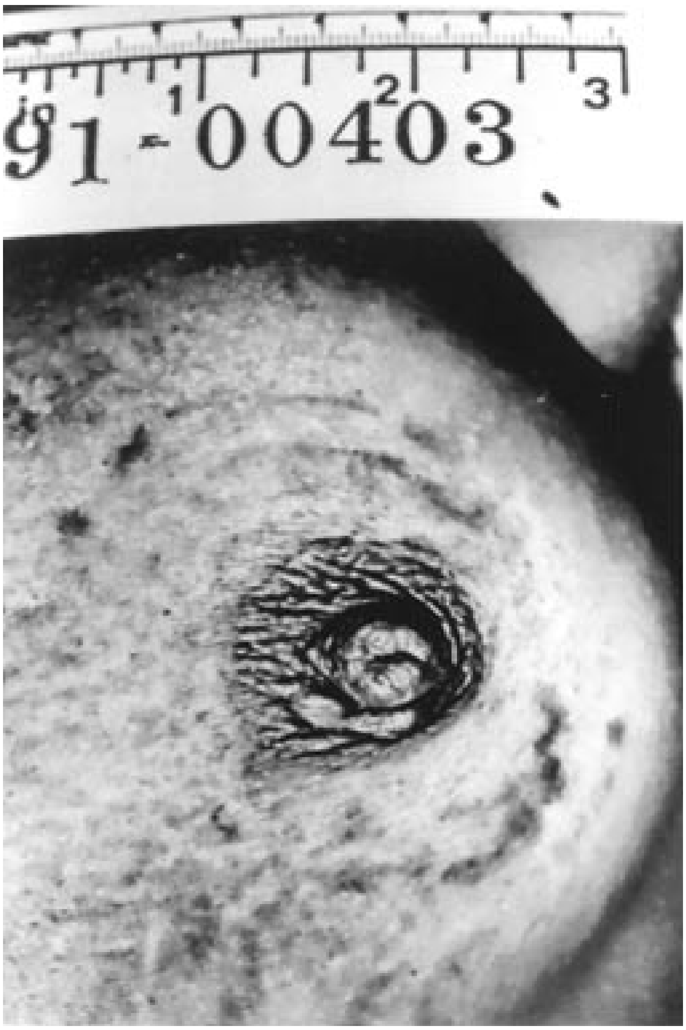

FIG. 4—*Image obtained by enhancing photograph, Fig. 3, with* Lucis.

sufficient characteristics in the enhanced bitemark image to make a finding that the bitemark was consistent with the dental plaster model of the suspect.

Case Two

A 9-month-old infant was brought to a hospital emergency room in critical condition. Examination of the infant revealed a fractured skull. During further examination of the infant a circular bruising pattern was observed on the infant's upper thigh. Aware that this injury may be a bitemark, hospital personnel took a color Polaroid photograph of the alleged bitemark. Unfortunately, they did not include a scale in this Polaroid. The Polaroid photograph was poor quality, with a portion of the bitemark area obscured by a shadow in that portion of the photograph (Fig. 5). The infant recovered from the sustained injuries, but there was great concern in that the father was the prime suspect. There was no other physical evidence, or statements that associated the father or any other suspect with the abuse.

After the color photograph was scanned and transferred to a digital image the circular bruise, consistent with a bitemark, was highlighted. The highlighted area contained portions of the bitemark that appeared properly exposed and lighted as well hidden in a visible shadow area.

Experimentation with a broad range of different *Lucis* cursor settings resulted in an excellent enhanced image with a *Lucis* setting of Big cursor—57, Small cursor—13 (Fig. 6). This enhanced image was printed with a color printer. The enhanced image was found to be of suitable quality for use in bitemark comparison with a known

FIG. 5—*Polaroid photograph showing a suspected bitemark on the upper thigh of an infant.*

FIG. 6—*Image obtained by enhancing photograph, Fig. 5, with* Lucis.

dental impression of the suspect. Sufficient characteristics existed in the enhanced bitemark image to make a finding that the bitemark was consistent with the dental plaster model of the suspect.

Discussion

This method has several advantages that make it an acceptable digital enhancement technique for use on images of forensic significance. First, it is relatively easy to use and does not require any substantial computer or program training before it can be reliably used in casework. Second, unlike many of the alternative digital imaging programs or methods *Lucis* can enhance a wide variety of image problems, including a mixture of problems in one image. For example, this program could effectively enhance an image that contained a bright reflective portion as well as a dark shadowed segment. Further, it works equally well as on overexposed or underexposed photographic images. Third, the results are easy to duplicate and record, therefore, the actual image enhancement process can be repeated in a courtroom or for other interested parties. Fourth, the process is based on a mathematical algorithm that can accurately predict the few potential artifact areas. In the vast majority of applications to common forensic images there will be no artifact production. However, under extreme situations were it is possible to create an artifact they can be mathematically predicted and accounted for, it would eliminate the possibility of misinterpretation or representation. Finally, this procedure can be defined as an image enhancement, not an image restoration method (7).

Some bitemark photographs submitted to an odontologist for examination do not reveal sufficient characteristics or points of identification for a conclusive determination. Unfortunately, in many cases there was sufficient detail in the original bitemark for comparison, however, the bitemark was not properly photographed to capture the necessary image detail and contrast. Digital imaging offers the odontologist an additional tool that may improve the percentage of bitemark photographs that are of suitable quality for comparison.

This particular imaging software proved to be a valuable tool for bitemark examination and likely a good resource for enhancing other types of forensic images. Not only did *Lucis* provide excellent results but also an examiner with minimal computer experience or knowledge could utilize it. The entire enhancement process took approximately 1 h for each image.

In this study, the best image enhancement settings were determined by a systematic selection of available cursor settings. Through experimentation on photographs of known bitemarks it was determined that a big cursor setting in the range of 51 to 57 best increased image detail associated with bitemarks on skin. Moreover, a small cursor setting in the 11 to 13 range diminished sufficient contrast variations to smooth the image and aid in examination and comparison. These cursor settings were determined to be the best range of settings for the enhancement of these bitemark images in the opinion of the forensic odontologist who performed the subsequent bitemark comparison of the enhanced image with a known dental plaster model of the suspect. It is possible that different odontologist may select slightly different cursor ranges. In addition, different surfaces may require slightly different settings to best enhance a specific image. The subjectivity of the cursor settings does not diminish the reliability of this method to enhance bitemark images.

As modeled and discussed in a technical paper by *Lucis,* the program will not result in artifact creation when utilized in the capacity and on the type of images as provided in these bitemark cases, (7). Further, unlike some commercially available digital enhancement programs *Lucis* was capable of handling an image with a variety of different problems. For example, with the bitemark of the infant case, the entire photograph was capable of being processed in one function despite the significantly brighter and shadowed regions within the same photograph.

There are upward limitations associated with digital enhancement, primarily due to the amount of available information in a particular image. Regardless of how efficient an enhancing program is proven to be it can only work with the available image data. Any program that restores lost images should be avoided for any forensic applications.

Therefore, every effort should be made to obtain the best quality original image, and then assure that the image data is not inadvertently lost during the various phases of image processing. In most cases a properly exposed, 1:1 color Polaroid photograph will contain sufficient image detail. Caution must be exercised to select the proper scanning and printing equipment so that image data is not destroyed during normal internal enhancement functions associated with most printers and scanners. Certain scanners and printers can be programmed to minimize loss of image data. The manufacturer of your equipment can be contacted for details as how to adjust your printers and scanners to minimize image loss.

Conclusion

In this study, digital enhancement of bitemark images was found to be a valuable tool for an odontologist. This particular digital image enhancement program was capable of improving the image detail and contrast of a poorly photographed bitemark to the extent that a qualified odontologist was capable of making a successful comparison of the enhanced photograph with the dental plaster model of the suspect. While there is no substitute for a properly exposed and illuminated, 1:1 color photograph of a bitemark, digital enhancement offers an opportunity to conduct a meaningful bitemark comparison when the only evidence is a poor quality photograph.

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