IMAGING

Contents

Photography
Radiology, Overview
Radiology, Non-Invasive Autopsies
Radiology, Pediatric, Scintigraphy and Child Abuse

Photography

H L Blitzer, Institute for Forensic Imaging, Indianapolis, IN, USA

Introduction

Purposes

In general, photography is used to provide a view of a scene or object that a viewer can see later, or in a different location, and understand what was at the original scene. This means that the devices used to capture the image of the original scene must be able to respond in a way that will enable the production of a replica that a person can view and understand. In essence, the photographic process is a surrogate eye. However, in investigative work, the issues are more complex because the objective is not limited to "seeing." There are three main reasons for using photography in forensic medicine (Table 1) and it is useful for the photographer to be aware of the intended purpose for each photo taken. This is because each photo will be optimized differently in each case.

Tools

Just a few years ago the tools of photography were films, cameras, and lights for use in the field. In the laboratory there were enlargers, chemicals, and optical and mechanical devices. Today the toolkit is expanded to include digital cameras and scanners for image capture, software tools for image enhancement and analysis, and a variety of output devices for making prints, displaying images, and storing image information. The photographer's capabilities are greatly expanded. In general, film-based photography is highly flexible, highly accurate, and easy to use. Digital techniques offer faster response and greatly expanded analytical capability.

Measures of Performance

In the early days, photographic quality was measured in terms of the ability to make "pleasing renditions." As the use of photography expanded into scientific investigation, new metrics were formulated, but these are largely specific to the purposes of each type of use. At this point in time, there is not a generally accepted set of measures of performance for forensic medicine. This lack of standards has been discussed by the scientific working group on imaging technology (SWGIT), organized by the US Federal Bureau of Investigation, but no action has been taken yet.

Comparisons: Human Visual System Versus Photography

It is often said that people see with their eyes. In reality, they see in their brains. The eyes capture data and only start processing it. The actual image is not retinal, but cortical. Eyes dart about, focusing on various locations within the scene in front of the viewer. As they do, they adapt to localized conditions and acquire a portion of the overall scene. The adaptations include adjustments in focus, exposure, colors, and resolution. The bits and pieces are put together by the brain and given meaning. It is the processed result that is "seen." Photographic systems are not nearly as versatile. Thus what the observer at the scene "sees" is not necessarily what the photograph will show and the photographer must consider the intended purpose for the photo and how best to portray that aspect (Table 2).

Definitions

The Nature of Light

It is not necessary to delve deeply into physics to understand the key photographic issues. First of all, light can be thought of as composed of small, massless particles called photons. These travel in straight lines unless their paths are bent by reflection (as off a mirror) or by refraction (as passing through a lens), or by diffraction (as by passing close to the edge of an obstacle). The paths that photons follow are called rays. Light can also be described as an electromagnetic wave. Each photon has a particular wavelength or

Table 1 Purposes for photography

Reason	*Future reference*	*Measurement and analysis*	*Communication*
Purpose	Record for review by the investigator of a perishable or large sample	A model of a sample that is suitable for certain analytical procedures	A surrogate of a sample that helps another person visualize a key point being made by the investigator
Objective	A representation that reminds one of the original situation	Accurate and rendered in a form suitable to the specific analytical procedure	Shows the key aspects of the original sample without evoking inappropriate emotional issues

Table 2 Differences between photo and visual processes

Issue	*Human vision*	*Photography*
Focus and depth of focus	Everything seems in sharp focus, from near to far	Only a limited portion of the image is in focus – the subject and short distances in front of and beyond the subject
Dynamic range	Detail in both bright highlight areas and deep shadow areas can be seen. Brightness range of about one million to one	With color negative films, a range of 20 000 to one is possible. With slide films, about 2000 to one; with digital cameras, less than 2000 to one
Sharpness	Retinal image processing enhances edges, providing higher than expected sharpness	Edge enhancement can be applied, but care must be used to avoid the creation of artifacts that can impair analyses and create misleading interpretation during communications with others
Color	The brain applies color names that we use to define our world. Some are based upon the wavelength of the incoming light (e.g., red). Others are based upon mixtures and have no physical wavelength basis (e.g., brown)	The system applies coloration according to the manufacturing parameters. There is the ability to adjust the settings. People tend to see reproduced colors differently than they see natural objects because of contextual interpretation differences
Adaptation	Our visual system can adapt in a matter of seconds from very dark environments (tens of photons) to very bright ones (tens of millions of photons)	Manual intervention is usually required. For example, change the film, apply a filter, change a camera setting, or, with digital cameras, use a different camera

frequency. Wavelength is what controls what is seen as color, and it also controls the energy the photon can impart to particles with which it might collide. Some of the measurements of light are key to making photographs, and these are described in Table 3.

Taking Pictures

The overall setup for taking a picture is as follows.

1. Ambient light is incident upon a scene containing a subject of interest.
2. Some of the light is reflected off the elements in the scene and moves toward the camera.
3. Some of that light is admitted into the camera through the lens. The amount of light actually entering the camera will depend upon the lens aperture and the exposure time.
4. The lens will project a real image on the image sensor.
5. Responses of the sensor to the light projected on it are used to form an image, which is representative of the original scene.

The photographer must compose the image to show the subject according to some photographic mission. Then the aperture, as determined by the f/stop (Table 4), and exposure time are adjusted based on the sensitivity of the sensor and the reflected light to ensure that the key features of the subject fall within the responsive portion of the sensor's dynamic range. When there is not sufficient ambient light, the photographer will employ additional lighting.

Most of the newer cameras have light meters built into the cameras and achieve "though-the-lens" measurement of light levels. In general, these are quite reliable and can accommodate a wide range of photographic situations, often including the use of electronic flash. The photographer can set the light metering system either to concentrate on the overall

Table 3 Descriptions of common terms

Term	*Description*	*Measurement*	*Photon basis*
Luminous intensity	An indication of the brightness of a light source	Candela (cd)	Total number of photons per unit time from a light source
Luminance	The brightness of a surface at a point	Candela meter^{-2} (cd m^{-2})	Photons per unit time per unit of area on the surface of a source
Luminous flux	The amount of light emitted into space	Lumen (lm) (cd sterradian^{-1})	Photons per unit time emitted into a solid angle of space from a source
Illuminance	Amount of light falling per unit area	Lux (lx)	Photons per unit time per square meter on a receiving surface
Exposure	The amount of light reaching a sensor	Lux seconds (lx s)	Photons per unit area on a receiving surface

Table 4 Exposure terminology

Measure	*Description*	*Controls*
Focal length	The distance between the center of the lens and the point behind it where it forms an image of a distant object, usually measured in millimeters	Image magnification
Aperture	The opening through which light can pass through a lens, normally the diameter of the limiting opening, measured in millimeters. Most lenses have an internal device called an iris, or diaphragm, which sets the aperture. In most camera lenses, this is adjustable	Illuminance on the sensor surface for the given lens
f/stop	A dimensionless number defined as the ratio of the focal length of a lens divided by its aperture. An indicator of the illuminance falling on the image sensor for any lens, no matter what its focal length	Illuminance on the sensor surface
Shutter	A device inside a camera that controls the exposure time	The time that the light impinges on the surface of the sensor. Determines the range of relative movement speeds that can be ''stopped''
ISO	A measure of the sensitivity of a sensor used in a camera. Defined by the International Standards Organization (ISO) and proportional to the reciprocal of the amount of exposure needed to achieve a threshold of sensor response. A film with an ISO of 400 requires only half of the light of an ISO 200 to achieve the same degree of response. ISO is often referred to as ''speed'' and a 400-speed film is twice as sensitive as a 200-speed film, and half as sensitive as an ISO 800 film	Sensor sensitivity
Depth of field	The range of distances in front of the lens at which scene details are rendered sharply. Adjusted by the f/stop setting	Range of subject to camera distances capable of sharp focus

frame, or on portions of it. Central weighting will give greater attention to the more central portions, while spot metering will concentrate on a very small portion of the center. In situations where the subject is not in the center of the frame, there is usually the means to lock in a reading by pointing at the subject first, then, while holding that reading, move the camera and take the photo. Instructions for accomplishing all of these are generally included in the camera manufacturer's user manual.

There are always special occasions where the photographer must manually override the automatic exposure controls. For small deviations, there is usually an adjustment knob on the camera, while for significantly unusual situations, such as "painting with light," the process can be fairly complex. Fortunately, most medical applications can be accommodated with the automatic metering capabilities of modern cameras.

Most automatic cameras will accommodate three exposure control modes. These are:

1. Program mode, in which the camera automatically sets both the aperture and the exposure time. This is quite suitable for most assignments and is usually the default setting on the camera.
2. Aperture priority mode, in which the photographer sets the aperture and the camera automatically chooses the exposure time. This is used when subject motion is not an issue, and the photographer wants to control depth of field. For example, if the photographer wants to have the subject in sharp focus and the foreground and background less well focused, a wide aperture, or low f/stop number, would be chosen. Conversely, if it were important to have as much of the foreground and background in focus as possible, a small aperture or large f/stop number would be chosen.
3. Shutter priority mode, in which the photographer chooses the shutter speed, and the camera selects the proper f/stop. Typically this is used when the subject is moving and the photographer needs to "stop action" by using a very short shutter time. This is also often needed when using a telephoto lens. The focal length of the lens is an indicator of the exposure time for a handheld camera. For example with a 300-mm lens, the slowest shutter time that should be used is 1/300 s.

It should be noted that, when electronic flash is used, it normally controls the exposure time. Typically, these have a very short flash duration, and so the mechanical shutter time is not an issue unless it is very short as well.

There are several well-known techniques used by photographers to deal with special assignments. A list of some of these is shown in Table 5. These techniques are well described in the literature given in the further reading section.

Composition

There are a few cardinal rules that one should follow when engaged in investigatory photography. They are as follows:

1. Crop in the camera. It is often the case that the really significant aspects of a photo are contained in only a small portion of an overall picture. While this is acceptable in amateur photography, it is not appropriate in professional work. The investigative photographer is expected to be aware of the true subject of a photo before the picture is taken. Accordingly, the photographer should move in on the subject either physically or by lens selection and frame the picture closely around the subject. The closely cropped photo should be augmented by "positioning" or "establishment" photos, which show the subject in relation to the broader frame of reference.

   Both film and digital photography sensors have finite resolving capability. This means they are capable of resolving only so many details across a frame. If the frame is dedicated to the subject, then the highest ability to render the subject is preserved. If the frame also covers a lot of noncrucial material, then some of the resolving power of the medium is used to reproduce background. The crop in the camera therefore provides the highest quality possible for the key subject matter. The positioning shots are exhibits that are used when communicating with others afterwards.
2. Insert a measuring instrument. In order to preserve the ability to make measurements of aspects of a photo at a later time, it is important to place a reference in the image itself. This is conveniently done by placing a ruler in the photo, close to the part of the image that will be measured. There are several rulers available for this purpose. Some, in addition to distance scales, include other markings such as squares, circles, and color patches. It is good practice to have several such rulers on hand and use them regularly. Many investigators will take two photos of certain key elements, one without the ruler and another, a repeat of the first shot, but with the ruler inserted. It is important that the ruler be located in the plane of the object to be measured.
3. Perpendicular to subject. In most investigative photos, there is a key subject that the photographer wishes to depict. If that subject has a flat surface, or a major dimension, the camera should be held perpendicular to that surface or dimension. This will greatly simplify subsequent measurement and analysis. In addition, the photographer should avoid extreme configurations that can complicate analysis. Examples of such configurations would include the use of very-wide-angle lenses (fisheye), very-narrow-angle lenses (long telephoto), and compositions that place the key subject near the edge of the frame instead of near the center.
4. Normal lenses for positioning shots. When the focal length of the lens is roughly equal to the diagonal of the image sensor frame, the angle of view and the depiction of perspective will closely resemble that of the human visual system. The lens is called the "normal lens" in this situation. Lenses with longer focal lengths (telephoto) will compress distances by comparison, and lenses with shorter focal lengths (wide-angle) will expand distances.
5. Subject failure. Over the years, engineers have developed all sorts of devices to take the guesswork

Table 5 Photographic techniques of note

Technique	*Objective*	*Basic description*
Painting with light	Record a large scene in very dim light	Place the camera on a fixed mount, leave the shutter open, walk around the scene, lighting each segment individually with a handheld flash attachment
Macrophotography	Produce close-up images of small objects, generating images that are the same size as the object or larger	Use of specially designed ''macro'' lenses
Alternative light source	Record images of special substances without confusion due to substrate patterns	In situations where there is a pattern on a substrate that either fluoresces or phosphoresces. Exposures are made at short wavelengths to excite the response and the image is recorded at a longer wavelength
Three-point lighting	Standard portrait studio lighting arrangement that controls contrast, provides some shading on the subject, and separates the subject from the background	Uses three lights. The first is in front and to one side of the subject; the second is in front, on the other side from the first and at a lower intensity. The third light is above the subject, highlighting the forehead and filling in background shadows. Sometimes a fourth light is used, shining from below and behind the subject to help separate the subject from the background
Direct flash	A convenient means of adding light with a handheld and frequently moved camera	Since the flash attachment is mounted on the camera, and is pointed at the subject, the light comes from roughly the point of image capture. The front of the subject will be brightly illuminated and the rest will be considerably darker. Scene contrast is high and shadows are pronounced
Diffused direct flash	To soften the harsh lighting associated with direct flash	A diffuser, such as a translucent sheet of plastic or cloth, is placed over the flash attachment
Bounce lighting flash	Retains the convenience of on-camera flash but reduces the harsh shadows that normally result	A flash attachment is used but it is aimed at a diffuse white surface such as a large card, a wall, or the ceiling
Ring light	In close-up work, this reduces sensitivity to surface roughness	Utilizes a camera-mounted flash attachment in the form of a ring that encircles the lens
45–90 illumination	A lighting arrangement meant to minimize front surface reflections	Typically used on copy stands, the axes of the lights are set to 45° relative to the object's main surface and the camera is set to 90° (normal to the surface). This is the standard for measuring instruments such as reflection densitometers as well
Perspective grid	To determine three-dimensional information from normal photographs	Typically used at crime scenes and accident scenes, a flat square of known size is placed in the scene, usually on the floor or ground in front of the camera and used to extrapolate to vanishing points and establish a basis for making measurements
Infrared photography	To see by means of heat instead of visible light. Also, to determine temperatures	Special films or digital sensors are used that have high sensitivity to long wavelength (infrared) light. Visible light is blocked. Special arrangements must be made to focus the camera
Zone system	A process for determining exposure levels in order to maximize the impact of a scene's dynamic range	The brightness levels of key parts of a scene are categorized into zones, then the exposure is set to locate these key parts on the usable exposure range of the film or sensor
Component panorama	A process of making a photographic representation of a very wide scene	Several photos are taken, each at a different angle from a single point. Care must be taken to ensure that the images overlap enough to be properly joined or ''stitched'' together to create a single image
Push processing	A process for taking photos in very low light using silver halide film	The film is deliberately underexposed by a fixed amount and then the film processing is modified to compensate. Often has contrast and grain consequences
Bracketing	A means to help assure getting a good exposure under conditions that are difficult to measure	For each object or scene, a few shots are made instead of just one. With each shot the exposure level is increased from below what is expected to be correct to above. One of the photos should be well exposed

Continued

Table 5 Continued

Technique	*Objective*	*Basic description*
Lens translation	A process for obtaining photos with the 90° perspective when there is an obstacle preventing the camera being held directly above an object	Using a flexible bellows device, the camera lens is moved laterally off to the side with its axis still normal to the object's principal surface
Polarized light	A process for reduction of front surface glare	A special polarizing filter is placed over the camera lens and rotated until front surface glare is minimized
Contrast filtering	A means for increasing or decreasing contrast for object elements of selected colors	Colored contrast filters are used over the camera lens to change the contrast of certain items in the scene selectively. Contrast in items of the same color of the filter will be decreased and those of opposite color will be increased. This is generally limited to black and white photography
Stereo photography	A means for showing depth in photography	One uses either two cameras or a single camera with two lenses. The lenses are slightly separated (as are a person's two eyes). The means is provided to show one of the images to one eye and the second image to the other eye. This can be done with polarizers, color filters, or stereo viewers
Three-dimensional scanning	A means for recording a three-dimensional photograph of an object with a single device. The resulting image is a computer model of the object	A special camera which takes both a normal photograph and also records spots that correspond from a location where a laser scanner intersects the subject surface. The laser points at an oblique angle to the object and its beam progresses along the object in preset steps. The device then computes a three-dimensional model of the object and attaches the normal photo to render the object's surface markings
Photomicrography	The capturing of images at very high magnification	A special adapter is placed on a microscope to allow a camera to receive the enlarged image
Fisheye photography	The capture of very-wide-angle photographs. These are distorted compared to normal vision, because the eye cannot capture such a wide angle	Fisheye photography depends upon the use of a specially designed lens. Fisheye lenses have very short focal lengths compared to ''normal'' and cover a view considerably greater than the 40° view of humans
Telephotography	The capture of detailed images of distant objects. Lenses with about twice the normal focal length are often used for portrait photography	Telephotography depends upon the use of a specially designed lens. Telephoto lenses have long focal lengths compared to ''normal'' and cover a small angle of view compared to normal human vision
Fill flash	A process for reducing harsh shadows resulting from existing light	A flash attachment is used to illuminate portions of a scene that are not well lit by existing light
Off-camera flash	A process for using a flash attachment to light an object at an oblique angle. It is used to show surface textures	A normal flash attachment is used along with an extension cable that allows the flash attachment to be held somewhere off to the side of the camera
Exposure compensation	Overriding the camera's automatic exposure control system or a light meter-based setting because of unusual contents of a specific scene	Using the camera's controls, purposely deviate from the indicated level of exposure to bring out needed detail in a subject where the metering system is responding too strongly to background light levels. Sometimes referred to as correcting for ''subject failure,'' examples include a dark subject against a light background, or a light subject against a dark background

out of photography. These include light meters, automatic exposure controllers, automatic printers, image analyzers, in-camera white balance devices, auto focus, to name a few. These are wonderful devices that usually allow the photographer to concentrate on the composition of the photo instead of the setting of the camera or printer. However, all of these devices assume a "normal" scene. For the investigative photographer most scenes are quite different from the normal vacation photos. For example, in a normal scene, one can generally assume that the average reflectance from the scene is close to that of a gray card that reflects 18% of the light. This can be used to set the exposure properly. In the case of a digital camera, it can read the overall red and blue light levels and determine the color temperature or basic coloration of the light source and balance accordingly (white balance). It can also generally be assumed that the subject of the photo is near the center and that the rest is background. The camera can thereby set correct focus. However, if a pathologist is taking a close-up photo of a red (blood) wound on dark-brown skin, the scene is not normal. The autofocus will probably work well enough, and the autoexposure will be fairly close, white balance will be greatly in error, and manual adjustment will be helpful (inserting a gray ruler in the image will help with subsequent color balancing). Engineers regard the nonnormal aspects of a scene as "subject failure," but nomenclature notwithstanding, the investigative photographer must know when he or she is taking a nonnormal photo and must take steps to make manual overrides. Some of the appropriate photographic techniques are listed in Table 5 and some of the more common postimage capture-processing techniques are listed in Table 6.

Film Versus Digital

With recent improvements in digital-imaging technology, digital approaches and the traditional silver halide film methods have begun to complement each other well. However, there is no longer much of a difference in areas such as sensitivity and resolution. Film still has a better dynamic range though, and it is more flexible (one can change the film and not have to exchange the whole camera). When considering the developing and printing of all images, silver halide technology is slightly cheaper. The big advantage to digital photography is the immediacy of the result. It allows the photographer to see the pictures immediately, and if not fully satisfied with the result, make changes and take the photo again.

It is becoming quite common that the best overall approaches involve hybrid systems. Films are used for certain photography assignments, and digital cameras and scanners are used for others. Film scanners can be used to convert film images into digital images for analysis. Digital printers that print to photographic papers are a low-cost output option. Moving files among media is becoming easier each year.

Image Processing

Photographers, over decades of darkroom work, have developed a large array of techniques to enhance (and modify) images to achieve special results. The publishers of digital image-editing software have now captured the essence of all of these using mathematics and computer algorithms. These allow one to apply complex and arcane techniques with ease on a wide range of photos, and it is recommended that the investigative photographer adopt this technology and learn to use it. There are protocols which help facilitate legitimate image enhancement and avoid questionable manipulation. These are available from the SWGIT *Guidelines*. SWGIT coordinates with counterparts in several other countries, and its findings are therefore quite robust.

As with photographic techniques, it is impossible to review all of the options in this article, so a listing of the more commonly used techniques is provided in Table 6.

Outputs

Hard-copy Prints

Paper-based reflection prints are what one most commonly takes to be the output from a photographic process. In traditional silver halide photography, negatives are printed directly on to photographic paper and the result is a paper print. Forensic pathologists have a history of using slide films in their cameras to create transparencies. Now, with the advent of digital technology, one is quite likely to use a digital camera or to use a film camera and scan the negatives to create a digital image. It is then easy to enhance the images, store them, and make prints using a digital printer of some sort. If the source of the image was a digital camera or a flat bed scanner, digital-printing technology is clearly a requirement. Digital printers are available in four distinct varieties. These are summarized in Table 7.

Projection

Increasingly, investigators are making computer presentations to both colleagues and courts since this allows them to show a wider range of photos and to intersperse video clips and animations. Frequently there are hard-copy versions of key images for members of the audience to study closely. Transforming all images to digital format greatly facilitates these options.

In a courtroom setting, the recommended arrangement is to have monitors on the lawyers' desks as well as one on the desk of the judge. This allows those people to preview images before they are shown to a jury. It is best to have the main screen near the witness so that the jury can see the witness and the presentation in a single view. Some courtrooms have installed

Table 6 Image enhancement techniques

Technique class	*Specific techniques*	*Objective*	*Summary description*
Size adjustment	Cropping, interpolation, sizing	To create a new image of a different size	Cropping is the process of cutting off sections of an image either to reduce its size or to concentrate on only parts of the image. Sizing refers to taking the existing image content and either spreading it over a larger area or concentrating it into a smaller area. Interpolation is a process for accomplishing sizing with digital images
Selection	Similarity outline, exclusion masking	To define areas of an image that will be subjected to further processing	Outlining involves drawing a line around the area(s) to be selected. Similarity tools allow one to identify a small area and use it to define a basis for seeking other similar areas. Exclusion tools allow one to identify a portion, and then select everything else. Once initially identified, masking tools allow one to cover an area and then process either the covered or noncovered areas
Tone scale adjustment	Brightness contrast curve adjust dodge burn equalization	To adjust the relative darkness, brightness, and rate of change of brightness within an image	Increasing the brightness makes the lighter portions lighter while contrast adjustments change the relative levels of bright areas relative to dark ones. Curve adjustment tools allow one to apply different amounts of adjustment to various portions of the tonal scale. One can increase the contrast in the bright areas and at the same time decrease the contrast in the mid-scale areas. The dodge and burn tools allow one to apply these adjustments to a geometric area instead of a tonal range
Color adjustment	Correction change copying	To change the coloration of either a full image or parts of an image	In color correction there are indicators of what the original coloration should have been, or the photographer is making adjustments to render colors of familiar objects in a color so that it can be recognized how those items should appear. Sometimes it is desirable purposely to change colors to highlight certain features of an image and there are several tools for accomplishing this, including the means to copy, directly change, or compute new colors based on image content. Any adjustments beyond simple color correction will require description and justification
Edge adjustments	Sharpening, blurring	To render the edges of objects in an image either more clear or more diffuse	There are a wide range of tools for both sharpening and diffusing images, but, as a general rule, they all involve changes in contrast only along edges. If edge contrast is increased, the edges appear sharper and, if the contrast is decreased, they are more diffused. These tools are useful up to a point, and then there is noticeable indication of image manipulation. Also, it is not possible to reconstruct what was never there in the first place

Table 6 Continued

Technique class	*Specific techniques*	*Objective*	*Summary description*
Defect removal	Cloning redeye, despeckle writing airbrush	To correct for known accidental image defects such as dust spots and redeye effect	Cloning copies image values from one area and writes them into another. It is a tool to be avoided in investigatory work since it begs questioning of the degree to which one altered an image. This is the tool one would use to add or remove items from a crime scene, put a person's face on another's body, etc. Redeye, despeckling tools are less inclined to support gross alteration. Writing involves the direct addition of information to an image that is not part of the original scene and the tool should only be used with clear need and clear description
Frequency filtering	Fourier spectral, other	To accentuate or remove patterns from an image	An image is nothing but a series of changes of brightness over space on a surface. As such they can be represented by a sum of sine and cosine waves of brightness with distance. In this way, all of the mathematically based frequency filtering techniques can be used selectively to enhance or remove patterns from images
Area and shape adjustments	Transforms perspective	Change the apparent shape of an object in an image. In the case where it was not possible to take the original photo perpendicular to the object, these tools can be used to change the apparent perspective	The area of the image containing the shape that needs to be repaired is selected and the tool is applied. These tools utilize basic geometric rules and interpolate as needed to complete local sizing

Table 7 Digital printers

Type	*Modes*	*Description*	*Pros and cons*
Inkjet	Paper transparency	Small drops of ink are applied to the surface of a receiver sheet. Several such drops are required to render a picture element, or pixel	Inexpensive; printer inks are moderately expensive. Can write to plain paper as well as to glossy, photolike paper. Does not make high-quality transparencies since inks scatter light. Printing speeds tend to be relatively low. Image stability can vary
Dye sublimation	Paper transparency	Dye is fumed off a coated ribbon and applied to the surface of the receiver sheet. The amount of dye applied in each location can be adjusted so that the number of dots and the number of pixels are the same	Devices are somewhat expensive, as are the materials. It makes high-quality paper prints and transparencies. Printing speeds are relatively high. Image stability is very good
Photographic paper	Paper	Laser beams are used to expose regular photographic paper. Usually the printing device is attached to a mini lab paper processor such that the same device can be used to process traditional silver halide photos as well	The device is somewhat expensive, but the paper is relatively inexpensive. Printing speed is fairly high. Image quality is very high and image stability is quite good
Photographic film	Negative or transparency film	Laser beams expose normal slide or negative films. The film is then processed normally to produce either negatives, or, more commonly, slides	The device is somewhat expensive. The image quality and stability are both excellent

smaller monitors in the jury area so that jurors have access to a personal, close-up view. The key factors in choosing a projector are brightness, resolution, and contrast ratio. Common today are projectors with at least 1500 lumens or more, and screen resolution of 1024×768 pixels. Contrast ratios of 200 to 1 are relatively easy to find. Almost all of the better projectors will also accept video signals and play audio.

Data Storage

When using photographic film, the film itself is the storage medium. To assure long-term stability of the images, they should be stored in a cool, dry, dark location. It is also important that the films are properly processed. Failure to remove certain chemicals from the film can lead to degradation during storage. A reliable filing index system must be developed so that a future user can find an old piece of film.

Storage of digital images involves additional and different issues. There are three main concerns: file format, storage medium, and filing system.

Digital images reside in computer files, and these files must adhere to a strict file format for them to be readable in the future. When presented on a screen or sent to a printer, an image has a certain number of pixels, and each pixel is defined by three numbers (for a color image). Consider an image with 6 million pixels, laid out in 2000 rows of 3000 pixels. If this is a color image, then each pixel has three numbers. Thus, the content of the file comprises 18 million numbers (there is additional header and trailer information also associated with each image file). This is a large file, and if one were to store a significant number of these files, the storage requirement for the overall system would become quite large.

Experimenters have found that there is a substantial amount of redundant information in the typical image and that steps can be taken to remove the redundancy. This is known as compression. If it is done without losing any essential information, the process is called "lossless compression." On average, one can achieve lossless compressions of as much as 2 to 1. Thus, the 18 million numbers (18-Mb) file can be reduced to 9 million without loss of information. When the file is opened to show the image, all of the original information will be intact. The most common such file format is called TIFF (tagged image file format).

In addition to lossless compression methods, there are "lossy compression" methods. These utilize complex mathematical relationships and are able selectively to eliminate information that is very unlikely to be important to the substance of the image. The most common such method is called JPEG (joint photographic experts group) and it has the advantage of being variable. The investigator can adjust the amount of compression that is applied. It is important to note that higher compression results in increased amounts of lost information. In addition to losing information, JPEG compression creates and inserts artifacts in the image. Again, the greater the degree of compression, the greater the insertion of artifacts. Modest levels of JPEG compression, achieving compression ratios of 5 to 1 or less, are generally quite satisfactory. There are several file formats and some of these are listed in Table 8.

Once the format issue has been resolved, one needs to choose a medium for storage. Some systems rely on servers that are backed up and protected as the means of archival storage. Others write the files to be archived to stable, write-once media such as WORM (write once, read many) CDs. The server approach is convenient for the end-user and, if properly maintained, is quite satisfactory. It has a downside, however. In forensic work, material must often be kept for decades, and there is a very low likelihood of calling any of this material up after the first few years. The result is that very large amounts of live storage space are dedicated to materials that may never be retrieved. The utilization of separate CDs, on the other hand, provides reliable long-term storage capability, but it does not require large amounts of active storage. The problem with CD storage is that of updating old records as technology evolves. For example, if DVD technology starts to replace CD technology significantly, then it would be necessary to call up large numbers of CDs and rewrite them on to DVDs. In practice, both approaches are being followed successfully today.

Summary and Conclusions

The evolution of new digital photographic technology has had a significant impact on all applications of photography, including forensic medical work. The trend will not stop any time soon. The result has been to expand greatly the capabilities of the investigator to document and analyze evidentiary material. Fortunately, there are organizations that are working to evaluate technology, recommend practices, and provide training. These include government-based organizations such as SWGIT, which is sponsored by the US Federal Bureau of Investigation. There are similar efforts in other countries and these can be found through national police forces. In addition, there are specialized organizations such as the Institute for Forensic Imaging, which is affiliated with Indiana University and is located in Indianapolis, Indiana, USA. Book and magazine publishers have developed good reference literature supporting this

Table 8 Common file formats

Format	Type	Compression	Comments
TIFF	NC	None	A robust and widespread format that does not compress the image. Often recommended for archiving
TIFF-LZW	LLC	2:1	Based upon the standard TIFF format but adds lossless compression
JPEG	LC	2:1 5:1 >10:1	A widespread file format that utilizes lossy compression. The user can adjust the amount of compression that is actually applied. At low levels, it is almost impossible to detect the losses. As the level of compression is increased, the losses increase, becoming quite noticeable beyond 10:1. Along with losses, this format inserts artifacts into images
PICT	Optional	Optional	Primarily designed for use on Apple Macintosh computers. Compression is optional and different routines, including JPEG, can be chosen
EPS	NC	None	Specific to the Adobe PhotoShop software
RAW	NC	None	Several professional digital cameras offer a RAW image file format. Each camera has its own version. These generally preserve more image details but require special techniques. They are primarily used by professional photographers and graphic artists
PCD	VLC	4:1	One of the earlier image file formats was Photo CD, developed by Eastman Kodak for home use. While this format is lossy, it preserves the image information that people can see, hence the term ''visually lossless.'' This format is no longer in widespread use
GIF	NC	none	Originally designed for use in web pages, it allows for transparent pixels. It suffers from a limited range of colors and is losing popularity
JPEG 2000	LC	<100:1	A very-high-quality compression is achieved, that will allow reductions of up to 100:1 or so with minimal image degradation. It is not available as ''freeware'' and so is not yet in widespread use
Fractal	LC		Very-high-quality system, but difficult to use

NC, no compression; LLC, lossless compression; LC, lossy compression; VLC, visually lossless compression.

evolution. Some of the literature is primarily scientific and describes the principles and how technology is implemented. Other writings are designed to help the practitioner learn how to apply the tools and techniques to advantage.

See Also

Crime-scene Investigation and Examination: Collection and Chain of Evidence

Further Reading

Blitzer H, Jacobia J (2002) *Forensic Digital Imaging and Photography*. London: Academic Press.

Burdick H (1997) *Digital Imaging Theory and Applications*. New York: McGraw-Hill.

Clark S, Ernst M, Haglund W, Jentzen J (1996) *Medicolegal Death Investigator*. Big Rapids, MI: Occupational Research and Assessment.

Giorgianni E, Madden T (1998) *Digital Color Management*. Reading, MA: Addison Wesley.

Hinkle D (1990) *Mug Shots*. Boulder, CO: Paladin Press.

Jacobson R, Ray S, Attridge G, Axford N (2000) *The Manual of Photography,* 8th edn. Oxford, UK: Focal Press.

Langford M (1985) *Advanced Photography,* 5th edn. Oxford, UK: Focal Press.

Meyer-Arendt J (1995) *Introduction to Classical and Modern Optics,* 4th edn. Englewood Cliffs, NJ: Prentice Hall.

Miller L (1998) *Police Photography,* 4th edn. Cincinnati, OH: Anderson.

Pedrotti F, Pedrotti L (1993) *Introduction to Optics,* 2nd edn. Upper Saddle River, NJ: Prentice Hall.

Redsicker D (1994) *The Practical Methodology of Forensic Photography*. Boca Raton, FL: CRC Press.

Russ J (1995) *The Image Processing Handbook,* 2nd edn. Boca Raton, FL: CRC Press.

Russ J (2001) *Forensic Uses of Digital Imaging*. Boca Raton, FL: CRC Press.

Radiology, Overview

W A Murphy, MD Anderson Cancer Center, Houston, TX, USA

Scope

Medical examiners and coroners are responsible for investigating all instances of human death by homicide, suicide, accident, injury, hazardous substance, or during custody, or if unattended by a physician, or if otherwise sudden or suspicious. Since such circumstances encompass the full range of human behavior and biology, broad expertise is necessary to unravel the facts of each death, to assure the greatest quality in the assessment, to interpret those facts in their proper context, and to present the facts and conclusions in a logical and effective manner. As a result, many scientific disciplines engage in death investigation.

Forensic radiology is the portion of science that deals with the relation and application of medical imaging facts to legal problems. It contributes to death investigation, medical malpractice, paleopathology, and examination of inanimate antiquities such as pottery, paintings, and musical instruments. This article only examines forensic radiology in relationship to death investigation.

Regarding death investigation, forensic radiology is a method that documents the anatomical features of the individual who died. It is based upon detailed knowledge of human anatomy, of the medical conditions that affect people, and of the imaging methods that display normal and pathological anatomy. Diagnostic radiologists are clinical experts who apply radiological methods to document anatomic features present at death. There are no subspecialty training programs that produce forensic radiologists. Such experts arise after clinical specialty training and certification when individual diagnostic radiologists develop a personal interest in forensic matters and learn by experience. Some medical examiner and coroner jurisdictions have attracted such interested radiologists. Working with volunteer diagnostic radiologists, forensic pathologists provide on-the-job training in death investigation. In return, diagnostic radiologists contribute their specialized expertise.

Team Effort

Forensic radiology is not practiced in a vacuum. Team effort is required for maximal success. Death investigation is initiated by police officers who are the first professionals to arrive on the scene. This officer or a professional death investigator is responsible for the integrity of the scene and the gathering of information regarding the circumstances surrounding the death. Once the body is removed from the scene, the forensic pathologist assumes responsibility for the scientific facts regarding the remains, including laboratory tests, imaging tests, and an autopsy.

A radiological technologist works under the supervision of the forensic pathologist to obtain the best possible images at the appropriate stage of the investigation without alteration of the remains. Since images are best interpreted within the standard conventions of clinical medical imaging, the technologist must adhere to these requirements even when inconvenient due to the condition of the remains.

The forensic radiologist should freely communicate with the death investigator, the imaging technologist, and the forensic pathologist to be certain that the correct facts are available. This ensures that interpretation of the images is in a proper context and presented in a logical and professional fashion. The characteristics that define a worthy forensic radiologist include inquisitiveness, dedication to public service, integrity and objectivity, and a willingness to testify in court. The forensic radiologist should define him- or herself as a cooperative partner and be willing to delve deeply into the complexities of the forensic sciences. The accuracy and success of future legal proceedings depend upon excellence of the team effort.

History

While studying the properties of cathode rays in a vacuum tube, the German physicist Wilhelm Conrad Röntgen (1845–1923) discovered the X-ray on November 8, 1895. On December 22, 1895, using his wife's hand he obtained the first human X-ray image. He mailed this image to colleagues in Europe on New Year's Day 1896 and an international sensation ensued. The ability to see through objects and within the human body fascinated the world. From this serendipitous beginning, the specialty of diagnostic imaging emerged. Today, imaging has subspecialties, certifications at several levels of expertise, new technologies every decade, and daily refinements.

During 1896, the first year following the discovery, X-ray pictures were used as evidence in a spectrum of legal matters. Cases in Canada, the UK, France, and the USA included X-ray evidence of gunshot wounds, negligence, malpractice, worker's compensation, and public transportation injury. These experiences set the foundation for the intensive use of imaging evidence that is so common in modern legal proceedings.

To achieve appropriate recognition, status, and acceptance in court, the court had to consider the accuracy and trustworthiness of X-rays. This happened quickly and generally followed the principles previously determined for photography. Of the several court cases in 1896, one in the USA became an accepted landmark regarding admissibility of the X-ray as scientific evidence. A young law student in Denver fell and sustained a hip injury. Upon examination, the treating surgeon found no evidence of fracture and recommended treatment for a contusion. Later, other surgeons diagnosed a femoral neck fracture and disagreed with the initial therapy. Thus, a malpractice action was initiated against the first surgeon. Before trial in December 1896, X-ray pictures of the hip were obtained. The defense argued that since the actual bone could not be seen, there was no proof that the X-ray actually represented truth. A defense expert witness explained how impossible it was to obtain images of complex hip anatomy. The plaintiff attorney displayed X-ray images of the injured hip alongside a normal hip. Following the theatrics, Judge Own LeFevre ruled:

> Modern science has made it possible to look beneath the tissues of the human body, and has aided surgery in telling of the hidden mysteries. We believe it to be our duty in this case to be the first ... in admitting in evidence a process known and acknowledged as a determinate science.

As with photographs, court cases tested the correctness of the content of X-ray images. The validity of photographs had been found to require certain skills, in particular the expert skill of the person taking or developing the photograph. Likewise, X-ray images were found to require expert verification and interpretation. Finally, X-ray images were determined to be secondary evidence. They could not stand alone, but were to be used by the expert to illustrate and clarify the expert's opinion.

Resulting from a series of judicial decisions in many countries, today X-ray images are admissible in courts of law, are accepted as scientific evidence, and provide a factual basis in support of expert opinion. The two major forensic applications of radiology are identification of human remains and documentation of injury.

Identification

Commonly, relatives or other persons visually identify the deceased with support by circumstantial evidence such as location where found (home, business, automobile), clothing worn, and forms of identification present (such as photoidentification cards). Unfortunately, simple visual identification with additional circumstantial corroboration is not possible with human remains that are decomposed, incinerated, dismembered, or skeletonized. In these situations, other methods of identification are utilized, but each has shortcomings. Forensic odontology is ineffective when teeth are absent or when no previous records exist. Fingerprints only provide identification when postmortem prints can be gathered and when matching prints are on record. DNA typing is only effective when other appropriate DNA is available for matching.

Identification by medical X-ray is effective for two major reasons. First, citizens of industrialized countries often obtain medical X-ray examinations. In the USA, the number of X-ray examinations per 100 citizens per year has steadily risen. In 1964, just over 30 examinations per 100 persons per year were obtained. By 1980, that number reached just under 60 examinations. Today, the number is estimated at 80 examinations. Records are the brackets that frame people's lives. Medical documents are important and maintained for long periods of time. Some X-ray files are maintained for 5 years, others for 10 years, and still others for the lifetime of the patient. Therefore, medical X-ray images exist for the vast majority of citizens and are readily available.

Second, each person's bone structure is unique. Just as DNA is individually unique, the anatomy (facial features, fingerprints, and bone structure) it codes is also unique. Bone is structured as a cortical sheath with internal trabeculae. Bone slowly replaces itself over many years; it is faithful to its structure. The minute details of cortical and trabecular patterns are specific for the individual and durable over long timeframes.

Moreover, bone resists destruction. Putrefaction may destroy soft tissues through enzymatic liquefaction, but the bone remains unaffected. Fire may burn away the soft tissues and char the surface of the bone, but the fundamental structure of the cortical and trabecular bone remains (**Figure 1**). Adipocere formation may alter the appearance of all soft tissues, but bone is totally spared (**Figure 2**). When a body is dismembered, bones remain. Bone is always available unless it has been mechanically destroyed in a deliberate manner – an exceedingly rare situation.

The magnitude of problem identifications is between 1.5% and 2.0% of the cases processed in forensic jurisdictions. Thus, for an office that accrues 2000 cases a year, the number requiring scientific identification is 30–40 cases. Identification is important to: (1) satisfy relatives that the unrecognizable remains are indeed their loved one; (2) prove death for financial matters, primarily survivor benefit; and (3) prove that a victim exists for legal action. These reasons persuade the medical examiner or coroner to provide a sound scientific identity in as short a time as possible. Dependent upon the resources available, DNA, fingerprint, dental, or medical X-ray comparisons may alone or together provide the scientific identification.

Availability of antemortem images is the fundamental requirement for scientific identification. Scientific identification by forensic radiology is only as successful as the death investigation is at establishing presumptive identity(s). Once possible identities are determined, relatives, friends, or acquaintances are interviewed to define a past medical history. Typically the investigator learns of hospitalizations, emergency room visits, or episodes of medical care, any of which

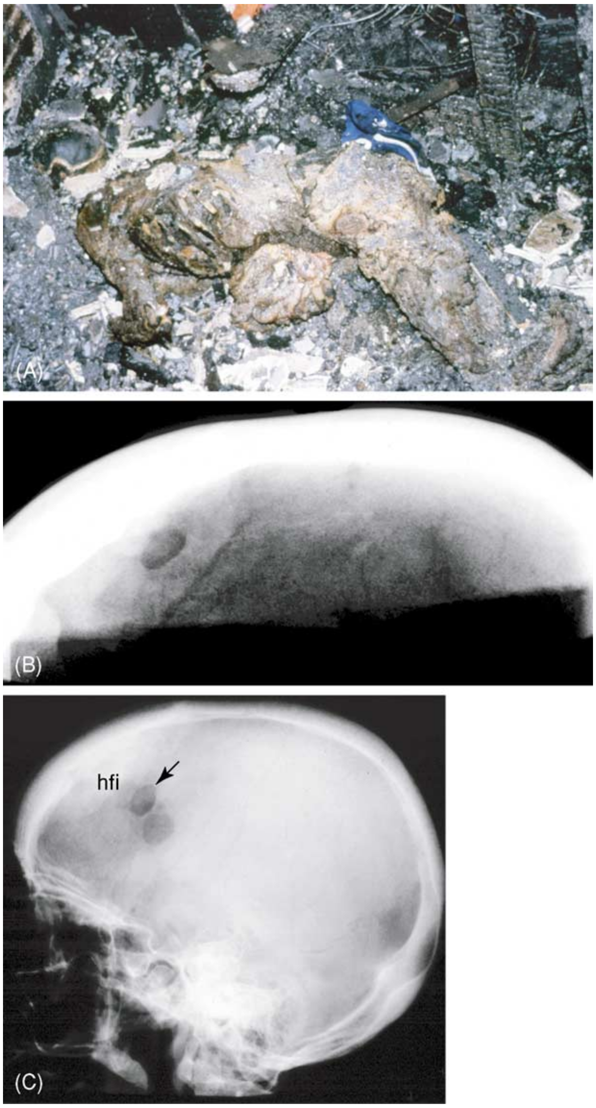

Figure 1 Identification of incinerated remains. (A) Photograph of scene in vacant structure shows a body burned beyond recognition; the skull is toward the upper left and the knee toward the lower right. (B) Radiograph of skullcap was obtained after autopsy but before presumptive identity was determined. (C) Antemortem skull film shows hyperostosis frontalis interna (HFI), a normal variant, and a surgical burr hole (arrow), features that exactly match the postmortem image. Scientific identification was successful. (B) and (C) reprinted with permission from Murphy WA, Spruill FG, Gantner GE (1980) Radiologic identification of unknown human remains. From *Journal of Forensic Science* 1980; 25(4): 731. Copyright ASTM INTERNATIONAL. Reprinted with permission.

may provide medical X-ray images. The large amount of medical care provided increases the likelihood that one or more antemortem images of a person will be available.

Successful comparison of antemortem and postmortem images depends on their technical similarity. Therefore, the radiologic technologist must approach imaging human remains as if the images were being

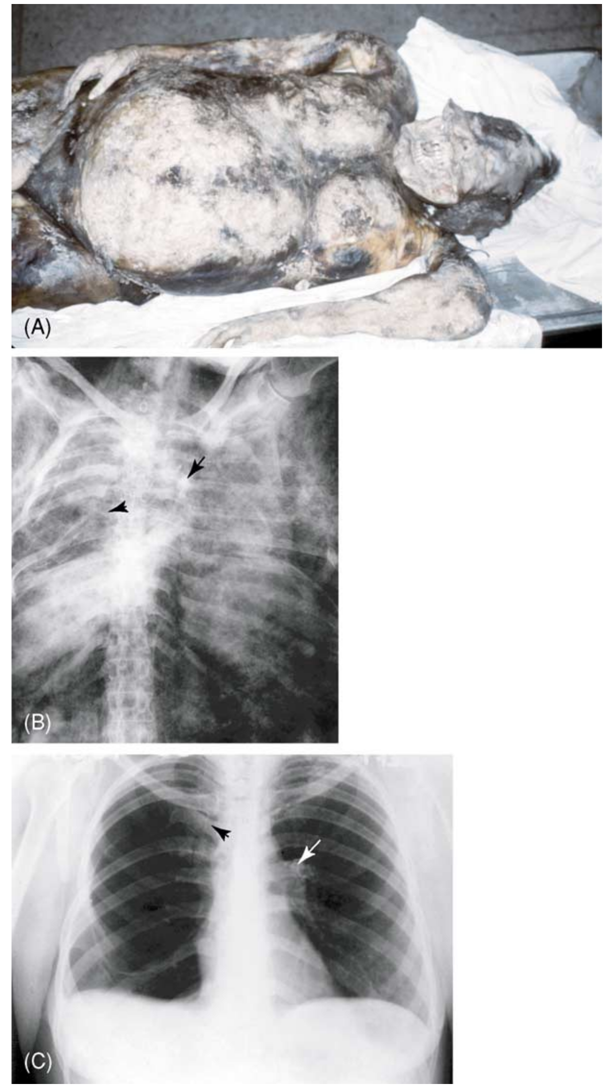

Figure 2 Identification of remains recovered from a river. (A) Photograph of recovered body shows adipocere formation and facial deformity preventing visual identification. (B) Postmortem radiograph shows gas throughout tissue caused by putrefaction, presence of a left hilar calcified granuloma (arrow), and a partially absent rib from a prior thoracotomy (arrowhead). All the left ribs are fractured due to trauma while in the river. (C) Antemortem 100 mm survey chest radiograph shows concordant features (arrow, granuloma; arrowhead, missing rib). Scientific identification was successful.

obtained in a routine clinical fashion. The technologist should attempt to replicate an ideal clinical antemortem examination when imaging the postmortem remains of the unidentified person.

The goal of the forensic radiologist is to confirm or exclude identity with scientific certainty. The task compares the images of unidentified remains with the retrieved antemortem images of the person selected as the best possible presumptive identity. The forensic radiologist screens the images and searches for concordant and discordant anatomic features. Concordance begins with detection of any major or obvious anatomic feature(s), such as presence of a specific anatomic variation that most other persons do not have. Presence of the major feature on both antemortem and postmortem images is indicative of eventual scientific identification. Other major unique features might include specific results of disease, presence of healed fractures, evidence of surgery, or presence of devices or unique calcifications. Once major features are detected and compared, general features (size, shape, and other general anatomic features of the visualized bones) are reviewed. Then minor anatomic details are surveyed, including local trabecular patterns, small cortical irregularities, or any other small details. No magic number of identical features exists that determines an exact match of antemortem and postmortem images. Usually, the evident features are simply concordant or they are discordant. If images are of standard quality, very seldom is there an in-between situation where the decision as to a match is unresolvable.

Discordance between antemortem and postmortem features occurs in several circumstances. First, when none of the antemortem and postmortem anatomic features match. The comparison excludes the proposed identity. Second, a transient discordance is encountered when an event occurred between the times when antemortem and postmortem images were obtained, e.g., all anatomic features match except for a certain explainable subset. An example would be intercurrent trauma. As long as a history of the trauma was documented, evidence of the trauma would not exclude the identity. All discordances must be adequately explained. Third, children may be difficult to identify when interval growth occurs and bones are no longer alike (Figure 3). Fourth, while not exactly discordant, poor-quality images may prevent confident analysis. In these instances the interpretation may be classified as indeterminate.

With skeletons, the tasks are more complicated. Bones must be radiographed as similar to a standard clinical image as possible. This may require several attempts with sequential repositioning of the part and adjustment of the exposure factors. At times, it helps to reassemble anatomic regions. At other times, it is more beneficial to examine bones individually. If unavoidable, random positioning with a mixture of bones still provides much useful information (Figure 4).

As skeletonized remains are often a serious challenge for the death investigator who may have few leads to identity, examination of the remains by a forensic anthropologist may provide useful information such as gender, estimated age, and stature. The anthropologist may also contribute information regarding prior health status and cause of death. The

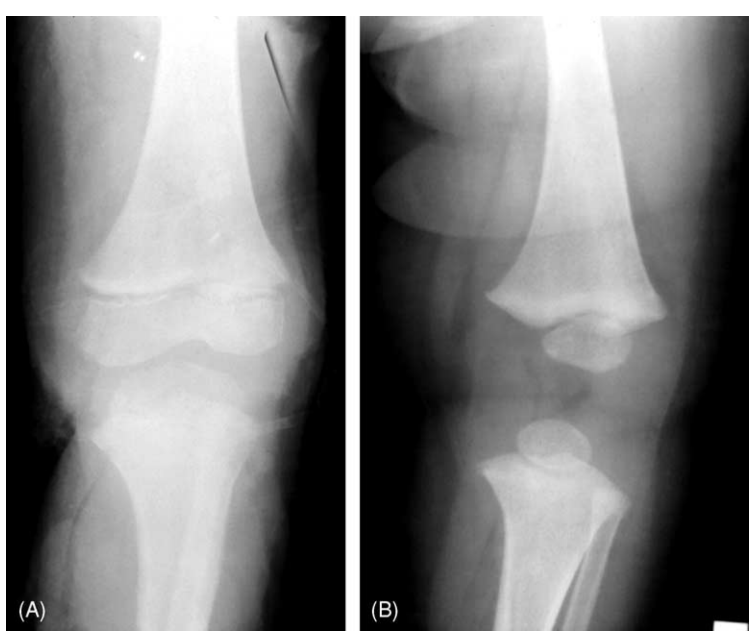

Figure 3 Interval growth interferes with identification. (A) Postmortem left knee radiograph of a 5-year-old child burned beyond recognition. Image shows burned soft tissues with bone structures normal for age. (B) The only antemortem image was from age 1. The differences between (A) and (B) are entirely due to interval normal growth. The discordant features prevented scientific identification by forensic radiology. Other forensic methods confirmed identity.

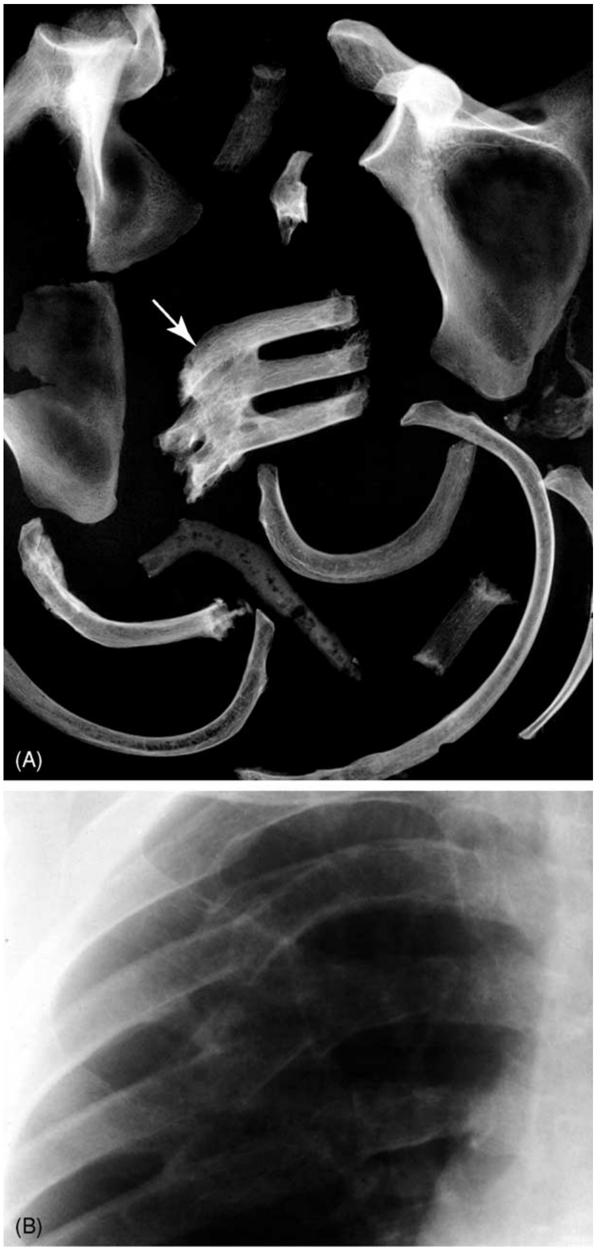

Figure 4 Identification of skeletonized remains. (A) Postmortem radiograph of random bones from skeletonized remains. Among the bones is a fragmentary set of ribs (arrow) fused together due to an injury years before death. (B) Coned-down image from antemortem chest film shows a concordant set of fused ribs. This unique feature was among many that contributed to successful scientific identification. Reprinted with permission from Murphy WA, Gantner GE (1982) Radiologic evaluation of anatomic parts and skeletonized remains. Adapted from *Journal of Forensic Science* 1982; 27(1):14. Copyright ASTM INTERNATIONAL. Reprinted with permission.

forensic radiologist can provide similar estimates. The combined information gathered by the team effort of anthropologist and radiologist may help the death investigator develop and narrow leads until a most likely presumptive identity is established.

Figure 5 Determination of species by forensic radiology. (A) A desiccated ''hand'' was found by workers on a roof. Radiograph shows unmistakable human features, even though the fifth metacarpal had fallen out and been reinserted upside-down (arrow). The source of the human hand was never determined. (B) A ''hand'' was found by children playing in a park. A radiograph shows the unmistakable features of a bear paw. No additional investigation was required. (A) Reprinted with permission from Murphy WA, Gantner GE (1982) Radiologic evaluation of anatomic parts and skeletonized remains. From *Journal of Forensic Science* 1982; 27(1):10. Copyright ASTM INTERNATIONAL. Reprinted with permission.

Effective death investigation then recovers the antemortem images. With appropriate postmortem images the forensic radiologist confirms or excludes identity based upon careful comparison.

When anatomic parts or single bones are recovered and taken to the police, the first task is to determine whether they are human (Figure 5). Generally, it is very simple for a forensic radiologist to differentiate animal anatomy from human anatomy. The forensic radiologist then examines the images to provide as much useful prior medical information about the person as possible. Any anatomic part may be sufficient for scientific comparison. Among the most well-studied anatomic sites are the paranasal sinuses. The frontal sinus displays so much variability that comparison is simple (Figure 6). Patterns of rib calcifications also provide targets for scientific comparison. The list of individual anatomic features useful for radiologic comparison is nearly infinite. Even single bones or bone fragments may be sufficient to establish a solid identity providing the quality of the antemortem and postmortem images is excellent and assuming due care is exercised by the radiologist (Figure 7).

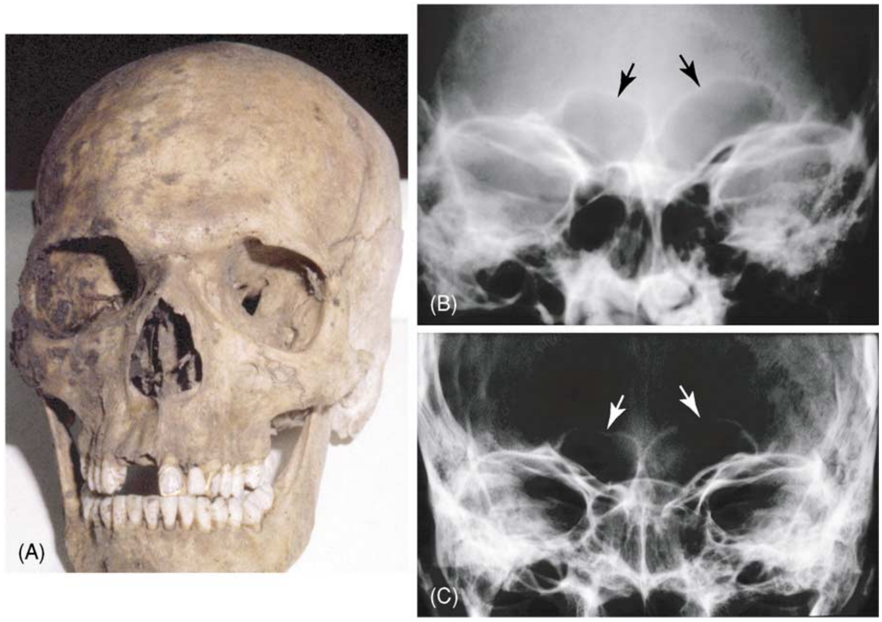

Figure 6 Identification of skeletonized remains through frontal sinus comparison. (A) Photograph of skeletonized skull. (B) Antemortem skull film obtained from medical record. (C) Postmortem skull image obtained by careful match of clinical position. The concordant sinus anatomy (arrows) established scientific identification. (B) and (C) Reprinted with permission from Murphy WA, Gantner GE (1982) Radiologic evaluation of anatomic parts and skeletonized remains. From *Journal of Forensic Science* 1982; 27(1):15. Copyright ASTM INTERNATIONAL. Reprinted with permission.

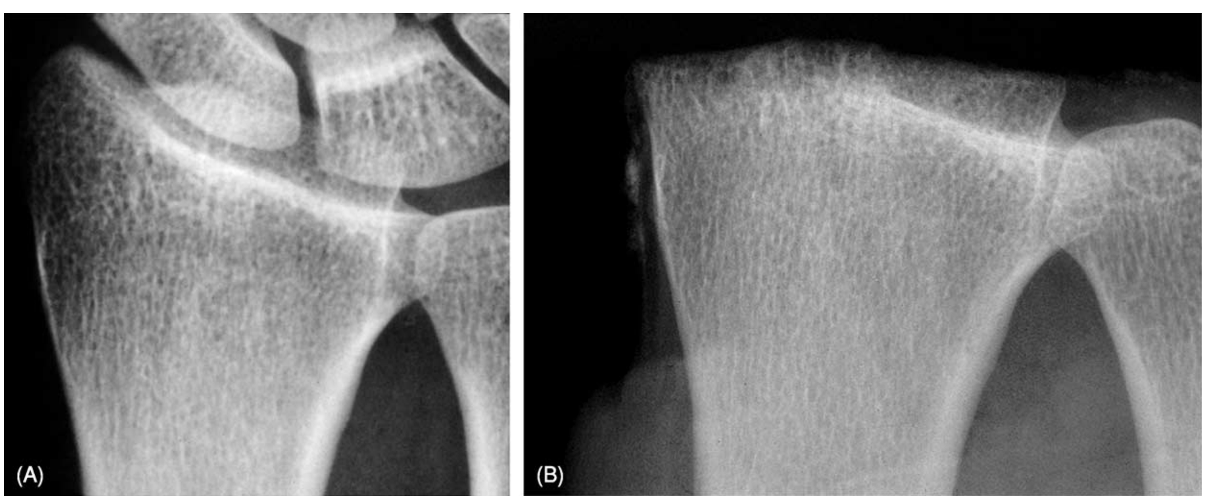

Figure 7 Identification of dismembered remains from a victim of torture whose body was mostly destroyed. (A) Antemortem wrist film. (B) Postmortem wrist image obtained with precise position and exposure shows that all details of bone size, shape, cortical contour, and trabecular pattern are concordant, yielding scientific identification.

Postmortem Artifacts Created by Scavengers

Scavengers alter and scatter human remains. These activities confound attempts to investigate the death and identify the individual because antemortem features may be destroyed or lost from the scene. Likewise, important perimortem skeletal trauma may be obscured or destroyed. The two major scavengers are rodents and canids.

Rodents create nearly all their damage with their incisors. This results in characteristic regular parallel groves of uniform pitch extending from the inner surface of a bone to its outer surface. Rodents rarely scatter human remains but on occasion transport the small tubular bones of the hands and feet.

In contrast to rodents, canids cause considerable damage. In general, the longer the interval between death and discovery, the greater the amount of damage done by canid scavengers. The magnitude of the damage depends upon tooth morphology, jaw mechanics, and the size and strength of the particular canid. Canids first deflesh the head, neck, and upper thorax, after which the upper extremities are dismembered and transported. Later the abdomen, pelvis, and thighs are consumed, with the lower extremities disarticulated and transported.

Bones are heavily damaged by gnawing, beginning with the softer cancellous articular regions (Figure 8) and flat bones, moving to the more resistant shafts of long bones and skull. Carnivore tooth marks include punctures through thin bones, pits, or indentations when penetration did not occur, scoring from teeth dragging across the bone, and furrows from molars scraping the bone. Spiral fractures of long bones occur with strong-jawed larger canids. Canid activity leaves tell-tale tooth marks and crushed, splintered bone ends (Figure 9).

Radiologically, bone alterations created by scavengers must be recognized as artifacts and not misinterpreted as features associated with the cause of death or confused with other antemortem trauma. Once recognized, the scavenger-induced skeletal changes may be correctly classified and the search for other features of importance in the death investigation may proceed. Cooperation between the radiologist, anthropologist, and pathologist resolves uncertainties.

When unidentified remains are discovered, even with extensive scavenger damage, an opportunity to complete a scientific identification by comparison of antemortem and postmortem radiography still exists. At times, a search for additional scattered remains is necessary to recover missing parts of the skeleton needed to complete the confident identification.

Figure 8 Canid gnawing of long bones. Radiograph of tibia, fibula, and talus that a dog brought into its owner's backyard. The image showed unmistakably human bones. Note that the ends of the bones are gnawed away. Later, the remainder of the body of this homicide victim was recovered. Reprinted with permission from Murphy WA, Gantner GE (1982) Radiologic evaluation of anatomic parts and skeletonized remains. From *Journal of Forensic Science* 1982; 27(1):11. Copyright ASTM INTERNATIONAL. Reprinted with permission.

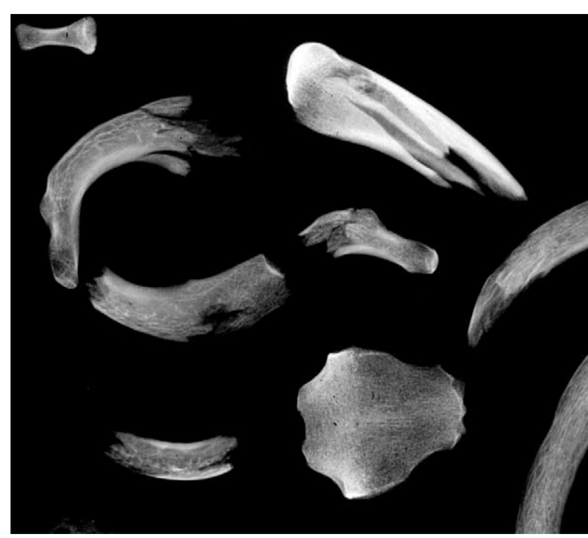

Figure 9 Canid fragmentation of small flat bones. Radiograph of assorted bones from scattered skeletonized remains shows perforated, crushed, and irregularly splintered margins of portions of ribs and clavicle.

Mass Casualties

In instances of mass casualty, the complexity of the identification effort depends on the number of casualties and the type of disaster. A multicar vehicular accident with a dozen casualties is much less complicated than an airline crash with 500 deaths. Disasters with mass casualties are challenging because the damage to bodies tends to be more (often incinerated and dismembered), the deceased are found in unfamiliar surroundings, often without personal belongings, and the remains may be commingled. The goal is to identify as many persons as possible, to the greatest surety achievable in the shortest amount of time attainable. The standard is to recover all remains with as much circumstantial documentation as is available. Then the remains should be tested with all applicable methods of identification. The combined results optimize the number of individuals eventually identified as well as the surety of those conclusions.

In 1949, forensic radiology was first tried in a disaster when the steamship Noronic burned at a dock in Toronto, Canada, and 119 passengers died, many with severe burns. Antemortem radiographs were recovered for 35 of the deceased and confident identifications were developed for 24 (70%). Also confirmed were the principles that any anatomy could be used for comparison and that a variety of skeletal features proved effective. Uniqueness of skeletal anatomy was firmly established. Since then, forensic radiology has helped identify human remains in many disasters. Well-documented examples include the March 1977 collision of two Boeing 747 jets in the Canary Islands with the loss of 576 lives, the December 1985 crash of an airliner in Gander, Newfoundland, with the loss of 256 lives, and the April 1995 bombing of the Alfred P. Murrah Federal Building in Oklahoma City, Oklahoma, with the loss of 168 lives. In each instance, multiple identification methods were employed and forensic radiology either confirmed the results of other methods or provided the unique identification.

Disasters with mass casualties have special requirements and considerations. Compulsive screening of all remains, tracking of features, and matching of findings are intense and complicated. Detailed organization, special data collection diagrams, computer programs to manage huge amounts of data, and task-oriented teams of investigators are required. Fatigue and emotional responses must be recognized and sensitively managed.

Beyond the urgency of human identification, disasters provide opportunities to study injury patterns. For an individual, the injury pattern provides hints about the mechanism of injury, the interaction with surrounding environmental structures, and perhaps the cause of death. For groups, injury patterns may shed light upon mechanisms of injury, factors that prevented survival, and similar injury patterns from previous situations. The ultimate goal is to learn enough to reengineer the physical features of a vehicle or building to improve safety and prevent future deaths and disasters.

Body Packing

Illegal transportation of drugs within human beings is common because it is simple to accomplish and lucrative. Body packers are persons who smuggle drugs from one country to another by filling balloons or condoms with drugs and then swallowing the sausage-shaped packets. If timing is accurate, the packets are transported in the alimentary canal and excreted at the target destination. If transportation is delayed or if bowel transit time quickens, the packets may pass through the intestines before the destination is reached, perhaps while still in transit. If the smuggler is unlucky, the packets may cause a bowel obstruction secondary to torsion, intussusception, or impaction. The resulting pain leads to medical attention and radiographs detect the packets. If the smuggler is particularly unlucky, one or more packets leak or rupture while in the intestine, leading to drug overdose and sometimes death. Postmortem imaging detects these packets because air trapped inside the packet or surrounding the packet outlines the shape. Travelers who are suspected of smuggling packets may be imaged upon arrival at international airports (Figure 10). Both conventional radiography and computed tomography (CT) successfully detect the drug-filled packets. Administration of an oral contrast agent may render the packets more conspicuous.

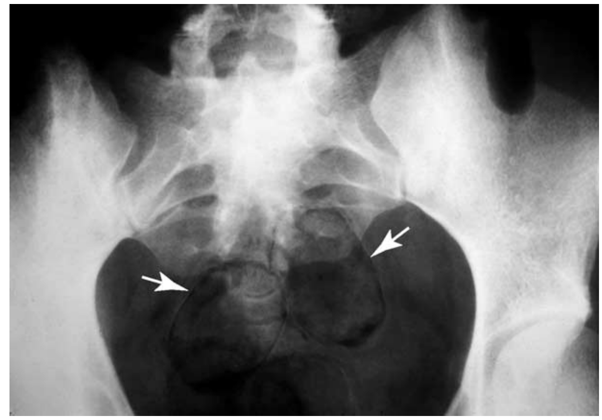

Figure 10 Body packer. Frontal view of pelvis shows packets (arrows) of drugs in rectum outlined by trapped gas.

Documentation of Injury

Forensic imaging has another major application: documentation of injury. Many physical forces accidentally kill people and there are many motivations for causing nonaccidental injury. Among accidental injuries, motor vehicle and industrial accidents are common. Among nonaccidental injuries, gunshot wounds, knife wounds, and various forms of physical abuse are most common. Bombings are deliberate acts of aggression perpetrated for many reasons.

Physical trauma results in fractures and soft-tissue injuries. Traditionally, orthopedic surgery and medical imaging define how the fractures are detected, characterized, and categorized. To detect traumatic soft-tissue injuries in confined spaces such as the skull (e.g., epidural and subdural hematomas) or the abdomen (e.g., ruptured liver and spleen), CT is sometimes used. Recently, some forensic scientists have recommended whole-body CT as a routine screening tool to detect fractures, soft-tissue injuries, and foreign bodies. As yet, CT has not been widely adopted for this function because the technology is expensive. Conventional radiography remains the imaging method of choice.

Postmortem imaging of vehicular deaths is valuable. Victims include occupants of the vehicles, pedestrians, or riders of two-wheeled conveyances struck by vehicles. Experience and academic studies documented the high frequency of injury to the skull, spine, chest, pelvis, and long bones. Studies show that the class and severity of these skeletal injuries were dependent upon the mechanisms and force of the injury. In the mid-1960s, vehicle occupants had high prevalences of skull fracture, cervical spine fracture, and craniocervical dislocation (Figure 11). Documentation of these injury patterns and their mechanisms contributed to engineering and legislation that resulted in seatbelts, front compartment airbags, and specialized child restraints. The forensic team worked to define a problem and effect corrective action.

Other injury patterns result from pedestrian–vehicular accidents. A tibia-fibular fracture occurs where an automobile bumper contacts the leg of a pedestrian. A boot-top fracture occurs in similar circumstances but with the booted foot firmly planted on the pavement. The force from the bumper is dissipated at the boot top where the leg is no longer protected instead of at the point of bumper contact.

Many industrial injury patterns have been detected and documented radiographically. Efforts by forensic scientists led to many improvements and reduced the number of victims and the severity of their injuries.

Figure 11 Vehicular accident with cervical dislocation causing death. The C1 vertebra (1) is posteriorly dislocated with respect to the C2 (2) vertebra, a finding best demonstrated with a lateral film of the cervical spine, like this one.

Gunshot Wounds

Forensic pathologists routinely employ radiographs to locate and document bullets, fragments, and other projectiles. Because this use of imaging is so routine and well established, it is unusual for a forensic radiologist to be involved. There are pitfalls to assessment of bullet caliber or shotgun range from radiologic features. Usually, radiologists do not have expertise in ballistics and casual analysis is hazardous.

Description of skull fractures caused by gunshot wounds is challenging. The fractures initiated by a bullet as it enters the skull travel rapidly until they reach an open suture or another terminus such as the foramen magnum, at which point they stop. By the time the bullet exits the skull, the entrance wound fractures have completed their course, and the new set of fractures initiated at the exit wound stop when they reach the already existing entrance fractures. Secondary fractures do not cross the existing fractures. Second bullet fractures stop when they reach fractures created by prior bullets. With carefully obtained radiographs and cautious interpretation, entrance and exit wounds may be determined and later bullets may be differentiated from the initial bullet.

Bombings

Bombs are detonated to intimidate or eliminate people. Individuals target relatives; organized criminals select rivals; drug dealers pick persons who place them at risk or fail to pay debts, and terrorists maim and kill for political ends. Most bomb-makers have particular construction styles or use certain components. Therefore, bombs tend to have personalized aspects to their construction.

Conventional radiographs are used to survey survivors or human remains following a bombing to detect bomb components (Figure 12). Three types of imbedded trace evidence (radiolucent and radiopaque materials and explosive residues) are recovered from victims. Repeated images may be required to recover all possible bomb fragments. The goal is to locate and recover as much trace evidence as possible for reconstruction of the particular bomb. In this manner,

Figure 12 Bombing victim. Radiograph of fragmented lower legs and feet shows many metallic objects, some of which are trace evidence of the bomb.

patterns of construction are identified that help to identify the bomb-maker and associate that individual with other similar bombings.

With undetonated bombs, radiographs of the device or package will show the details of construction yielding information about the detonation system, containment of the explosive, electronics that control the device, and an energy source.

Nonaccidental Injury

Abuse comes in many forms (e.g., child, spouse, elderly), occurs in many venues (e.g., homes, schools, hospitals, chronic care facilities), and takes place for many reasons (e.g., drug dependence, anger, mental illness). Forensic radiology plays a documentary role through detection and characterization of skeletal and visceral trauma. The results are particularly valuable in the courtroom. Discussion of abuse is beyond the scope of this article, with the exception of child abuse.

Child abuse is a combination of neglect, battery, and sexual molestation perpetrated on very young children. It is the fourth largest cause of childhood death under age 5 with a prevalence of about two million cases per year in the USA. At least 2000 children die each year. In 1946, John Caffey, one of the foremost pediatric radiologists, described the association of subdural hematomas and long-bone injuries in young children. Imaging has since become the primary method to identify, classify, and document the anatomic features of child abuse.

Imaging identifies sites of injury, documents patterns consistent with abuse, and helps establish a sequence of events and timeframe. A skeletal survey is used to detect fractures. Since the injuries may be very subtle, the highest-quality images are preferred. CT is the method of choice to assess blunt abdominal trauma. Either CT or magnetic resonance imaging is effective to document, localize, and classify intracranial injury. Since many abused children spend time in an emergency room or hospital, imaging examinations may be obtained from these sources.

Figure 13 Nonaccidental childhood injury. Radiograph of arm shows diaphyseal fractures of humerus (healing) (arrow) and ulna (fresh: arrowhead) indicative of at least two episodes of trauma, a characteristic of child abuse. These probably occurred when the arm was grabbed and the child thrown on more than one occasion.

Diaphyseal fracture is the most common skeletal injury, but it is not specific. Femora and humeri are frequently affected, but fractures of other long bones also occur. When multiple bones are involved and when various stages of fracture healing are present, these findings indicate more than a single episode of trauma (Figure 13). Transverse fractures correlate with direct blows. Spiral fractures correlate with torsional forces. Typically, interviews with caregivers indicate a history of trauma that is disproportionately small as compared with the magnitude of detected fracture.

Metaphyseal fractures are less common than diaphyseal fractures, but are more specific for child abuse (Figure 14). These fractures occur at the corners of metaphyses, where the periosteal attachments are very strong and the bone is weakest. Sudden traction or twisting causes the corners of the metaphyses adjacent to the physeal plates to break free. Such “corner” fractures are most common about the knee joints.

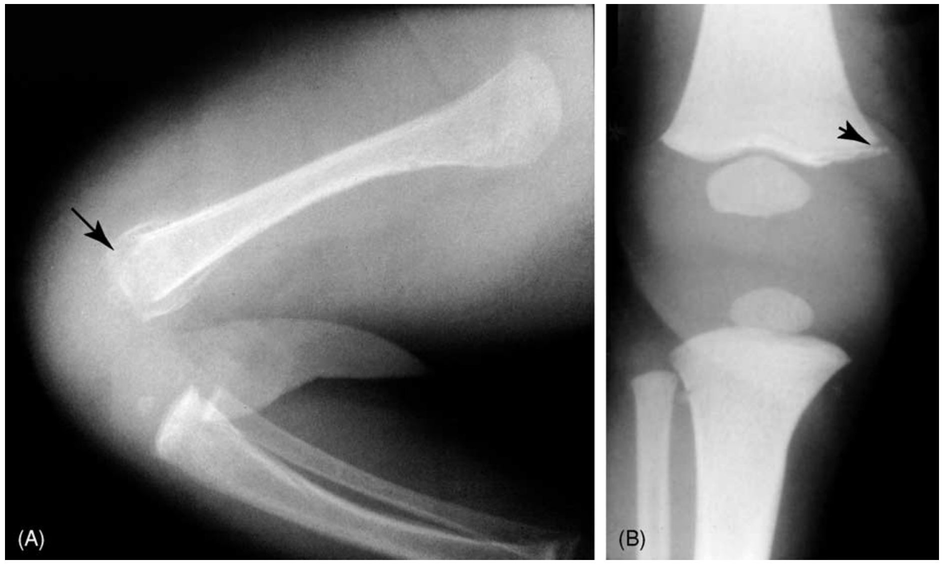

Figure 14 Nonaccidental childhood injury. (A) Radiograph of knee shows transmetaphyseal fracture (arrow) with periosteal healing indicating a subacute injury. (B) Radiograph of knee from another child shows metaphyseal ''corner'' fracture (arrowhead). Both examples are specific features of child abuse. These probably occurred when the legs were held and quickly twisted.

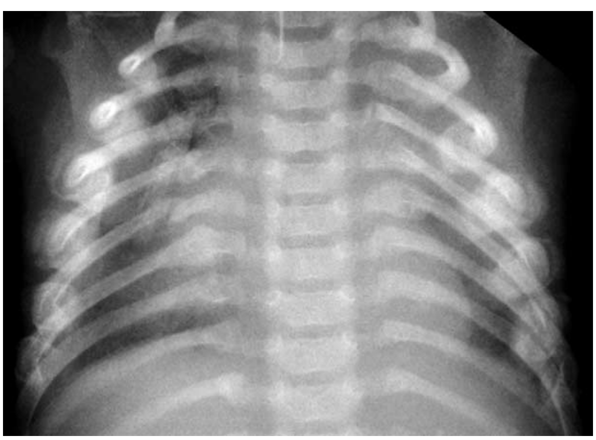

Figure 15 Nonaccidental childhood injury. Chest radiograph shows bilateral healing rib fractures. These probably occurred when the child's chest was held tightly with two hands as the child was shaken. Two sets of fractures (posterior and lateral) are present bilaterally.

Rib fractures, the third most frequent fractures in child abuse, are caused by squeezing the thorax during episodes of shaking (Figure 15). Sudden compression causes the ribs to break. Rib fractures tend to be multiple and in similar locations in a series of adjacent ribs.

Visceral injuries include duodenal and mesenteric hemorrhage, laceration of liver and spleen, and contusion of kidneys, bladder, and colon. Major chest trauma produces pulmonary contusion, pleural effusion, and cardiac injury. Direct blunt force, such as a kick, is causative.

A common cause of death, particularly for young victims, is cerebral injury due to direct blunt trauma, violent shaking, or both. Subdural hematomas, brain contusions and lacerations, and cerebral edema are all common injuries.

The forensic radiologist must be prepared to supervise the radiographic examination to ensure optimum positioning, spatial resolution, and exposure factors. Otherwise minute corner fractures or other subtle injuries may escape detection. The forensic radiologist must be certain the detected injury patterns are consistent with abuse and cannot be attributed to some other situation or condition. He/she must be prepared to go to court to present and defend the opinion in an evidence-based scientific manner.

Summary

For many reasons, medical examiners and coroners may not have established partnerships with radiologists. When the facilities in which each work are geographically separate, cooperative efforts are inconvenient. Possibly, medical examiners and coroners do much imaging themselves and feel comfortable being alone. Perhaps, utilization of imaging facilities or engagement of a radiologist is too expensive. Maybe radiologists are too busy, uninterested, or wary of involvement in legal matters or with a system they do not understand. Whatever the reason, failure to build a team effort with an interested radiologist is a lost opportunity. Combined professional expertise and perspective enhance results. To a great degree, the outcomes of forensic radiology are only limited by the willingness of professionals to act as a team, to follow natural investigative curiosity, and to use combined imagination to solve human anatomic problems.

See Also

Head Trauma: Pediatric and Adult, Clinical Aspects; Neuropathology; **Imaging:** Radiology, Pediatric, Scintigraphy and Child Abuse; **Injury, Transportation:** Motor Vehicle; **Mass Disasters:** Role of Forensic Pathologists

Further Reading

Alker GJ, Young SO, Leslie EV, *et al.* (1975) Postmortem radiology of head and neck injuries in fatal traffic accidents. *Radiology* 114: 611–617.

Brogdon BG (1998) *Forensic Radiology.* Boca Raton, FL: CRC Press.

Gill JR, Graham SM (2002) Ten years of "body packers" in New York City: 50 deaths. *Journal of Forensic Sciences* 47: 843–846.

Haglund WD (1992) Contribution of rodents to postmortem artifacts of bone and soft tissue. *Journal of Forensic Sciences* 37: 1459–1465.

Kahana T, Hiss J, Smith P (1998) Quantitative assessment of trabecular bone pattern identification. *Journal of Forensic Sciences* 43: 1144–1147.

Kirk NJ, Wood RE, Goldstein M (2002) Skeletal identification using the frontal sinus region: a retrospective study of 39 cases. *Journal of Forensic Sciences* 47: 318–323.

Kleinman PK, Blackbourne BD, Marks SC, Karellas A, Belanger PL (1989) Radiologic contributions to the investigation and prosecution of cases of fatal infant abuse. *New England Journal of Medicine* 320: 507–511.

Kuehn CM, Taylor KM, Mann FA, Wilson AJ, Harruff RC (2002) Validation of chest X-ray comparisons for unknown decedent identification. *Journal of Forensic Sciences* 47: 725–729.

Lichtenstein JE (1996) Forensic radiology. In: Gagliardi RA, McClennan BL (eds.) *A History of the Radiological Sciences Diagnosis,* pp. 579–605. Reston: Radiology Centennial.

Lichtenstein JE, Madewell JE, McMeekin RR, Feigin DS, Wolcott JH (1980) Role of radiology in aviation accident investigation. *Aviation Space and Environmental Medicine* 51: 1004–1014.

Messmer JM, Fierro MF (1986) Radiologic forensic investigation of fatal gunshot wounds. *RadioGraphics* 6: 457–473.

Mulligan ME, McCarthy MJ, Wippold FJ, Lichtenstein JE, Wagner GN (1988) Radiologic evaluation of mass casualty victims: lessons from the Gander, Newfoundland, accident. *Radiology* 168: 229–233.

Nye PJ, Tytle TL, Jarman RN, Eaton BG (1996) The role of radiology in the Oklahoma city bombing. *Radiology* 200: 541–543.

Owsley DW, Mann RW, Chapman RE, Moore E, Cox WA (1993) Positive identification in a case of intentional extreme fragmentation. *Journal of Forensic Sciences* 38: 985–996.

Puerini S, Spruill FG, Puerini A (1977) Forensic odontology: identification problems in Rhode Island. *Rhode Island Dental Journal* 10: 5–7.

Quatrehomme G, İşcan Y (1999) Characteristics of gunshot wounds in the skull. *Journal of Forensic Sciences* 44: 568–576.

Singleton AC (1951) The roentgenological identification of victims of the "Noronic" disaster. *American Journal of Radiology* 66: 375–384.

Stewart JH, McCormick WF (1981) A sex- and age-limited ossification pattern in human costal cartilages. *American Journal of Clinical Pathology* 81: 755–759.

Radiology, Non-Invasive Autopsies

M J Thali and P Vock, University of Bern, Bern, Switzerland

Introduction

In recent times, radiology has been one of the few fields in medicine that have witnessed impressive progress: digital data acquisition and postprocessing of images have revolutionized the practice of radiology and have brought about a growing interest in this field on the part of other medical professionals. The application of imaging methods for documentation and analysis of relevant noninvasive forensic findings in living and dead persons has lagged behind the enormous technical development of imaging methods. There are only a few textbooks dealing with forensic radiology, most of which concentrate on classical roentgenographic methods and hardly cover the newer sectional imaging techniques of computed tomography (CT) and magnetic resonance imaging (MRI) in detail.

Forensic radiology, including all techniques and their many uses for forensic purpose, now is a rapidly growing interdisciplinary subspecialty of both forensic medicine and radiology.

Imaging Techniques and Historical Development

In 1895 Conrad Roentgen obtained the first radiograph of a human being: the hand of his wife. He called the new kind of rays "X-rays." Shortly after the detection of X-rays, the new noninvasive technique was used for forensic documentation purposes.

Since the 1970s, there have been several impressive new developments in radiology: ultrasonography, CT, MRI and magnetic resonance spectroscopy were developed and soon utilized for medical applications. The introduction of true tomography, increased contrast, and resolution opened absolutely new possibilities of two- and three-dimensional visualization. Diagnostic imaging is still underutilized in forensics, because its potential is less well known and also because of the cost. There is also limited access to and training for newer cross-section modalities, such as CT and MRI.

Computed Tomography

Computed tomography was introduced by Hounsfield and Cormack in the early 1970s, for which they won the Nobel Prize in 1979. CT was also called computed axial tomography (CAT), and the examinations, thus, were named CAT scans. CT uses the same technique as radiography to produce X-rays. However, to obtain transverse (axial) images of body sections, the tube rotates around the longitudinal (*z*-) axis of the body, transmitting radiation from many angular positions through the body. Within the human body, X-rays are absorbed according to the radiographic density of tissues; those not absorbed reach the detector system beyond the patient, contributing to the absorption profile of one specific tube angle. The many profiles measured during one rotation are used by the computer to calculate a density map of the body section with discrete absolute density values of all image elements (voxels). Density is expressed in Hounsfield units (HU): −1000 HU corresponds to gas, around −50 HU to −200 HU to fat, around −10 to 20 HU to fluid, 20–70 HU to solid tissue, whereas >100 HU usually means calcification; metal objects can reach very high densities, far more than 1000 HU, and may then cause streak artifacts. Historically, the first CT scanner was specifically engineered to image the brain; the total scan time was approximately 25 min. Although imaging time for one slice has been reduced to less than 1 s in the meantime, these CT scanners, now referred to as conventional CT scanners, involved alternating patient exposure and patient translation. A major advance in CT technology occurred with the development and implementation of helical or spiral CT in 1989. CT became very fast, and instead of one slice previously measured during one rotation of the tube and the detectors, a spiral (or helical) scanning technique, combining tube rotation with longitudinal transportation of the patient, allowed for acquisition of a complete volumetric data set of a body region. The most recent advance in CT technology has brought multidetector row helical CT, multiplying the measurement capacity by acquiring 4–16 or more slices during each tube rotation. As a result, CT data can be obtained faster, with thinner slice collimation and/or over a larger volume than with single-slice helical CT. With the development of "multislice CT" and current imaging workstations, the examiner is no longer restricted to axial slice review. Isotropic voxels, that is, image volume elements of identical dimension in all three directions of the space, are an ideal basis for image postprocessing using multiplanar reformation to obtain images in sagittal, coronal, oblique, or curved planes; similarly, three-dimensional presentation methods allow for specific views of the entire volume. Multislice CT offers many advantages over single-slice CT and has become the standard for CT imaging.

Magnetic Resonance Imaging

In MRI, because of the dependence of resonance frequency on local magnetic field strength, it is possible to encode spatial information by using a magnetic gradient in the slice direction. Although a large number of nuclei offer the magnetic characteristics required for magnetic resonance, medical MRI nearly exclusively uses hydrogen nuclei (^{1}H). A strong magnetic field is primarily produced by a supraconducting magnet, and gradients are temporarily superposed to minimally change the field strength during the measurement in order to encode the topographic position of specific nuclei. Radiofrequency waves of the specific wavelength matching the field strength of protons in one specific position are then used to stimulate the tissue; energy introduced into the body will be emitted again as radiowaves of identical wavelength. Their intensity depends on the delay period and characterizes the chemical neighborhood of the protons. A coil or antenna is needed for sending and receiving these radiofrequency waves. The unique advantage of MRI is its flexibility in producing variable contrast, reflecting different tissue characteristics, just by modifying the sequence (this term means the specific combination of radiofrequency waves and magnetic field gradients used to acquire a number of usually parallel images). For instance, MRI can produce separate images of the protons bound to water and of those chemically bound to lipids of the same plane of tissue. In routine practice, the majority of the MRI sequences now in use are two-dimensional techniques, producing a number of separate parallel images, whereas three-dimensional sequences produce a three-dimensional data set, similar to spiral CT.

Furthermore, a modification of the method called magnetic resonance spectroscopy (MRS) concentrates on differentiating molecules based on the minimal modification of the resonance frequency by the chemical neighborhood of ^{1}H or other nuclei. This nondestructive chemical analysis has recently gained wide clinical interest, and it has the potential to become an important forensic tool despite its low spatial resolution.

Postprocessing: Two- and Three-Dimensional Visualization

Postprocessing, particularly three-dimensional reconstruction of cross-sectional images satisfies an esthetic requirement and also has become a tool useful for representing complex anatomical structures and for the understanding of relevant forensic pathological changes and traumatic findings. Surface rendering (surface shaded display, SSD) and volume rendering (VR) displays represent the most important techniques used for three-dimensional visualization.

SSD represents a visualization technique which is well established for three-dimensional imaging of skin and bone surfaces. The key idea of surface-based rendering methods is to extract an intermediate surface description of the relevant objects from the volume data. The SSD method basically involves construction of polygonal surfaces in the data sets, whereas VR assigns a color and an opacity value to each voxel of the data set and projects the elements directly onto the image plane without the use of polygons. VR is a popular and basically more powerful technique than SSD to represent and analyze volume data. In volume rendering, images are created directly from the volume data, and no intermediate geometry is extracted; however, the volume of data to be handled is much larger than for the pure surface extraction of SSD.

History of Forensic Application of CT

The first forensic application of CT was a description of the pattern of a gunshot injury to the head. In the early years of CT application, due to limited image quality, resolution, and postprocessing techniques, only a few studies correlated pathologic findings of full-body postmortem CT to forensic autopsy. Even the introduction of spiral CT, which opened the door to three-dimensional data acquisition and processing, did not significantly increase the interest of forensic science in this new modality. In contrast, nondestructive analysis by CT has been used for many years in paleoimaging, e.g., for examining mummies.

History of Forensic Application of MRI

Full-body postmortem MRI in nonforensic cases has been described by different groups for the detection of gross cranial, thoracic, and abdominal pathology.

The Swiss Virtual Autopsy Project (VIRTOPSY)

The Institute of Forensic Medicine, with the Institute of Diagnostic Radiology, the University of Bern, Switzerland, started a research project in 2000, hypothesizing that noninvasive imaging might predict autopsy findings and perhaps give additional information. In this joint project called “VIRTOPSY” the newest generation of multidetector row CT (MSCT) and a 1.5 T MR scanner were used. Nearly 100 forensic cases have since received a full-body examination by CT and MRI before autopsy. The results of CT and MRI were correlated with the findings of autopsy.

Based on this experience, CT is the superior tool for two- and three-dimensional documentation and analysis of fracture systems, pathologic gas collections (whether air embolism, subcutaneous emphysema after trauma, hyperbaric trauma, or decomposition effects) and it also shows gross tissue injury (Figures 1–3). The scan times are short, around 1–10 min, depending on the slice thickness and the volume to be covered. Postprocessing with three-dimensional SSD and VR can provide useful visualization for use in court (Figures 1 and 2). For example, in gunshot cases, the determination of entrance and exit wounds is possible based on the characteristic fracture pattern with inward or outward beveling of the bone, respectively. CT and MRI are excellent tools for visualizing bullet tracks with hemorrhage. Metal artifacts from the bullet can appear on CT images; these effects will be reduced in the near future by metal artifact reduction algorithms. As compared to clinical imaging in trauma or forensic victims, the major drawback of postmortem CT is the lack of availability of intravenous contrast enhancement after circulatory arrest, which makes analysis of parenchymal and vascular injury much more difficult, less sensitive, and less specific.

MRI, compared to CT, clearly has a higher sensitivity, specificity, and accuracy in demonstrating soft tissue injury, neurological and nonneurological organ trauma, and nontraumatic pathology (Figures 4–7). Studies of child abuse victims confirm the sensitivity of postmortem MRI for contusion, shearing injuries, and subdural hematoma. Differences in morphology and signal characteristics between antemortem and

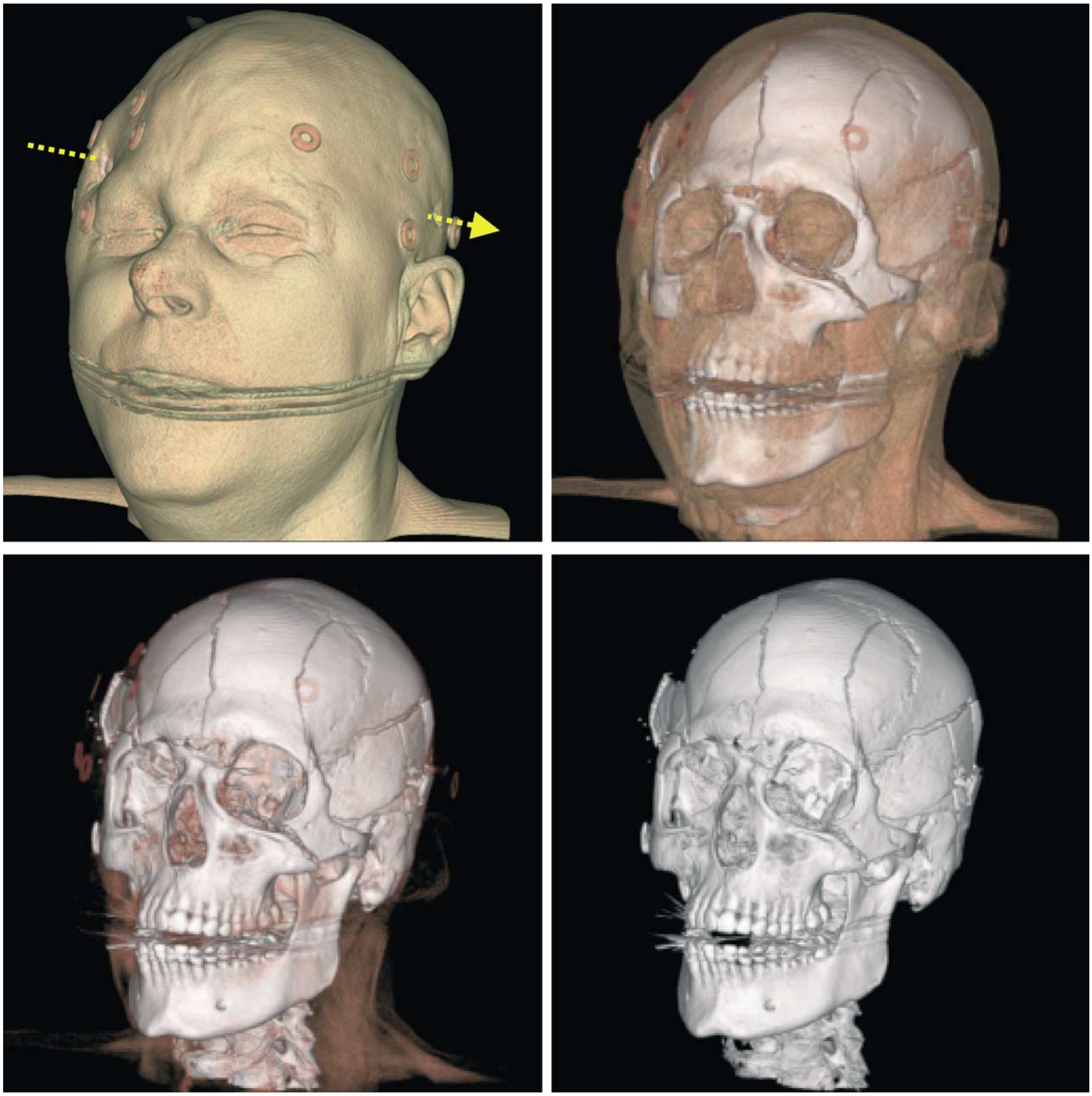

Figure 1 Gunshot entrance wound at the right temple and exit wound at the other side (arrow): three-dimensional CT reconstruction (VR and SSD) showing skin defect and fracture system. (Radiological ring landmarks are used for orientation purposes.)

postmortem MRI do exist; however, they have not yet been studied systematically. If the results of clinical MRI can be transferred to postmortem analysis, there is a great future for nondestructive analysis of visceral pathology, such as cardiac (including coronary), pulmonary, and hepatic disease.

Finally, MRS, combined with MRI, has a great potential in documenting preterminal and postmortem metabolite concentrations in tissues. Since decomposition continuously changes the concentration of chemical compounds, postmortem MRS might be helpful in determining the time of death.

Forensic Application of Radiological Microimaging: Virtual Histology

In many cases, the resolution of clinical scanners is not sufficient to answer questions relevant to forensic medicine nondestructively. This favors the idea of using microimaging methods with their much higher resolution to visualize forensic specimens. We have used micro-CT of a knife blade inside cortical and trabecular bone to determine the injury pattern and the weapon involved. In forensic soft tissue injury, retinal hemorrhage and electric injury to the skin

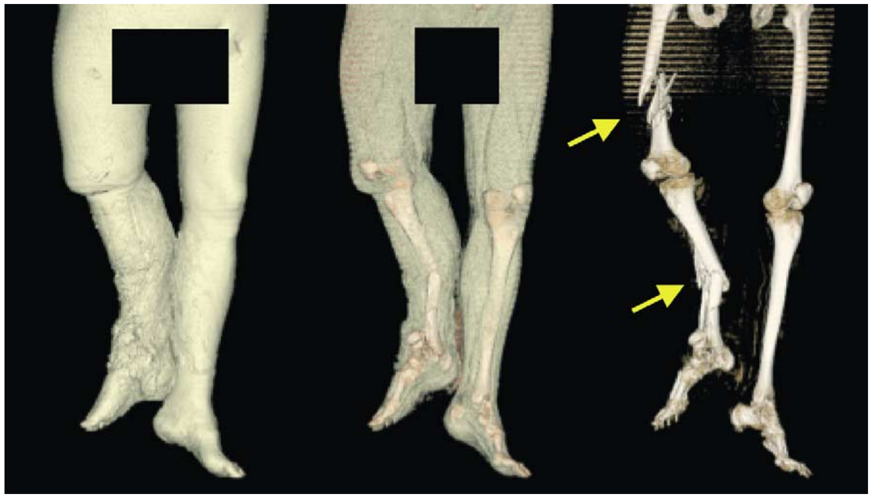

Figure 2 Three-dimensional CT reconstruction (VR) of a right leg fracture.

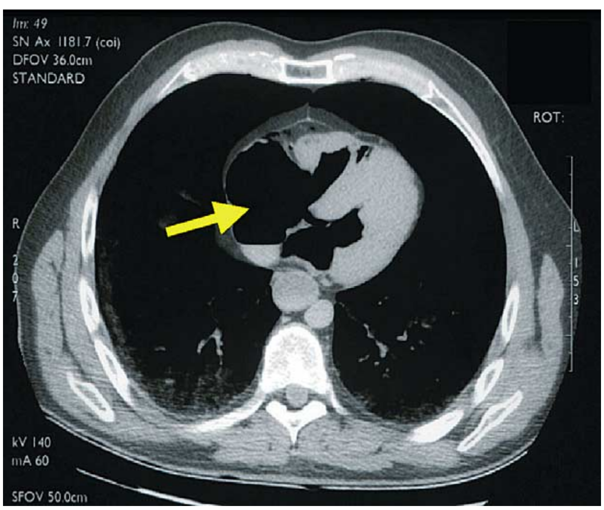

Figure 3 CT showing intracardial air embolism in heart chamber (arrow).

were studied by micro-MR (MR microscopy). We expect these new radiological cross-sectional micro-imaging methods to have a comparable impact on (forensic) histopathology, leading to virtual histology.

Outlook

Evidently imaging techniques are excellent tools for forensic medicine. Although these are similar to inspection and photography, with imaging techniques it is possible to freeze the findings at the moment of investigation without causing any damage. Freezing means permanent (analog or digital) preservation as a document of proof, whether the victim is dead and undergoing postmortem decay or surviving and losing evidence due to healing. Causing no damage is an essential prerequisite in a living person, which is

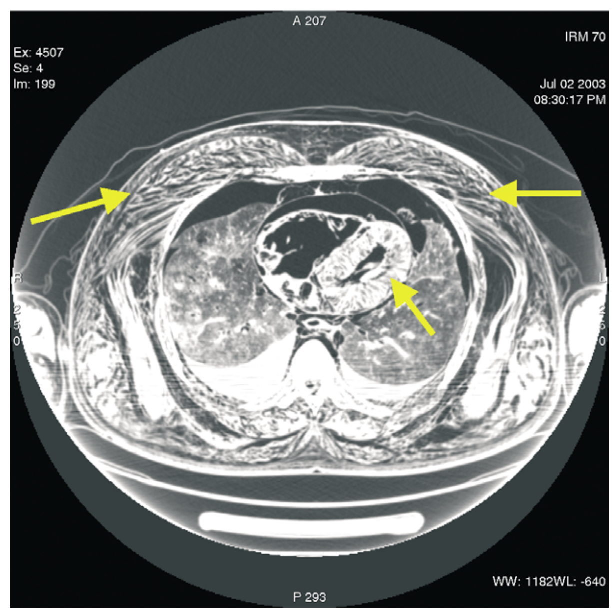

Figure 4 Decomposed body: CT showing typical signs of soft-tissue decomposition with decomposition gas in muscle and heart tissue (arrows).

indisputably fulfilled by these techniques. Even in the case of dead persons, nondestructive documentation is important for two reasons. First, it brings the information without precluding any other conservative or destructive forensic investigation. Second, it can be used in cultures and situations where autopsy is not tolerated by religion or is rejected by family members. Whether and to what degree radiological minimally invasive "virtual autopsy" will replace the classical dissection technique in well-defined situations will be decided in the near future.

Two innovative forensic documentation methods will soon be available: the combination of sectional

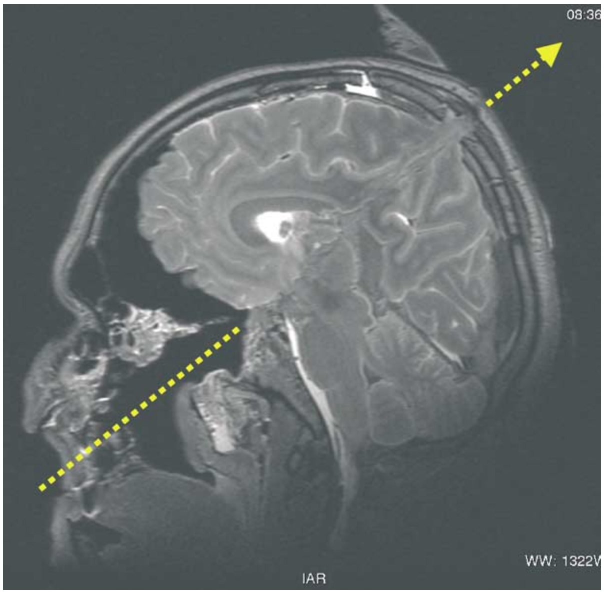

Figure 5 Gunshot through the mouth: sagittal MR image showing the bullet track (arrow) through the brain. Note the typical configuration of the exit lesion of the skull (arrowhead).

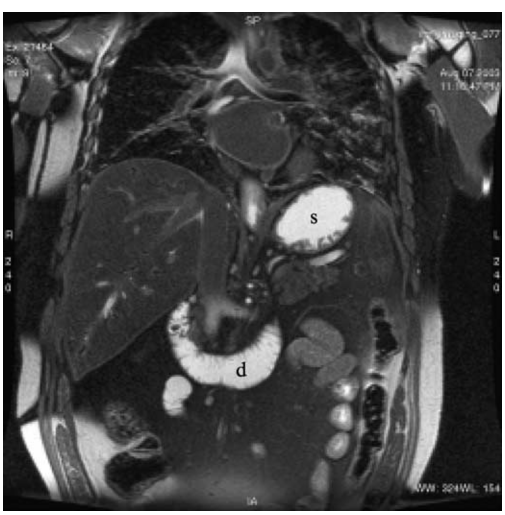

Figure 6 Coronal MR image showing swallowed fluid in both the stomach (s) and the duodenum (d) in a case of drowning. This finding is a forensically relevant feature, the so-called ''vital reaction sign,'' in drowning cases.

imaging with surface documentation methods, such as photogrammetry and three-dimensional optical scanning and the combination of noninvasive imaging with minimally invasive image-guided tissue sampling from any body location needed. Tissue samples can be used for cytologic, histologic, chemical, and microbiological analysis. Radiologic virtual autopsy offers other advantages, such as easy examination of bodies contaminated by infection, toxic

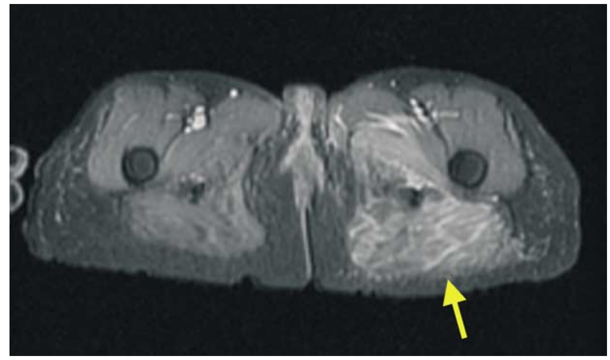

Figure 7 Axial MR image of the pelvic area showing contusion and hematoma of the left musculus gluteus maximus (arrow) after blunt force impact by a motor vehicle.

substances, radionuclides, or other biohazards. Two- and three-dimensional postprocessing helps in visualizing the findings by people not present during the examination, e.g., in court. Complete, easily retrievable digital archives will support the process of quality improvement.

Imaging technology is developing fast, and new technical solutions will be introduced soon, such as area-detector CT, high-field MRI, or moving-table whole-body MRI. They will be supported by improved two- and three-dimensional sequences and user-friendly postprocessing two- and three-dimensional software with a significant impact on forensic sciences. The cost of high-tech imaging systems, although currently often a hurdle that is slowing their routine forensic application, will decrease in the near future.

In conclusion, imaging has already proved to be a reliable tool in modern forensic medicine to answer a number of questions. It is currently limited where color is important and where *in vivo* imaging uses contrast agents distributed by the circulation and accumulated locally by a tissue leak or metabolism. In these and other situations, upcoming approaches have to undergo validation by correlation with classical autopsy before their value can be assessed. Further technical developments in radiology are likely to enhance the forensic applications of imaging.

See Also

Imaging: Radiology, Overview; Radiology, Pediatric, Scintigraphy and Child Abuse

Further Reading

Brogdon BG (1998) *Forensic Radiology*. Boca Raton: CRC Press.

Hart BL, Dudley MH, Zumwalt RE (1996) Postmortem cranial MRI and autopsy correlation in suspected child abuse. *American Journal of Forensic Medicine and Pathology* 17(3): 217–224.

Institute of Forensic Medicine and Institute of Diagnostic Radiology, Berne University (2001) "VIRTOPSY" project. Available online: www.virtopsy.com

Thali M, Braun M, Kneubuehl B, *et al.* (2000) Improved vision in forensic documentation: forensic, 3D/CAD-supported photogrammetry of bodily injury external surfaces, combined with volumetric radiologic scanning of bodily injury internal structures to provide more leads and stronger forensic evidence. In: Oliver W (ed.) 3D Visualisation for Data Exploration and Decision Making. *SPIE,* 2000, pp. 213–221.

Thali M, Taubenreuther U, Braun M, *et al.* (2001) *Micro-CT and Forensic Pathology.* Proceedings of the 80th Annual Congress of the German Forensic Society 2001. Germany: Rostock.

Thali M, Dirnhofer R, Potter K (2003) *Forensic MR Microscopy: Analysis of Blunt Forces Trauma in Skin and Subcutanous Fat Tissue*. Proceedings of the International Society for Magnetic Resonance in Medicine 2003. Canada: Toronto.

Thali M, Potter K, Dirnhofer R (2003) *From Virtopsy to Micro-Virtopsy: Virtual Forensic Histology.* Proceedings of the 81th Annual Congress of the German Forensic Society. Germany: Rostock.

Thali M, Braun M, Dirnhofer R (2003) Optical 3D surface digitizing in forensic medicine: 3D documentation of skin and bone injuries. *Forensic Science International* 137: 203–208.

Thali M, Braun M, Wirth J, Vock P, Dirnhofer R (2003) 3D surface and 3D body documentation in forensic medicine: 3D/CAD photogrammetry merged with 3D radiological scanning. *Journal of Forensic Science* 48(6): 1356–1365.

Thali MJ, Yen K, Schweitzer W, *et al.* (2003) Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI) – a feasibility study. *Journal of Forensic Science* 48(2): 386–403.

Radiology, Pediatric, Scintigraphy and Child Abuse

C M Hall, Great Ormond Street Hospital for Children, London, UK

Introduction

Nonaccidental injury or physical abuse is most commonly seen in nonambulant, totally dependent infants. It accounts for 22% of all forms of child abuse, the most common being that of neglect. The number of reported cases of physical abuse has been rising steadily over the years, partly as a result of increased recognition of the problem by clinicians, healthcare workers, and social workers, and partly because of an increasing incidence attributable to poverty, family stresses, and a general breakdown of family stability, structure, and support. Whilst abuse is most common in deprived, lower-social-class families, often with a history of substance abuse and themselves having been the subject of physical abuse in childhood, it occurs in all strata of society and across all ethnic groups.

Clinical presentation is often as a result of the superficial evidence of bruising, burns, or bleeding from an orifice or torn frenulum. It may also be as a result of a major fracture, the effects of which cannot be ignored by the regular carers, or by an acute collapse from intracerebral trauma or a ruptured abdominal viscus. Whenever physical abuse is suspected social services should be informed and it is imperative that a skeletal survey and a computed tomographic (CT) head scan should be performed. This is because many of the fractures caused by abuse are clinically silent in that they are not associated with overlying swelling or bruising, and in a similar way subdural bleeding following shaking may be occult.

Imaging Strategy

The skeletal survey should be performed in normal working hours after explaining the reasons for it to the carers. Two healthcare professionals (radiographer or nurse) should remain with the baby throughout the examination and initial each film. The skeletal survey should include:

- skull – anteroposterior (AP) and lateral
- spine – lateral
- chest – AP
- upper and lower limbs – AP
- pelvis – AP
- both hands – posteroanterior (PA)
- both feet – dorsoplantar (DP).

Additional views may be necessary. These may include oblique views of the chest to identify rib fractures, coned views of the metaphyseal regions when these are not clearly seen on the limb views, lateral long-bone views when a fracture has been identified to evaluate displacement, and a Townes view when an occipital fracture is suspected.

Delayed images after a few days or weeks may help in identifying previously unrecognized acute rib fractures and in dating fractures. Early new bone formation (periosteal reaction) at the site of a fracture is first seen 7 days after the injury and then gradually increases in size (soft callus) and consolidates (hard callus), before remodeling takes place. When the fracture is relatively undisplaced, remodeling of rib and long-bone fractures has occurred by about 12 weeks. The fracture line usually disappears between 6 and 8 weeks after the fracture has been sustained.

If fractures are identified, then other children under the age of 2 years with the same carers should be examined clinically and have a skeletal survey performed to identify clinically occult fractures. Children over this age would be expected to be able to communicate painful areas and do not require a full skeletal survey.

A radioisotope bone scan is not a routine investigation and should not replace the skeletal survey, but as an adjunct it may identify unrecognized injuries, in particular those involving the spine and ribs, which may be missed on conventional radiography. Scintigraphy, however, fails to demonstrate certain fractures. Skull fractures show no evidence of increased uptake of isotope and because normal infants' metaphyses show increased uptake, metaphyseal fractures may be missed.

A CT head scan is recommended as part of the initial investigation whenever physical abuse is suspected, even when there are no neurological signs, to identify occult and old subdural hematomas. This should also be performed on bone window settings for further evaluation of any fractures, but should not replace the skull views on the skeletal survey. Sometimes skull fractures may not be demonstrated on the CT scan when they lie in the same plane as the plane of the scan.

When the infant presents with an acute head injury, the initial CT head scan should be followed by magnetic resonance imaging (MRI) head scans for clinical management and for more accurate dating.

Cerebral ultrasound, in experienced hands, may be a useful adjunct to the CT scan in the acute phase but is not a routine part of the investigation.

If visceral injury is suspected, ultrasound is the initial imaging modality of choice, followed by a CT scan of the abdomen or a contrast study of the gastrointestinal tract.

This imaging strategy is broadly recommended by the UK Royal College of Radiologists, but certain local protocols may differ depending on specific expertise and timely availability of equipment.

The role of the radiologist is to supervise the films being performed, both their number and quality, to identify all the bony injuries and soft-tissue changes, and to give an age range for each fracture and indicate potential mechanisms of causation. Any explanations for the injuries occurring as a result of accidents should be fully explored and evaluated. The skeletal survey should be carefully examined for the radiological changes of any medical condition that might predispose to fracturing. Knowledge of normal variant findings, which may be present in the infant's developing skeleton, is essential and generally requires consultation with a specialist pediatric radiologist. A full report should be issued immediately and the findings communicated to the relevant consultant pediatrician. This process should not be delayed, even if a further opinion from a specialist pediatric radiologist is being obtained. The radiologist should recommend delayed views when appropriate for more accurate dating of specific fractures. The radiologist may be the first person to identify specific injuries associated with nonaccidental injury, for example, rib fractures on a chest radiograph performed for a chest infection, and should be personally responsible for ensuring that the relevant agencies are informed and the child is safely placed in a nonabusing environment.

Diaphyseal Fractures

The commonest presenting fracture is of a diaphyseal long-bone fracture, most commonly affecting the humerus. The fracture may be spiral, caused by an applied twisting force below the site of the fracture, or occurring when the infant is rapidly lifted by one limb, with the counter forces of gravity and the weight of the infant resulting in the body twisting. Alternatively, the fracture may be transverse (oblique), caused either by a direct blow at the site of the fracture or by an applied levering force with the pivot or fulcrum at the site of the fracture. Diaphyseal fractures are not specific for nonaccidental injury but there would need to be an appropriate accidental explanation of a significant incident to account for such a fracture in an infant. The specificity would increase if an additional injury is present, there is an inappropriate history, or if there has been delay in presentation for medical attention. Deformity may be immediately apparent if there is angulation of the broken ends of the bone to each other. Diaphyseal fractures are usually associated with overlying soft-tissue swelling from edema, which may extend up and down the injured limb, gradually developing over the course of the first 2 days. The presence of bruising will depend on the mechanism of causation of the fracture. Forces applied by adult hands cover a relatively large surface area and are usually not associated with superficial bruising. Fractures resulting from a direct blow however are more likely to have bruising. The infant experiences pain when the fracture occurs and whenever the limb is handled and on movement of the injured limb, resulting in a reluctance or inability to move it, with the limb appearing floppy. The pain is demonstrated as soon as the fracture occurs and is ongoing on being handled for about 1 week (Figures 1–3).

Figure 1 There is a transverse fracture of the upper shaft of the right femur with surrounding soft tissue swelling and loss of definition of the soft tissue planes due to edema.

Metaphyseal Fractures

Metaphyseal fractures occur at the ends (the metaphyses) of the long bones, commonly above and below the knees, and consist of a thin rim of bone detached from the adjacent metaphysis. Depending on their angulation relative to the X-ray beam they may have a "bucket-handle" appearance or appear as "corner" fractures. They are considered to be highly specific for nonaccidental injury as they are caused by applied gripping, twisting, and pulling forces applied to the ends of the bones. Rarely they are caused by shaking when the limbs flail around and are subject to torsional forces. The amount of force required to cause them is entirely inappropriate for the normal handling of an infant and they do not occur as a result of heavy-handedness, playful handling, or inexperience. They are difficult to date as they may heal without callus formation, gradually consolidating to the adjacent metaphysis. An estimate of the age of the injury may be made from the clarity or otherwise of the fracture line. When it becomes indistinct the fracture is in the process of healing and is at least 7 days old. Unless

Figure 2 (A) An oblique fracture of the lower shaft of the left humerus showing a very early healing reaction. (B) The same fracture three weeks later shows a good healing response with callus formation. The fracture line is still visible.

Figure 3 (A) Acute oblique fracture of the upper right femur. (B) The fracture two weeks later shows soft callus formation.

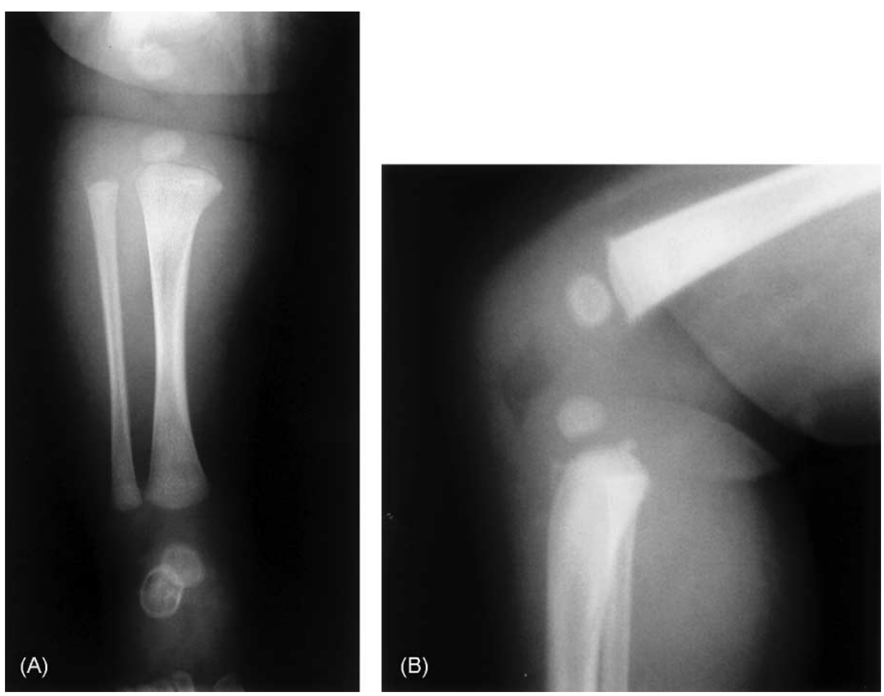

Figure 4 (A) There is a fracture separation of a right upper tibial metaphyseal fracture together with the adjacent epiphysis. The metaphyseal fracture is seen as a rim of bone giving a 'bucket handle' appearance on this frontal projection. (B) The same fracture on a lateral projection has an appearance of 'corner' fractures.

they are widely displaced from the adjacent shaft of the bone, metaphyseal fractures have completely healed by 4 weeks. They are rarely associated with overlying soft-tissue swelling or bruising and therefore are not apparent on clinical examination. Metaphyseal fractures result in tenderness on direct palpation of the injured area for a few days (Figures 4 and 5).

Figure 5 There are metaphyseal fractures of the lower end of the left femur and the upper end of the left tibia. These are both in the process of healing with consolidation to the adjacent bone and loss of definition of the fracture lines. They are therefore more than one week but less than four weeks old.

Figure 6 Multiple healing rib fractures with good callus formation are present at the posterior ends of the ribs, along the posterior arcs of the ribs and in the mid axillary line at the side of the infant.

Rib Fractures

Rib fractures are caused by severe compressive or squeezing forces to the chest and may occur at any point along the ribs, although posterior fractures adjacent to the spine are thought to be more specific for nonaccidental injury. The amount of force required to produce them is considerable, for example, they hardly ever occur as a result of cardiac resuscitation when the chest needs to be compressed by one-third of its depth to be effective. In the absence of an underlying medical condition rib fractures are highly specific for nonaccidental injury. They are not usually associated with superficial changes in the form of swelling or bruising at the sites of the fractures, although rarely there may be evidence of fingertip bruising in the position of the applied squeezing force. Occasionally the carers identify a crackling sensation, felt when the infant is picked up: this signifies a rib fracture. Rib fractures result in immediate pain and there is ongoing pain when the infant is picked up for a period of a few days. One effect of the pain from rib fractures is for the infant to breathe more rapidly and shallowly than usual and this may lead to the development of a lower respiratory chest infection. Occasionally underlying lung contusion or hemothorax may occur as a direct consequence of the chest trauma. Rib fractures may not be identified until healing periosteal new bone is seen some 7 days after they have occurred. This is because only those fractures in the same line as the X-ray beam can be identified in the acute phase (first 7 days). Oblique views of the chest help to reduce the number of acute fractures that are missed. The squeezing force causing rib fractures may sometimes be associated with a shaking action, resulting in subdural hemorrhages. If the infant dies, acute rib fractures are readily identified at postmortem examination because of bleeding, but the pathologist may not readily identify older fractures where the callus has almost remodeled (Figure 6). Specimen high-resolution radiographs performed postmortem provide more information on the number of rib fractures and other subtle fractures (metaphyseal) (Figure 7).

Costochondral Junction Fractures

Costochondral junction fractures at the very anterior ends of the ribs are difficult to identify and commonly missed. They behave like metaphyseal fractures in that they usually heal by gradually consolidating to the adjacent rib without developing callus; this makes them difficult to date with any accuracy. Whilst they may be caused by a squeezing force to the chest, they may also result from a direct blow or punch to the epigastrium. This latter mechanism is more common in young, actively mobile children, rather than in infants. There is a significant association between costochondral junction fractures and abdominal visceral injuries.

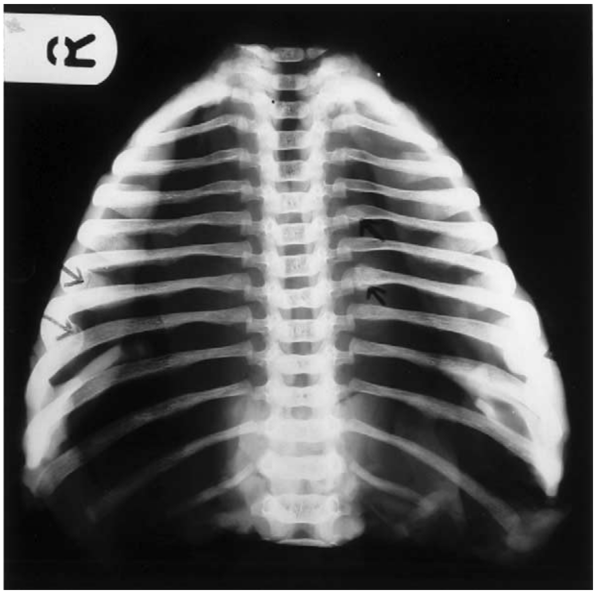

Figure 7 High-resolution specimen radiograph following dissection of the thorax at postmortem. Arrows identify anterior rib fractures which would have been difficult to identify before the postmortem.

Periosteal reactions along the shafts of long bones may occur from gripping and twisting shearing forces around the limbs. They are the healing response to damage to the superficial periosteum around the surface of the bone. Those resulting from trauma usually extend down to the metaphyses, and may be asymmetric or layered like an onion skin. To be visible on the radiograph they must be at least 7 days old. They gradually consolidate to the adjacent bone. They need to be differentiated from normal physiological periosteal reactions, which are the result of rapid bone growth and are seen in about 40% of infants under the age of 4 months. They are usually symmetrical and affect only the mid-diaphyses.

Unusual Fractures

Unusual fractures in infants are considered to be highly specific for nonaccidental injury. These include fractures of the acromion processes, first ribs, short tubular bones of the hands and feet, pubic rami, vertebrae, and long-bone epiphyseal separation fractures. Because they are unusual it is difficult to be certain of their precise mechanisms of causation. A fracture of the acromion process of the scapula is thought to be caused by forcefully swinging the infant by one arm. Fractures involving the hands and feet occur from crushing, bending, or stamping actions. Pubic rami fractures occur as a result of direct forces on the front of the pelvis. Vertebral body crush fractures are thought to occur when the infant's body is forcefully flexed or when forces are transmitted along the spine, for example, from a blow to the top of the head. Long-bone epiphyseal separation fractures occur when the limbs are forcefully pulled, pushed, and twisted (Figures 8–11).

Figure 8 The coned view of the hips shows a healing fracture of the right pubic ramus.

Figure 9 The dorso-plantar view of the right foot shows subtle healing fractures of the bases of the third and fourth metatarsals.

Skull Fractures

Skull fractures may occur as a result of accidental or nonaccidental injury and presentation may be because of an overlying soft, boggy swelling. The

Figure 10 There is a healing fracture of the base of the first metacarpal in this young infant.

Figure 11 The lateral spine shows several crush fractures with loss of height of the affected vertebral bodies in the lower thoracic region.

commonest pattern is that of a single, linear, hairline, parietal fracture, which may be seen as a result of either accidental or nonaccidental injury. Accidental skull fractures need an appropriate history of a significant incident, usually of a fall from at least a meter on to a firm or hard surface, to account for them. Even these significant domestic falls rarely result in any fracture, the incidence being of the order of 2%. Fractures resulting from accidental domestic falls are rarely associated with intracranial injuries. Patterns of skull fractures which indicate that forces greater than those normally occurring as a result of simple domestic falls of between 1 and 2 m are recognized. Each one is suggestive, but not diagnostic, of nonaccidental injury and include wide fractures (5 mm or more), fractures affecting more than one bone in the skull, multiple fractures, those crossing sutures, those which are fissured or branching, those affecting the occipital bone, or those which are depressed. Skull fractures do not heal by developing callus. They may remain visible for weeks and even months and cannot be dated from the radiographic appearances. If soft-tissue swelling is present overlying the fracture it is likely to have occurred within the previous 7 days (Figures 12 and 13).

Any isolated fracture occurring in a nonambulant infant, without an appropriate incident to account for it, should be regarded as being the result of nonaccidental injury. It should be remembered however that sometimes an accident has occurred which the carer is unable to admit and the whole family and social circumstances should be evaluated. Medically it is important to exclude any skeletal disorder which may predispose to fractures, such as osteogenesis imperfecta, a metabolic bone disease, or underlying neurological disorder. When more than one fracture is present, or there is evidence of other forms of abuse, and when they have occurred on more than one occasion without appropriate explanations, then the diagnosis of nonaccidental injury becomes more certain. Inevitably a multidisciplinary approach is required.

Differential Diagnosis

Infants who present with multiple fractures need full evaluation for possible medical causes of undue bone fragility. In general, by the time the infant is sustaining fractures from an underlying medical condition, there will be some evidence of specific and diagnostic findings on the radiographs. These need to be evaluated in conjunction with clinical and biochemical findings and with the family history. Osteopathy of prematurity is seen in a small proportion of neonates of 32 weeks' gestation or less who have not had

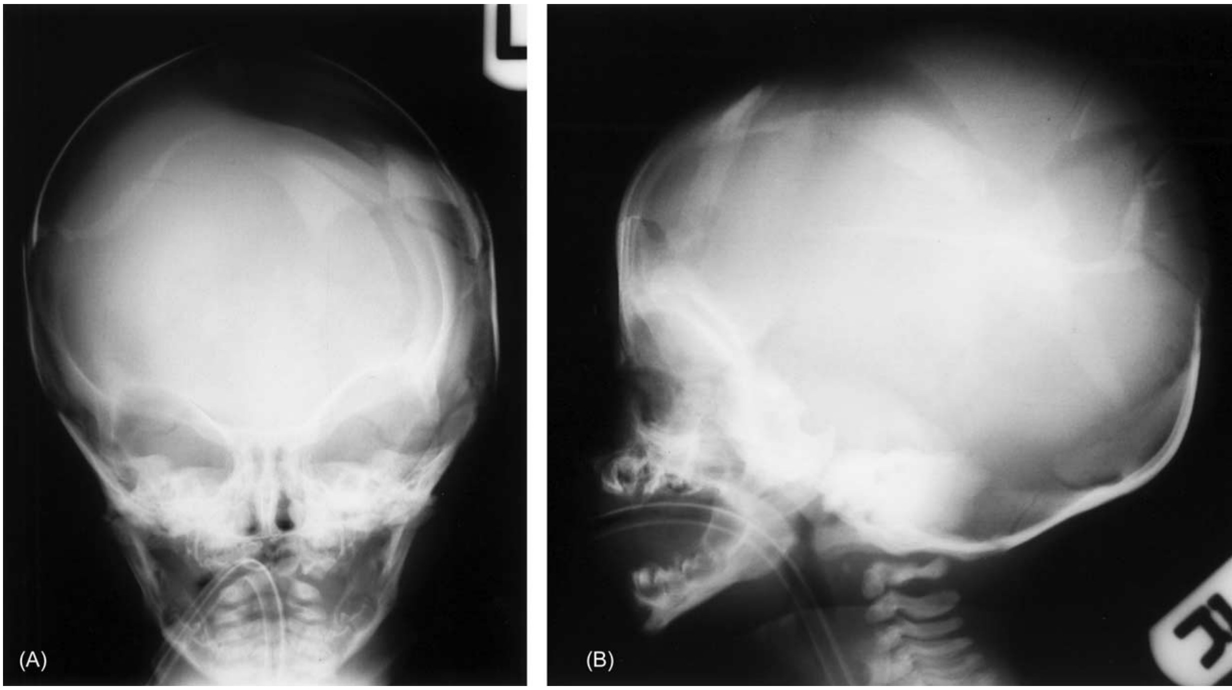

Figure 12 (A) Frontal and (B) lateral views of the skull showing multiple, depressed, wide fractures affecting serval bones in the skull, all fractures suggesting significant impacts.

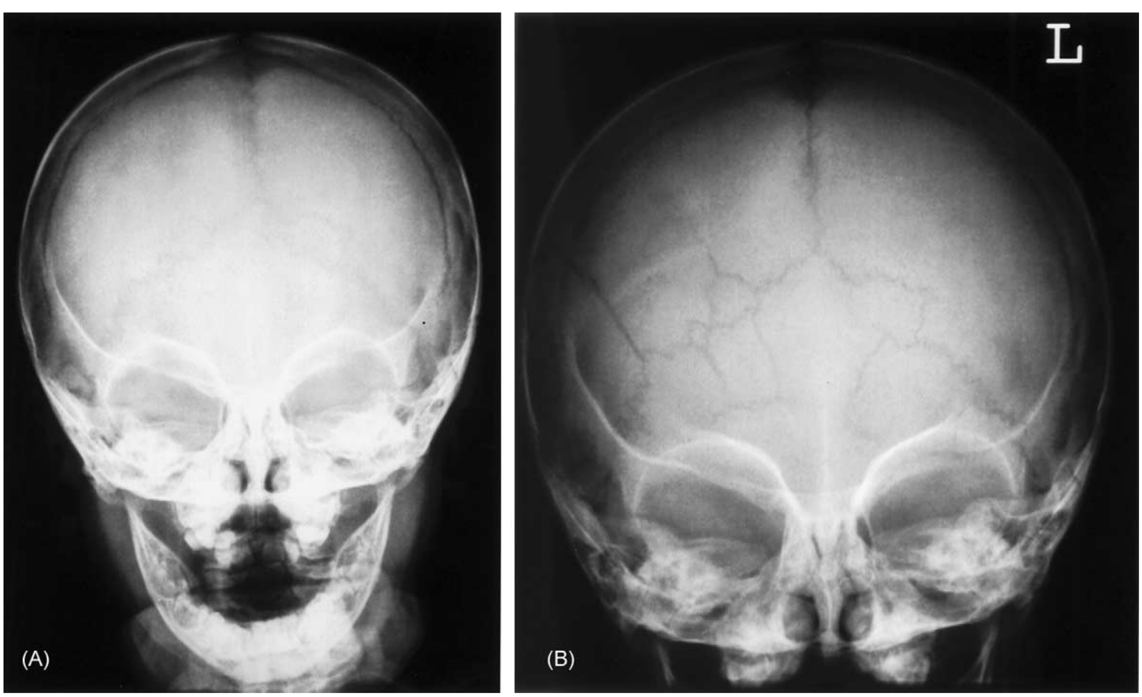

Figure 13 (A) A normal frontal skull radiograph showing a single wormian (sutural) bone in the left limb of the lambdoid suture. (B) The same patient three months later showing multiple occipital and right parietal fractures. The occipital fractures were mistakenly identified as multiple wormian bones.

appropriate phosphate supplements. Fractures may occur under 6 months of age and radiologically there is osteopenia with coarsening of the trabecular pattern and some irregularity and fraying of the metaphyses (Figure 14). Similar radiological changes occur in older infants suffering from rickets, resulting from various causes. Copper deficiency may predispose to fractures, but by the time fractures occur,

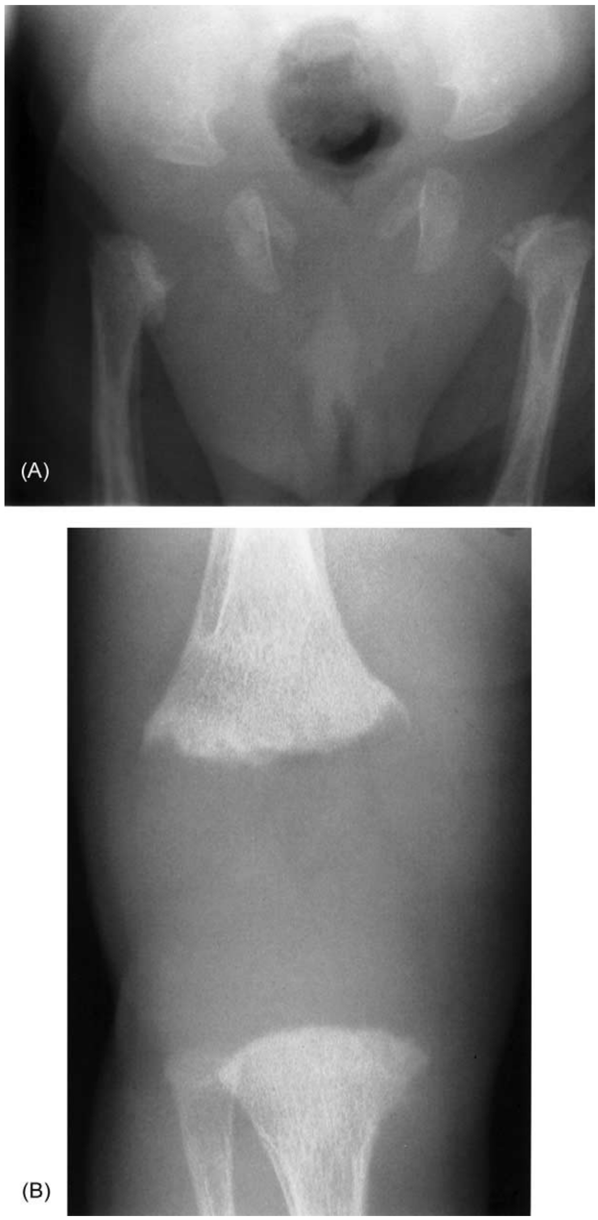

Figure 14 (A) This premature infant shows the typical findings of osteopathy of prematurity with irregular femoral necks and periosteal reactions. (B) The same infant has irregularity of metaphyses adjacent to the knees and absent (delayed) ossification of the epiphyses at the knees. They should be ossified by about 32 weeks gestation.

there is osteopenia with changes at the metaphyses in the form of sickle-shaped spurs. This is rarely seen, and only in small neonates who have required prolonged intravenous feeding and in which the parenteral fluids are deficient in copper. Scurvy, resulting from vitamin C deficiency, is hardly ever seen in developed countries nowadays. Radiologically there is osteopenia with a "pencil" outline of epiphyses, "pelcan" spurs at the metaphyses, and extensive subperiosteal bleeding with calcification and subsequent ossification. Clinically there is bleeding from gums and easy bruising. The milder forms of osteogenesis imperfecta (types I and IV) show the radiological features of osteopenia, slender long bones and ribs, and wormian bones. These are small discrete islands of bone seen within the sutures of the skull. Wormian bones are present in about 80% of patients suffering from osteogenesis imperfecta. There should be more than 10 in a mosaic distribution to differentiate them from those that are few, small, and discrete, present as a normal variant in about 10% of the normal population. Clinically, patients with osteogenesis imperfecta often have blue sclerae, although many normal infants also have this finding. A positive family history may help to establish the diagnosis. The vast majority of patients with osteogenesis imperfecta may be diagnosed from the combination of radiological, clinical, and family history findings. In difficult cases, testing for mutations in type 1 collagen from a skin biopsy and fibroblast culture may assist. However, this is still a research tool and only about 85% of patients who have been clearly diagnosed with osteogenesis imperfecta will demonstrate an abnormality of collagen or procollagen. In addition, it is not known what proportion of the normal population may have minor abnormalities of collagen, but never present with fractures. Another genetic disorder presenting with fractures is Menke's syndrome, in which there is an abnormality of copper metabolism resulting in a neurodegenerative disorder. Radiologically there is osteopenia and multiple wormian bones in the skull.

Normal Variants

Misinterpretation of normal variants may result in overdiagnosis of nonaccidental injury when interpreted as fractures, or in underdiagnosis when fractures are attributed to normal findings (Figure 15).

Intracranial Injuries

These are the commonest cause of death as a result of nonaccidental injury. Typically they result from shaking or an impact injury or a combination of the two. A shaking injury may be associated with rib fractures and retinal hemorrhages. Subdural hemorrhage results from tearing of bridging veins over the cerebral convexities during a shaking episode and also is typically seen in the interhemispheric fissure. Hypoxic–ischemic changes result in swelling of the brain and separation of the sutures and may

Figure 15 Small spurs are present at the metaphyses of the lower femur and upper tibia. These are normal variants seen in a small proportion of normal infants.

result in the "reversal sign" on the CT scan, in which there is low attenuation of the cerebral cortex and high attenuation of the white matter and basal ganglia. These changes have a poor prognosis. Shearing injuries in the form of small tears may also be seen in the brain substance. Localized contusion or bruising of the brain may be seen underlying a skull fracture following a direct impact, as may a localized subarachnoid or subdural hemorrhage. In addition, contrecoup injuries may be seen on the opposite side of the brain to the site of impact.

There is a wide range of presentation as a result of intracranial injury. The infant may be irritable, vomiting, not feeding, or may show major neurological signs in the form of seizures or loss of consciousness. When presentation is as a result of an acute collapse with loss of consciousness, the injury has occurred shortly before. An estimate of dating subdural hemorrhage may also be made from the initial CT scan. High attenuation (white) indicates recent bleeding, occurring within a week of the scan. There is a gradual reduction in attenuation from gray to black with increasing age of the subdural hemorrhage. Bleeding older than about 1 month appears black and is the same attenuation as normal cerebrospinal fluid. In practice, the age of an intracranial injury is assessed from a combination of the history, clinical findings, and CT scan.

Visceral Injuries

Intraabdominal injuries are relatively uncommon, found in between 2% and 3% of all cases of nonaccidental injury. They arise mainly from blunt trauma resulting in contusion, laceration, or rupture of solid or hollow organs such as liver, spleen, kidneys, pancreas, and bowel and bladder. Small-bowel hematomas, mesenteric tears, and vascular injuries may also occur.

Oral and pharyngeal injuries occur when objects are forced into the mouth, causing mucosal tears. These may be complicated by perforations resulting in mediastinal air and mediastinitis, pneumothorax with lung collapse, and surgical emphysema.

Conclusions

The safety and welfare of the child are paramount and generally this results in the baby being moved to a place of safety and care proceedings being instituted through the civil courts. Occasionally, and when there is some acknowledgment of responsibility for the injuries, or of a failure to protect, it is possible to work with the family to address the problems and with appropriate safeguards the child may eventually be returned to the family. This would seem to be the most desirable outcome. In other cases the child may be placed with the extended family or with foster parents and then placed for adoption. Depending on the extent and severity of the injuries the perpetrator may be charged with criminal offenses through the criminal courts and undergo a custodial sentence.

The pediatric radiologist as an expert witness should be familiar with the radiological aspects of nonaccidental injury, both the standard texts and the peer-reviewed literature. There should be an awareness of the relative significance of isolated case reports. There should be knowledge of the normal skeletal findings in infants and of normal variants, together with the skeletal findings associated with accidental trauma. This means that significant experience of pediatric casualty radiology is necessary. Specialist knowledge of skeletal changes associated with skeletal dysplasias, such as osteogenesis imperfecta and metabolic bone diseases, and deficiency disorders, such as rickets or renal osteodystrophy, and neurological changes from cerebral palsy is also required. In addition to identifying the injuries, their ages, and mechanisms of causation, the report should indicate the anticipated clinical findings such as swelling and bruising and evaluate the explanations which have been put forward and the effect of the individual injuries on the baby. This again requires an understanding of normal babies and how they respond to pain, both from pediatric casualty work and from experience of performing painful (but necessary) procedures on neonates and infants, such as intravenous injections and catheter placements. Sometimes levels of probability for each injury occurring by a particular mechanism are helpful. The report, participation in experts' meetings, and oral evidence given in court should be confined to the professional limitations of the individual expert. It is important that the court is aware of the areas of expertise of individual expert witnesses and that undue weight is not given to nonexpert medical opinions. The evidence should be independent of all the parties involved and provided to assist the court.

See Also

Children: Legal Protection and Rights of Children; Physical Abuse; Sudden Natural Infant and Childhood Death; **Expert Witness:** Qualifications, Testimony and Malpractice

Further Reading

Hall C (1994) Non-accidental injury. In: Carty H, Shaw D, Brunelle F, Kendall B (eds.) *Imaging Children,* pp. 1188–1202. Edinburgh, UK: Churchill Livingstone.

Kleinman PK (1998) *Diagnostic Imaging of Child Abuse,* 2nd edn. St Louis, MO: Mosby.