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Optical and Digital Techniques for Enhancing Radiographic Anatomy for Identification of Human Remains

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ABSTRACT: Out of a total of more than 300 radiographic identifications made by one of us (JJF), there were 11 cases in which radiologic adjuncts were used because the antemortem radiographs were either miniaturized or because anatomical landmarks could not be clearly discerned. The techniques used included slide projection (two cases), photographic enlargement and enhancement (two cases), digitization (three cases), and digitization with computer enhancement (three cases), commercial digitization (one case). In a 12th case, where identification was made by comparison of antemortem and postmortem film X-rays, the films were digitized as a further evaluation of a commercial system. This is the first reported use of these techniques.

KEYWORDS: forensic science, forensic pathology, forensic anthropology, forensic dentistry, X-ray identification, radiologic identification, identification, forensic radiology, digitization, computer image processing

Identification of unknown deceased individuals is important for humanitarian reasons, estate purposes, and criminal investigation. In 1915, 10 years after the discovery of X-rays by Roentgen, Schuller first suggested using X-rays for identification. Culbert and Law published the first radiologic identification in 1927 (1), and the first use of X-ray identification in a mass disaster was by A. C. Singleton in 1949 (2). Radiologic identification is gaining popularity as a means of identification, and reports of its use are increasing in frequency (3–12).

The standard identification procedure is to compare anatomical landmarks of the antemortem radiographs with those of the postmortem radiographs. However, in some cases, anatomical landmarks are not clearly seen. For example, the pedicles, transverse processes, and spinous processes of thoracic vertebrae are often not visible in underpenetrated chest radiographs. In other cases, the antemortem film may have been stored as a miniaturized radiograph such as a 35-mm slide/transparency, a photofluorograph, or a preliminary scanogram of computed tomography (CT).

The photofluorographic system commonly used in mass tuberculosis screening projects in the 1950s and 1960s and screening of military draftees, is still occasionally used. The technique involves exposing 100- by 100-mm (4- by 4-in.) film to the X-ray image on a fluorescent screen, producing a miniaturized radiograph.

The scanogram image is produced by moving the patient through the gantry of the scanner. An image similar to a standard X-ray is produced but measures about 6- by 7-cm (2.5 by 3 in.). The scanogram is an X-ray template used for the visual selection of the levels at which CT cross sectional scans of the anatomy are to be made.

The standardization of positioning for various radiographic examinations allows postmortem radiographs to be taken in a position similar to an anticipated antemortem film, even though the antemortem film is not available at the time of radiographing. Although slight degrees of obliquity usually do not interfere with the identification process, marked rotation often interferes with the comparison of antemortem and postmortem radiographs. Rarely, the postmortem skeletal specimen may have to be positioned and radiographed exactly as the antemortem skeletal image. Positioning in the antemortem radiograph may be exactly duplicated by using the shadow positioning technique described by Fitzpatrick and Macaluso in 1985 (13).

When the antemortem film is a 35-mm slide or other miniaturized radiograph, or the skeletal detail is imperceptible because of underpenetration, reliable identification is difficult. In such cases, adjunct imaging techniques of enlargement and computer enhancement can be used to overcome these deficiencies.

We have successfully used slide projection, photographic enlargement with photographic contrast enhancement, digitization alone, and digitization with computer enhancement to visualize faint and imperceptible landmarks. When the antemortem radiograph image is a 35-mm slide, the image is projected and compared with the postmortem radiographic image seen on the viewbox.

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Photographic enlargement can be combined with modified developing times and temperatures, to increase image contrast with the production of both positive and negative images. With these techniques, imperceptible skeletal details, such as transverse process of the thoracic spine, can be elucidated for identification purposes.

With the advent of laser scanning, radiographs can be digitized rapidly at a high level of resolution. The image data can be manipulated by computer to enhance edges, or to improve local contrast (14), and the resulting image displayed on a video monitor or printed on film. By computer enhancement techniques, we have been able, for example, to identify small osteophytes on a vertebral body when the vertebral body itself was not clearly visualized on the original underpenetrated chest examination. This paper reports the use of these methods with special discussion of our computer imaging experience.

Projection

The projection and photographic methods are straight forward. Miniaturized X-rays such as 35-mm slides may be projected and compared to postmortem radiographs that are illuminated on viewboxes as was done in Cases 1 and 2, or photographically enlarged as was done in Case 3.

In Cook County, Illinois, the Medical Examiner's Office routinely obtains full body X-rays in anatomic position of unidentified persons. Case 2 illustrates the value of this procedure. Full body X-rays of an unidentified homeless person, found beneath an expressway overpass, revealed a healed femoral intertrochanteric fracture treated with Ender rods. A name was obtained from other derelicts who frequented the site where the body was found. Records at Cook County Hospital revealed that a patient with that name had been treated for a femoral fracture. The original X-rays could not be located. However, 35-mm transparency slides of the fracture, made for teaching purposes were available. Projection of the slides revealed bone detail which, when compared with postmortem X-rays, revealed identical anatomy and confirmed identification.

The antemortem films reveal an intertrochanteric femoral fracture treated with Ender rods. At that time, Ender rods were not commonly used other than at Cook County Hospital. The postmortem films revealed absence of the femoral head and neck and the femoral condyles secondary to destruction by rodents (anthropophagy). Callus and posttraumatic ossification indicate a healed intertrochanteric fracture. The femoral shaft is similiar. The Ender rod positioning is identical in both films. The identification was confirmed (Figs. 1, 2).

Photographic Enlargement and Variation of Photographic Development

From 1976 to 1982, approximately 10,000 victims of a military junta in Argentina were abducted, tortured, and murdered. They were buried as unknown persons in unmarked graves, cremated, or dumped from aircraft into the Atlantic Ocean. Liliana Pereyra (Case 3) was approximately five months pregnant when abducted in Mar del Plata by military authorities in 1977. She was incarcerated at a clandestine detention center until the birth of her child, who was then taken away from her. Shortly following delivery, she was executed by a shotgun blast to the head. Skeletal remains believed to be those of Liliana were exhumed in 1985. Age, race, sex, and stature were consistent. An antemortem minichest radiograph was photographically enlarged by the Agfa-Gevart laboratory (now Agfa Division, Bayer Corporation) in Buenos Aires. Previously obscured cervical and thoracic anatomical details were visualized.

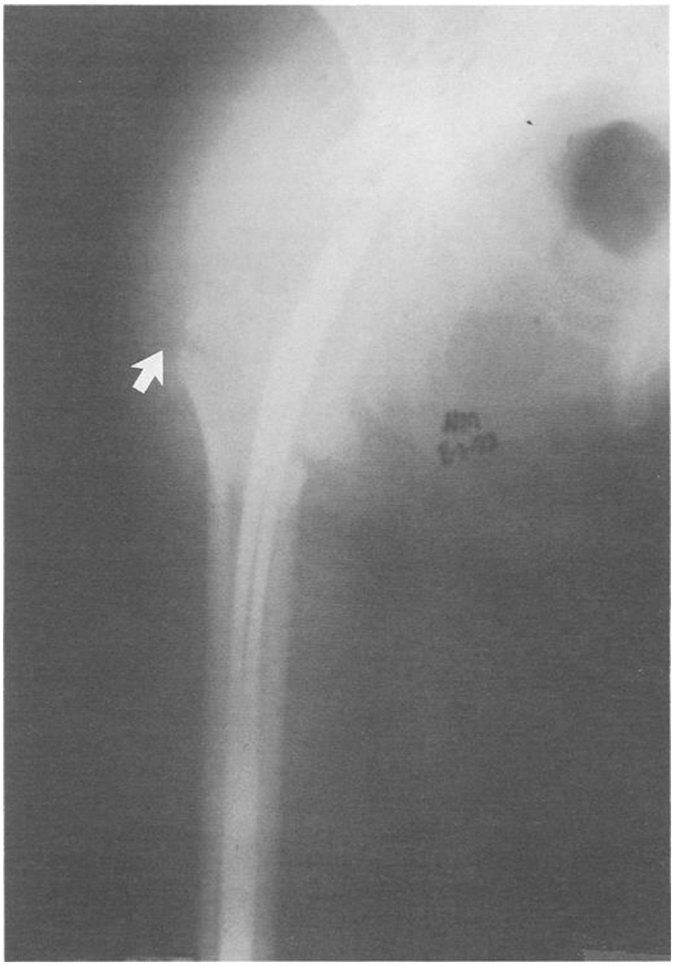


FIG. 1—*Case 2 antemortem post internal fixation of intertrochanteric fracture treated by Ender rods.*

Comparison of the enlarged photographs of the antemortem chest radiograph with the postmortem radiographs demonstrated the skeletal images to be identical (Fig. 3).

Digitization and Computer Edge Enhancement

Cases 7, 8, and 9 illustrate the advantages provided by film digitization and computer edge enhancement. Case 7: The decomposed remains of an elderly man were found in an abandoned building. A surviving brother denied that the deceased was his sibling. Full body radiographs were taken prior to burial of the body as an unknown person. Two years later, the brother reconsidered and informed authorities of an antemortem chest radiograph. Because of decomposition and differences in positioning between antemortem and postmortem examinations, the lower cervical, upper thoracic spine, and ribs could not be used for comparison. The mid and lower thoracic spine were not visualized in the antemortem radiograph due to underpenetration. The antemortem chest film was digitized. Using a computer, the digitized image was enhanced allowing detailed visualization of the thoracic spine

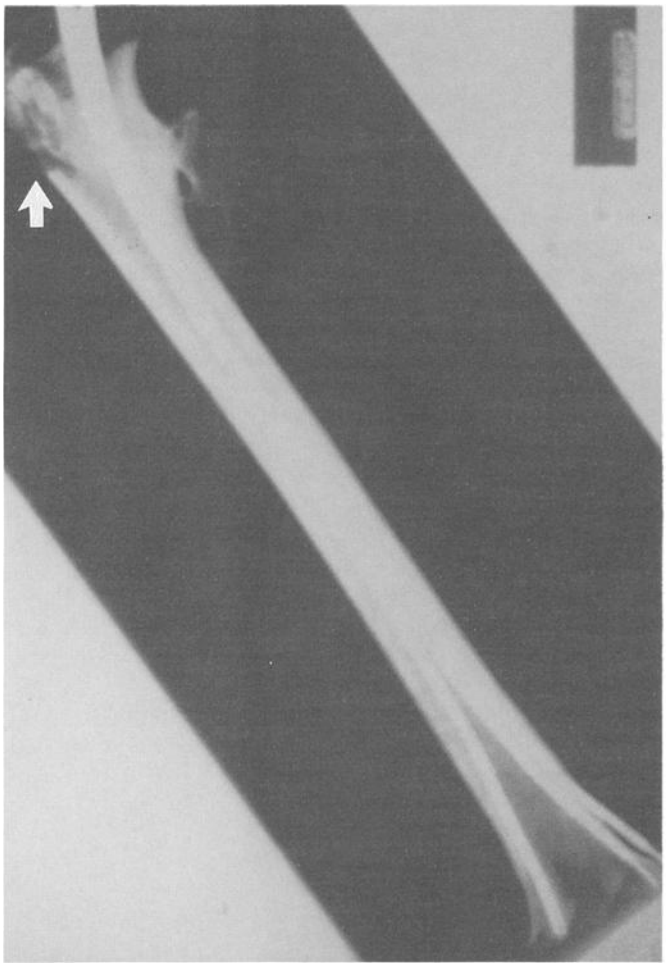


FIG. 2—*Case 2 postmortem film: Mutilation by rodents (anthropophagy) of the head of the femur is noted. Posttraumatic ossification and callus formation indicate a healed intertrochanteric fracture. Ender rods are seen. An excellent point of identification is the lucent defect (white arrow).*

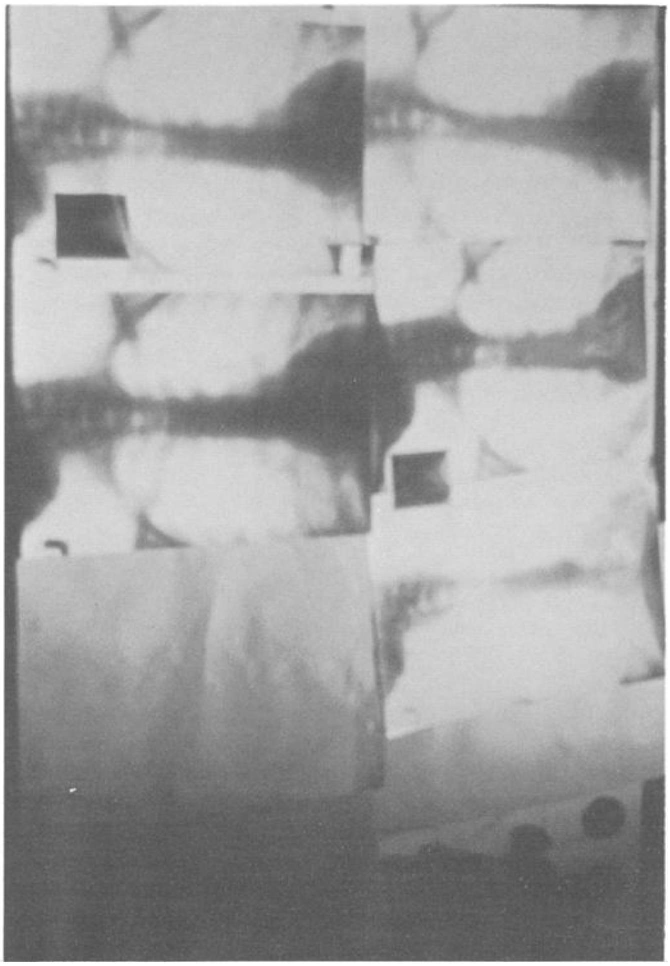


FIG. 3—*Case 3 enlarged photographs produced by varying development and printing of Lilliana Pererya's antemortem mini radiograph of the chest made obscure anatomy sufficiently conspicuous for identification.*

including very small osteophytes. Hard copy images were compared with the postmortem film, permitting identification (Figs. 4–11).

In Case 8, a question arose as to whether the proper cremated remains had been interred in a crypt. Radiologic examination of the cremated remains revealed a dental post that had been cut by the dentist before implantation in the patient's mandible during dental restoration. An antemortem bite wing showed a similar post, but details could not be 12-visualized. The bite wing antemortem radiograph was digitized. Using computer enhancement, a small spur, threads, and other modifications were identified. These were identical to the post found in the cremains. Hard copy prints of the computer images were made. Computer enhancement enabled visualization of details not clearly seen on the antemortem film. The head was shaped like an iron cross. The threads were identified clearly. The identification points were identical to the post found in the cremains (Figs. 12–16).

Case 9: A US helicopter was shot down in Vietnam with the loss of 12 men. There were three survivors. The identification of one victim was later questioned by the family and a nationally syndicated television program. Thoracic vertebrae T1, T2, and T3 were available for analysis and were X-rayed. A 70-mm antemortem photofluoro chest film was digitized. Anatomical details, not

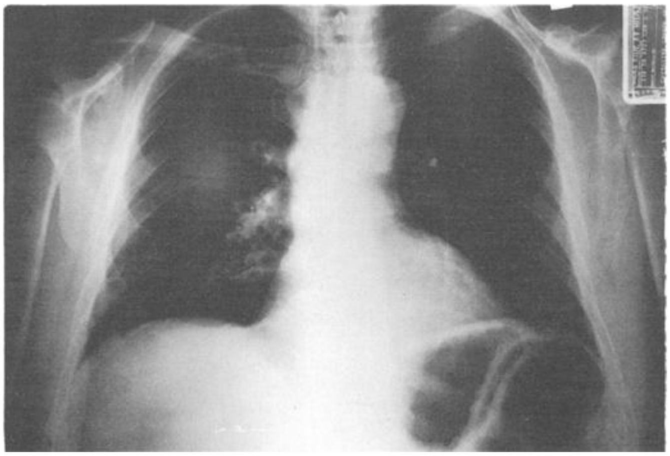
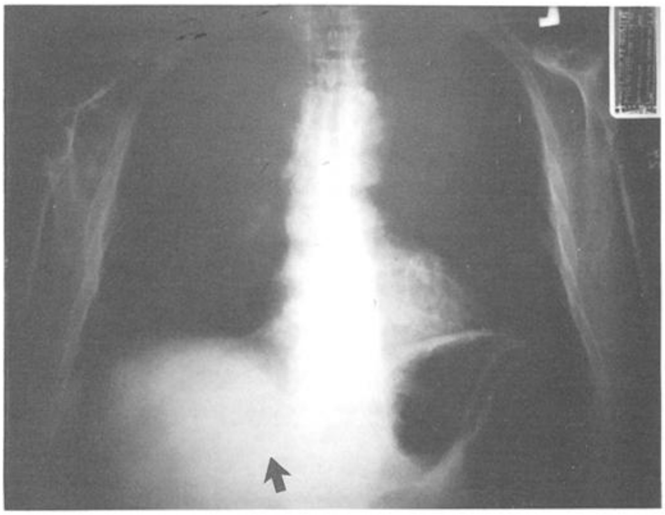
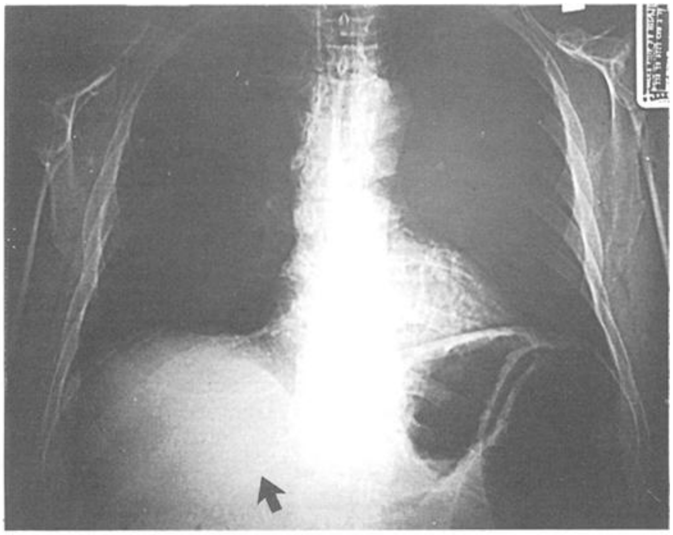
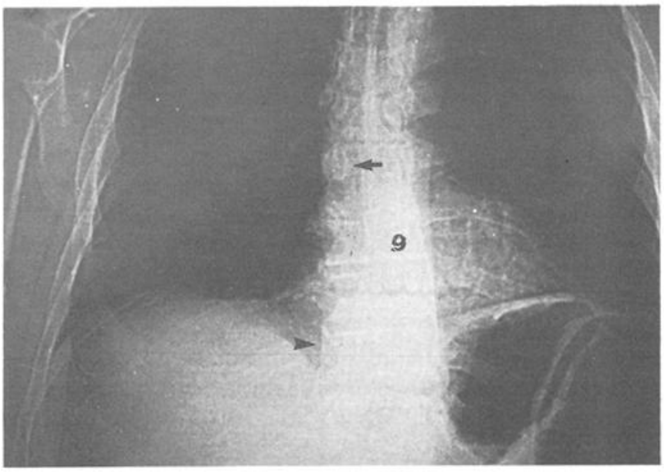
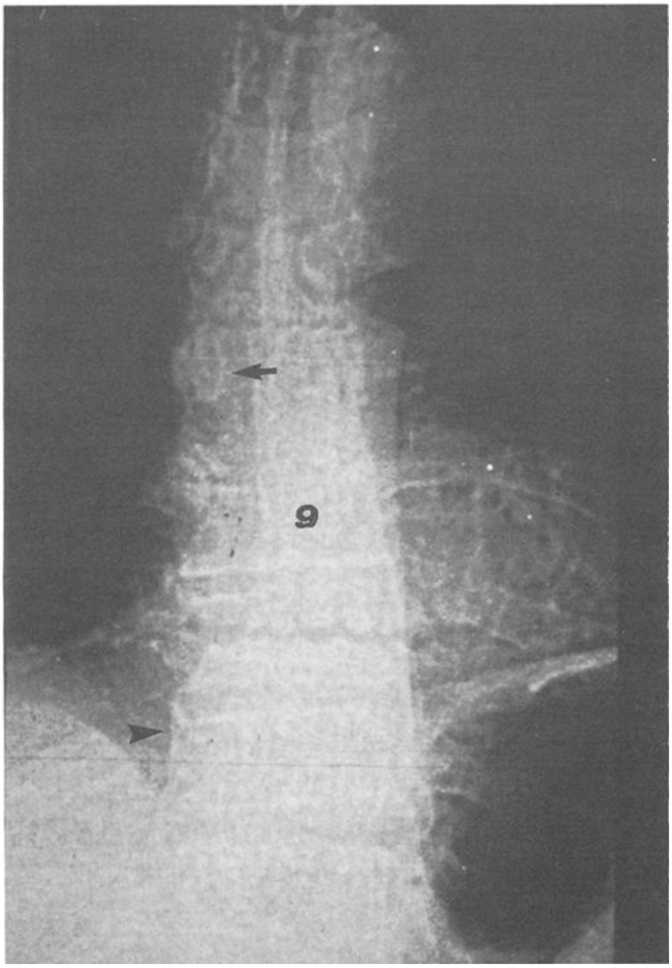


FIG. 4—*Case 7 antemortem chest film (35 × 43 cm; 14 × 17 in.). Position is different from postmortem film so visualized spinous processes (arrow) cannot be seen. Skeleton behind the heart cannot be seen.*









FIGS. 5 to 8 (Fig. 5, top left; Fig. 6, bottom left; Fig. 7, top right; Fig. 8, bottom right)—*Case 7 digitized and computer enhanced images of varying density which allow visualization of skeletal points of identification: pedicles, spinous processes, transverse processes, medial ends of ribs not seen in antemortem film.*

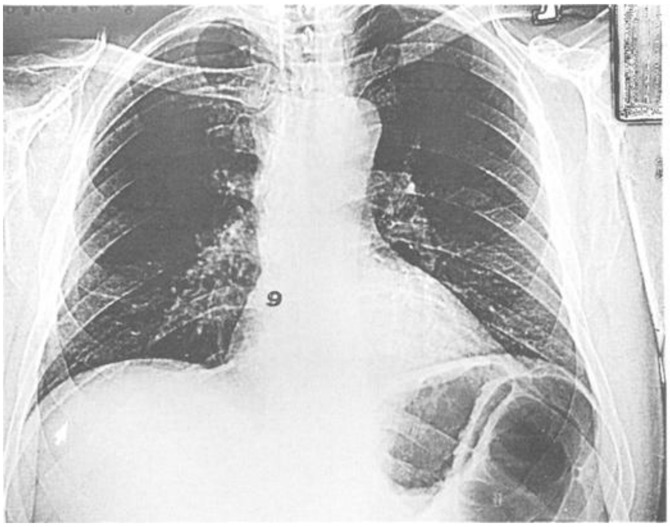


FIG. 9—*Case 7 postmortem film was taken two years before antemortem was located. Body was buried so other views could not be obtained.*

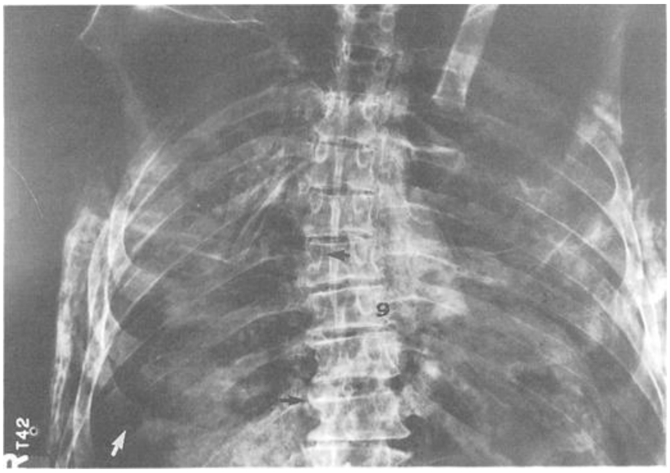


FIG. 10—*Case 7 postmortem film of decomposed body. The posterior ribs, spinous processes, pedicles, and transverse process of the antemortem and postmortem films were identical, confirming identification.*

previously seen on the 70-mm film, were visualized and compared with those of the antemortem film. Many points of identification were visualized. The identification was confirmed. Chest photofluorofilms of eight other casualties were available. Comparison of spinous processes easily excluded these (Figs. 17–20).

Commercial Digitization

Personal effects found on a decomposed body (Case 11) including documents indicated that it was that of a former private detective whose license had been revoked. He was known to have been hired by other private detectives for possible illegal work. He was also in debt.

Antemortem frontal and lateral chest films were digitized on a commercial digital system (Agfa Division of Bayer Corporation). Identification was confirmed by comparison of the lateral spines of the antemortem and postmortem films in both the positive and negative modes. The head, neck, and thermic spine above the sixth thoracic vertebrae were missing. The frontal chest film was underpenetrated, and the mid and lower thoracic vertebra and

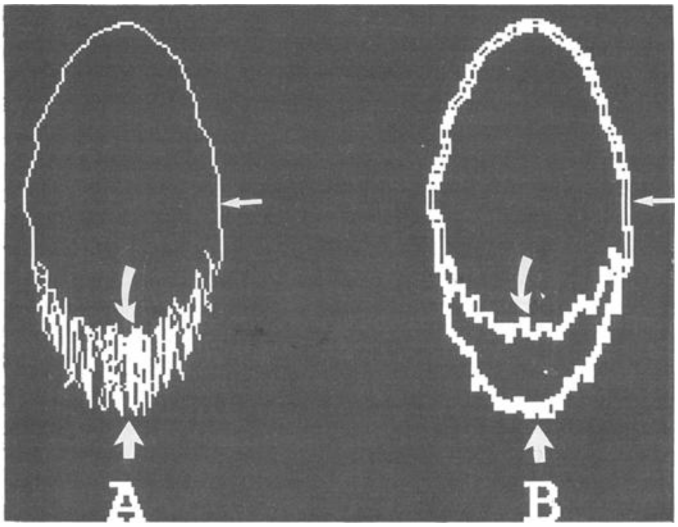


FIG. 11—*Diagrammatic analysis of enhancement of the T8 pedicle from the images of Case 7. In* A, *the inferior aspect of the pedicle outline is thickened, forming a crescent shaped density as seen on the postmortem image. In* B, *the margins of the crescent shaped density are highlighted due to application of edge enhancement, as seen on the enhanced antemortem image.*

FIG. 12—*Case 8 close-up of antemortem tooth with post. The head is not seen. There is suggestion of a serrated appearance to the post (arrow). The tip is offset.*

FIG. 13—*Case 8 computer enhanced image of antemortem tooth and post shows the threads of the post. Asymmetry of the tip is seen; Note that the X ray has been reversed in this figure.*

FIG. 14—*Case 8 computer enhanced image of tooth shows head of post that is shaped like iron cross.*

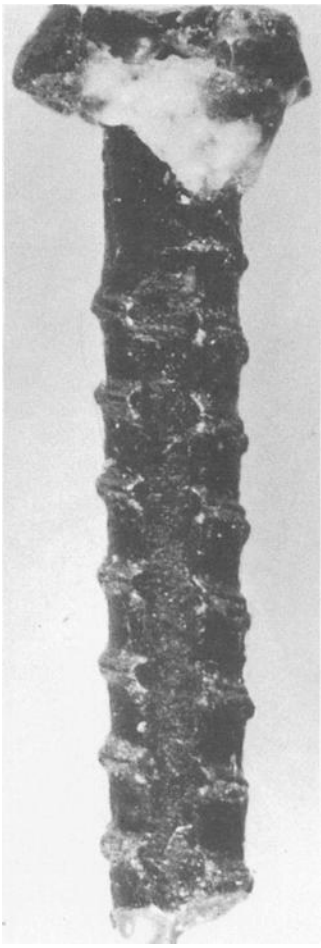


FIG. 15—*Case 8 post found in X-rayed cremains. The threads, shaft of post, and asymmetry of tip are identical to those on enhanced images of antemortem tooth.*

FIG. 16—*Case 8 head of post is shaped like iron cross.*

posterior ribs could not be seen. We were unable to visualize these areas on the digitized images (Figs. 21–23).

Case 12 illustrates similar methodology. A headless body was found floating in Lake Michigan several months after a private plane had been lost over the Lake. The anthropomorphic data matched that of the pilot. Enough skeletal detail was visible in an antemortem chest film to make a positive identification. Because the mid and lower thoracic vertebrae were barely perceivable, an attempt was made to improve their resolution by digital computer enhancement with a commercial scanner (Figs. 24–27). Table 1 summarizes the identification methods used in the cases reviewed.

Methods

The films in the last six cases, on the other hand, required digitization and, in some cases, computer processing for reliable identification. These were done in facilities with research equipment. The last two cases were done on commercially available equipment. These techniques are not widely used for forensic identification and will be detailed here. They are, however, in common usage by the imaging industry (14,15). Rosenfeld and Kak have written a comprehensive review of the subject (14).

The earliest computer-assisted cases were completed several years ago. Optical scanning equipment has developed rapidly over the last few years, and the technologies used here reflect the changes in this dynamic field.

Image digitization, in our context, is a process whereby the radiographic film image is divided into tiny picture elements or pixels. In this process, an illuminated image is scanned by a photosensitive transducer that samples the image density many times along a line. The process is repeated along adjacent lines until the entire image has been scanned. Spatial resolution of such an image is measured, along a horizontal scan line, in pixels per inch, and vertically across adjacent lines, in lines per inch. Usually, the resolutions are the same in both directions and simply stated in pixels per inch. Contrast resolution, on the other hand, refers to the number of gray levels that the transducer can detect or that can be stored in computer memory. One gray level, or image density value, is detected and stored for each pixel.

The numbers that express the spatial locations of the pixels (two numbers for each pixel; the x and y coordinates, for example) are stored electronically as a two dimensional array. The numbers that express the image density values of the pixels (one number for the corresponding pixel it describes) are placed into the two dimensional array. This results in a three dimensional array, two numbers describing pixel location and one additional number describing density value at that location. The third dimension, which stores the density value, is often called pixel depth. This array is stored in computer memory as a digital data file.

There is a ubiquitous shorthand method for describing the pixel depth, or the maximum number of densities that the image can portray. A number is stored electronically, not in base ten (a series of decimal digits), but in base two (a series of binary digits, or bits; eight bits are byte). In binary, the largest number that can be accommodated in a computer memory location is often stated as 2 raised to the power n, where n is the maximum number of binary digits. Thus, an 8 bit (1 byte) depth (derived from 2^8) refers to a contrast resolution that can be described by a value whose maximum number of binary digits is 8, corresponding to a maximum decimal value of 256 gray levels. Each gray level is a shade of

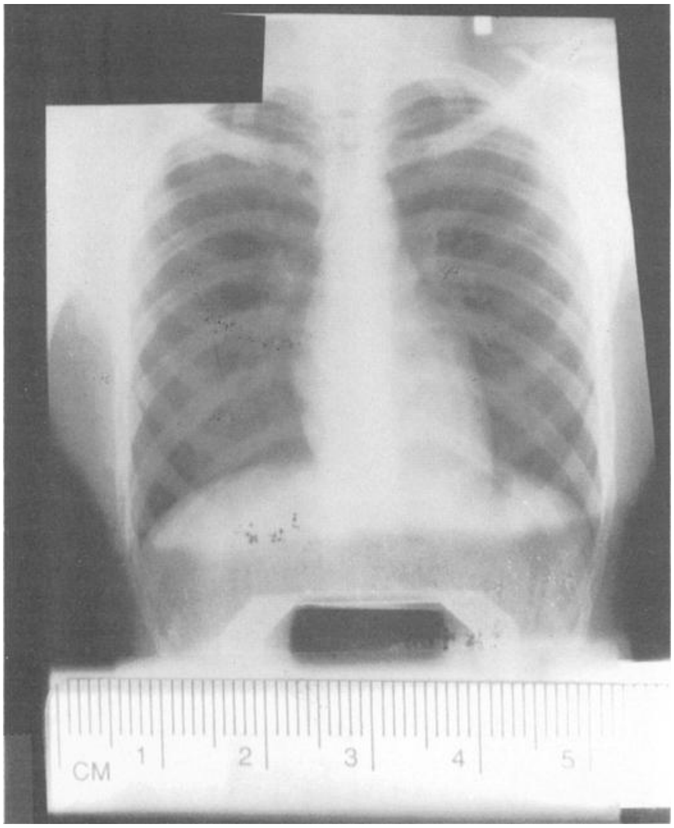


FIG. 17—*Case 9 photofluorofilm: upper thoracic spines and transverse process are indistinct.*

gray. Obviously, images with greater spatial and contrast resolutions dictate larger data files, which use more computer memory and require faster speeds for realistic processing times, both of which are expensive options.

Films from Case 7 were shipped to a commercial digitization service (Lumisys Corporation), where the digital data were stored on 8-mm tape. We were unable to process the tape locally. Such changes in format often resulted in loss of image identification data and reflected the state of the industry in the late eighties in handling format incompatibilities.

Subsequently, a high resolution, flat bed laser scanner (Lumisys Corporation) became available in-house for image digitization. The output of this device had a contrast resolution of 16 bits (2 bytes), capable of reproducing any one of over 6500 gray levels for a given pixel (2^{16} = 65,536, or 16-bit depth). For a 14- by 17-in. (36-by-43 cm) film scanned at a spatial resolution of 130 pixels per inch (about 1800 by 2200 pixels), the image would occupy a data file of about 64 million memory locations (1800 by 2200 by 16 = 63,360,000, that is, about 64 Megabits, or 8 Megabytes). However, the final image was to be processed by, viewed on, and transparency film printed from, a Macintosh II computer (Apple Computer Corporation) with contrast resolution of 8 bits. To effect this bit depth conversion (16 to 8 bit depth), the byte order from the scanner (in MS-DOS format) had to be inverted (to Unix format) so that the 8 least significant bits could be truncated. The conversion was performed on a high-speed workstation (Sun Microsystems). Today, inexpensive, commercial scanners are readily available that are fully compatible with the variety

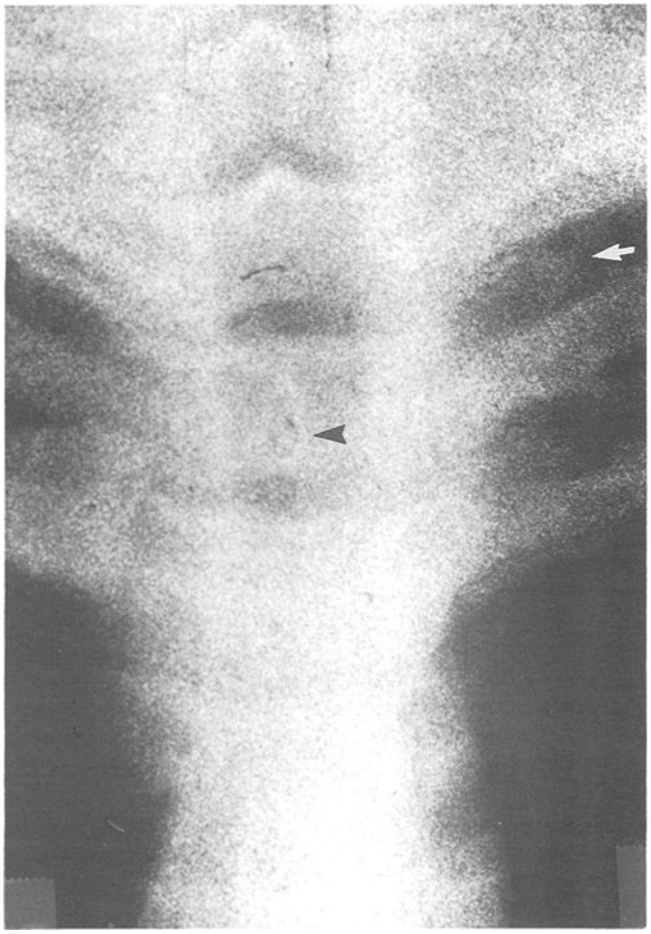


FIG. 18—*Case 9 digitized film in positive mode. The small dots are mottle. The spinous process of T1 and T3 (black arrowhead) are similar to those seen in the postmortem radiograph. The left transverse process of T3 (white arrow) is similar; however, the sclerosis of the tip of the transverse process is not evident.*

FIG. 19—*Case 9 digitized film in negative mode. The mottle is markedly less evident. The sclerosis at the tip of T3 (small white arrow) is evident. Spine of T3 (large white arrow).*

of computer imaging systems, and eliminate the need for such intermediate steps.

The digitized image file was processed on the Macintosh in the image processing program, developed by Shuo-Juin Wu. *Image v*1.07 was developed by Wayne Rasband at the National Institutes of Health. The program, originally designed for microscope image analysis, is in the public domain, and readily available without charge. Similar capabilities are embodied more currently in commercial programs, such as Photoshop *v*3.0.1 (Adobe Systems), and other radiological imaging software.

Our enhancement procedures used primarily two of the many functions available in *Image:* Small region edge enhancement and noise filtration. In edge enhancement, the density difference between groups of pixels comprising an edge, or sharp density change in the image, is amplified to accentuate the edge even further. This increase in contrast is applied only at edges and not throughout the image. Noise filtration, in our context, is a complex technique that attempts to remove some forms of noise, or artifacts that are spatially and temporally random and are often unavoidably introduced into the original image. For example, in radiography, decreasing the number of X-rays forming the image desirable for patient safety increases a form of noise called quantum mottle, the "graininess" of the X-ray field (15). When X-ray photon flux is low, the radiation field is not uniform microscopically, and X-ray interactions become distinctly separated in space and visible as nonconfluent events. Unfortunately, noise filtration is a compromise in which some useful image information is also lost in the process. Of course, quantum mottle can be minimized in postmortem radiography in which radiation dose need not be limited. The results of these techniques are discussed in the next section.

Hard copy documentation of the enhanced images were acquired by screen capture. High resolution laser printing on film can be accomplished by transferring the image file to the CT printer available in most radiology departments. In the latter case, changes in file formats, as discussed above, may be necessary. The images can also be photographed on the screen. A detailed example of how enhanced images facilitated identification follows. In Case 7, the known postmortem radiograph was compared with the underpenetrated antemortem chest film. The right pedicle of thoracic vertebral body T8 demonstrates an exceptional morphology and would constitute an excellent point of identification. However, that pedicle is not seen on the antemortem study due to underpenetration of the mediastinum. By digitization of the antemortem film and regional edge enhancement, the T8 pedicle is not only distinctly visible but demonstrates predictably the effects of edge enhancement. The thickened outline at the inferior aspect of the pedicle forms a crescent shaped density (see Fig. 10). The superior and inferior "edges" of that density form density gradients that will

FIG. 20—*Case 9 postmortem radiograph of T1, 2, and 3.*

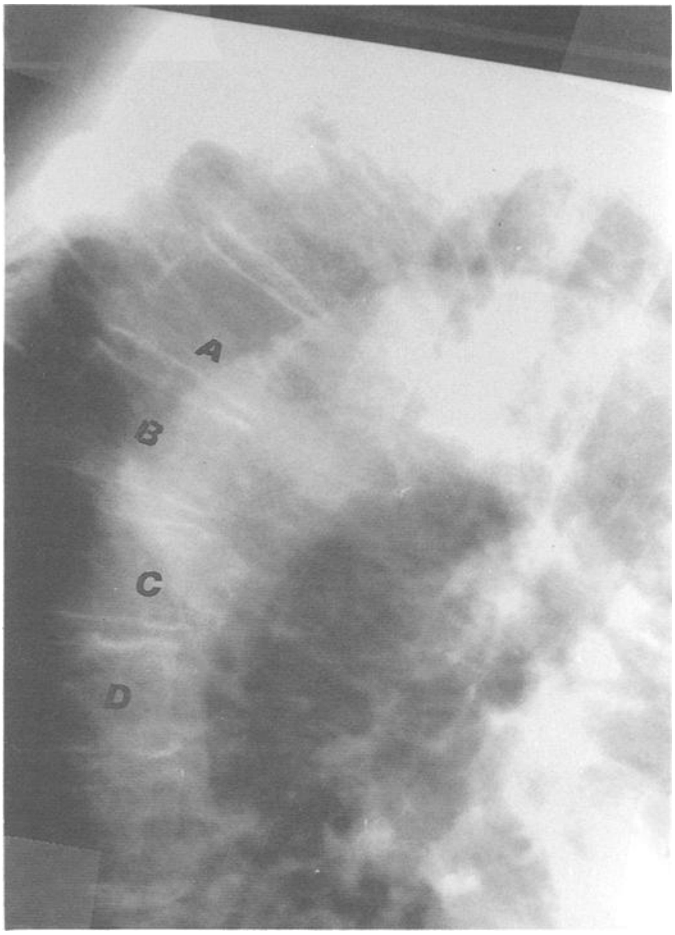


FIG. 21—*Case 11 monitor image of the lateral skeletal thoracic spine that demonstrates small spurs and vertebral body wedging. Small cystic areas are seen in some end plates.*

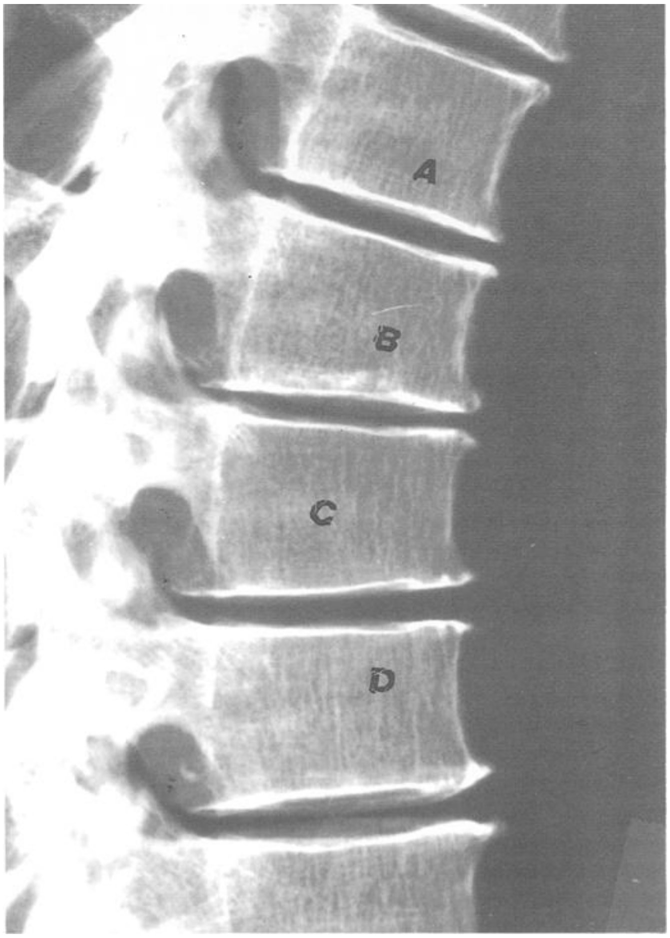


FIG. 22—*Case 11 monitor image of the thoracic spine visualized in the positive mode.*

be highlighted by enhancement. Indeed, the postenhanced chest film demonstrates these features that are depicted diagrammatically in Fig. 11.

In Case 11, a commercial digitizer and processor in a hospital was used. This equipment rapidly digitized images that were transferred to a consul in another room. Two side-by-side monitors enabled the comparison of antemortem and postmortem film images that were viewed in positive and negative modes and magnified. Small anatomic characteristics were frequently more conspicuous in either the positive or negative mode. Magnification was also helpful. The raster can mark vertebrae facilitating comparison by keeping track.

The spine was removed from the decomposed body and cleaned of all soft tissue. It was radiographed in frontal and lateral projections. Only the lateral projections of the thoracic spine were useful for identification purposes. In the antemortem radiograph, the spine was obscured by the heart and mediastinum. Because of the lack of an edge enhancement program, spinal anatomy was not visualized. Because the frontal chest is the most commonly preformed radiographic examination, the lack of an edge enhancement may result in either failure to identify an individual or using more expensive techniques.

Case 12 was identified without the use of digitization. The ribs and the frontal chest image were digitized, because the thoracic vertebral anatomy such as the pedicles were faintly visualized, but not enough for identification purposes.

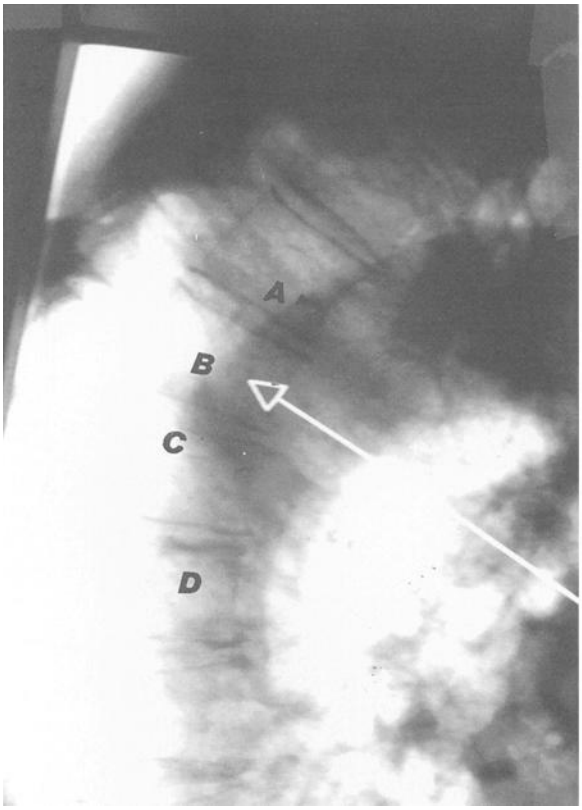


FIG. 23—*Case 11 in the negative mode image, two small cystic areas are seen in the inferior end plate of vertebra* C *but not in the positive mode image. The raster arrow marked vertebra facilitating comparison. At photography, the tip was placed over the sclerosis seen in vertebra* B.

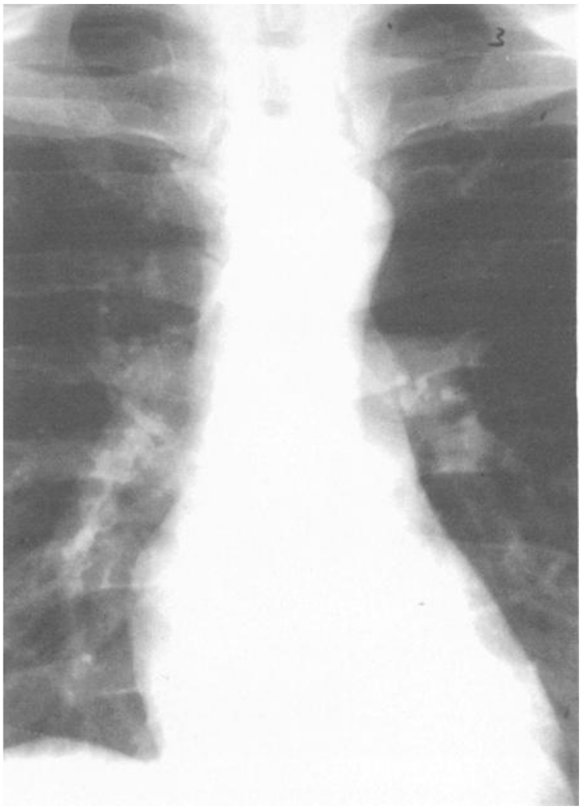


FIG. 24—*Case 12 the vertebrae and pedicles are not seen in these photographs of the antemortem chest but were very faintly visualized in the X-ray.*

Discussion

Several analyses with different techniques were attempted to extract from the entire image features, such as pedicles for comparison. Many structures that were previously visible but could not be identified with certainty could be extracted with relative ease after enhancement. This contributed to the assuredness of identification. Other regions required greater effort to extract features resulting in somewhat less adequate demonstration for reasons to be discussed below.

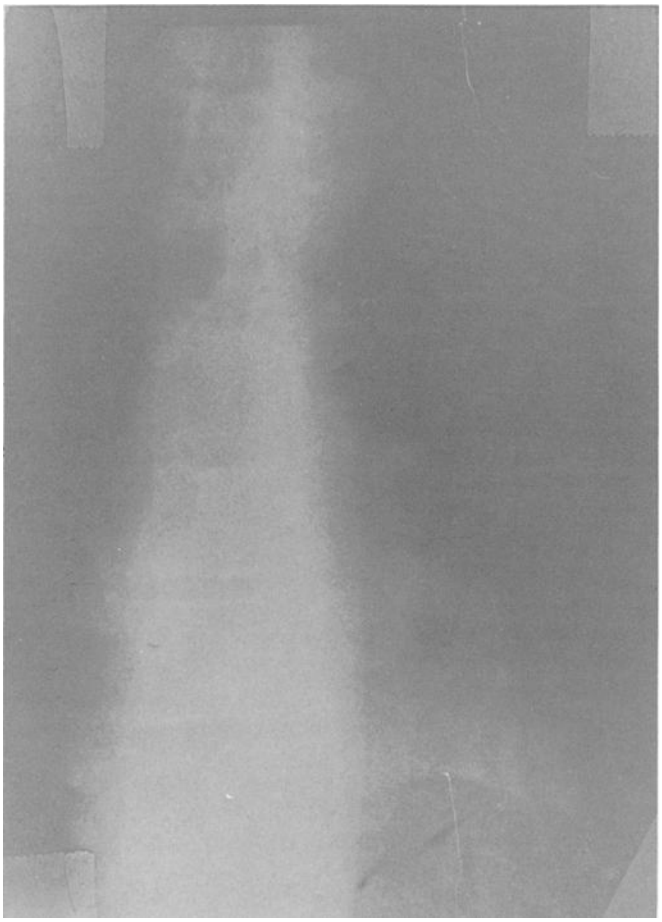
Certain technical problems were encountered that had been unanticipated. For images that required contrast enhancement at very high levels, ring-like artifacts became visible in the image. Two causes were postulated for this effect: moiré patterns and Newton's rings (Fig. 27).

A moiré pattern is a secondary geometric pattern formed by the inexact superimposition of two, usually identical, parallel line or curve patterns. Moiré patterns are often visually disturbing and appear to be shimmering. There are several possible explanations for this. These artifacts were developed in Cases 7 and 12. The film that was digitized was a copy film. The pattern did not develop in cases when an original film was digitized. Another explanation is that two families of line patterns producing this effect may have been parallel grid lines on the radiograph, and the parallel scan lines from the laser scanner. Grid lines result in radiographs exposed through a grid, which is a sandwich of extremely thin, slightly separated slats of X-ray absorbing lead oriented parallel to the X-ray beam. The purpose of this collimating grid is to absorb scattered X-rays that would, otherwise, arrive at the cassette at an angle and, register X-ray/patient interactions substantially offset from their true locations. Scatter radiation adds to fog on the radiograph. During scanning, if these grid lines are oriented at a very slight angle to the scan line direction, a moiré pattern develops in the scanned image. Perfect registration would be nearly impossible to achieve and would be undesirable, because no image information exists in which the grid slat blocks exposure; a resultant full line of "empty" pixels would, in itself, be a highly noticeable image artifact. In general, moiré patterns are alleviated by greater misregistration of the superimposed sets of curve families. To correct for moiré patterns in Case 7, we scanned the images at 90° to the grid lines, and found this an adequate solution for this artifact. No attempt to alleviate the moiré pattern was attempted in Case 12.

Another explanation for these findings is the phenomenon of Newton's rings (16). This phenomenon appears as multiple, concentric, alternating bright and dark ring-like bands, similar to the contour lines of a topographical map. Newton's rings result from optical wave interference among the "trapped" light waves reflecting between two surfaces in nearly intimate contact. Where

TABLE 1—*Methods of radiographic enhancement for identification.*

Case	Antemortem Image	Antemortem Area	Method Used	Reason
1	35-mm slide	Humerus	Projection	Small size
2	35-mm slide	Femur	Projection	Small size
3	35-mm slide	Chest	Photographic	Small size
4	35 × 43 cm 14 × 17 in.	Chest	Photographic	Under penetrated
5	35 × 43 cm 14 × 17 in.	Chest	Digitization	Under penetrated
6	70 mm	Chest	Digitization	Small size
7	35 × 43 cm 14 × 17 in.	Chest	Digitization and computer enhancement	Under penetrated
8	70 mm	Chest	Digitization and computer enhancement	Small size
9	Dental bite wing	Dental post	Digitization and computer enhancement	Small size
10	70 mm	Chest	Digitization	Small size
11	35 × 43 cm 14 × 17 in.	Chest	Commercial digitization	Delineate spine
12	35 × 43 cm 14 × 17 in.	Chest	Commercial digitization	Evaluation




FIGS. 25 and 26—*Case 12 digitized images in the positive and negative modes revel the vertebral bodies and ribs, but the pedicles and spinous processes are not seen. Detail is insufficient for identification.*

the surface separation distance approaches the wavelength of the incident light, waves from different origins interfere either destructively, producing a dark band, or constructively, producing a bright band. Note that the interfering waves must be reflected and thereby, coherent, that is, identical in wavelength and phase. As the separation distance increases, further away from the area of intimate contact, the interference progresses through alternating bright and dark bands. For surfaces in point contact, the bands appear as rings that trace circumferential loci where the separation distance remains at a constant value. Linear areas of contact produce adjacent, parallel, and linear alternating bands. In our case, the two surfaces in nonuniform contact are the glass window of the laser scanner and the radiographic film. Note also that laser is an inherently coherent light source. Newton's rings effects are well-known in the scanner industry, and are eliminated during manufacture of professional scanner models by etching an extremely fine matte texture onto the glass surface to subdue reflections. Another known, but less satisfactory, fix is a fine coating of oil. In most cases,

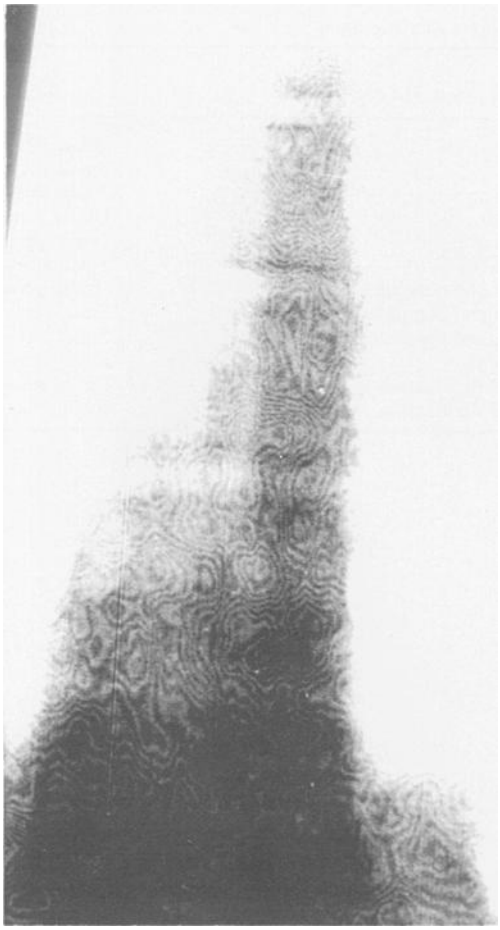


FIG. 27—*The curvilinear lines are a moiré pattern or Newton's rings that were developed when the window and level were manipulated in an attempt to bring out more details. This was developed in two cases in which the digitized film was a copy film, but not when an original film was digitized.*

Newton's rings did not interfere with feature extraction for postmortem identification. However, at high levels of contrast enhancement, this effect became substantial, and obscured significant amounts of information, especially when attempting to differentiate the circular pedicles of vertebral bodies.

The second technical problem was encountered in low contrast regions and appeared as "snow" in the image. (Figures 18 and 19 of Case 9). This was a particular problem in the areas of the mediastinum where there was very little exposure of the film. The low photon flux in such areas results in the form of noise called quantum mottle, described above (15). During computer processing, mottle was enhanced as if it were true information and resulted in further increases in the graininess of the enhanced image. Some forms of noise can be suppressed by histogram equalization and similar contrast manipulation techniques, available in *Image*. But, as expected, efforts to suppress quantum mottle without low contrast image degradation were unsuccessful. We have found that no adequate correction for this particular problem is currently available as there is insufficient information in the image to be extracted. (Note that the photophosphor plate radiographic imaging system, a radically different approach to X-ray image production, has approximately 10 times greater contrast resolution than traditional systems with consequent reduction in quantum mottle. However, these systems require substantial new equipment investment and are not yet widely available.)

Finally, our hardcopy production, by screen capture or photographing the computer monitor screen, although bypassing computer-to-printer format incompatibilities, lacks the consistency and uniformity derived from laser film printers available for CT. Networking such equipment within the radiology department for access for all digital image processing needs will avoid the image format incompatibilities discussed above.

Available commercial equipment allows rapid digitization and computer manipulation including the ability to visualize images in either the positive or negative mode. This saves time over the piecemeal approach. Lack of an edge enhancement program in commercial equipment may result in failure to visualize sufficient anatomy to make an identification. Although it is possible to incorporate within the commercial equipment an edge enhancement program, vendors do not plan to do this at the present time. A program for superimposition of antemortem and postmortem films is also possible. To protect trade secrets, vendors are unlikely to allow customers access to their programs for the purpose of incorporating edging enhancement and superimposition programs.

Summary

Digital enhancement techniques allowed us to identify human remains in cases that would otherwise have been unresolvable. However, several difficulties were encountered. Problems included digital format incompatibilities and image artifacts introduced or aggravated by the digitization process. With further improvement in the imaging systems and with the implementation of digital radiography, many of these problems will be overcome. The continuing improvement in image acquisition, processing, and display made possible by advances in computer hardware and software, digital techniques will be used increasingly in the future. For financial reasons that include the cost of film and archiving radiographs, and to allow rapid access of patients' radiographs and imaging studies by physicians, departments of radiology are becoming entirely digitized. Film radiography will probably be in low volume centers such as clinics. However, only a few entirely digitized sites are currently available in the US. The integration of digitized systems are in the near future. The American College of Radiology (ACR) and National Electronic Manufacturers Association (NEMA) have established a set of standards. The third version referred to as ACR-NEMA 3 or DICOME (Digital Imaging Communication in Medicine) meets the International Standards Organization (ISO) requirements. The goal of DICOME is to network not only radiology imaging systems but also other specialities such as pathology with radiology. It is hoped that when these standards are adopted by the variety of imaging system manufacturers, many of the problems currently faced in digital image usage will be alleviated. Networking and integration of digitized images, including those of various manufactures, are under commercial development and will shortly be available. It is hoped vendors will incorporate an edge enhancement program and the capacity for superimposition, or they will allow customers to incorporate such programs.

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