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Forensic Radiology

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31.1 Introduction

Forensic radiology (FR) started within months of Röntgen discovering “X-rays” (see Chapter 17). The term “forensic” is commonly thought to mean the application of scientific methods and techniques for the investigation of death, but it actually relates to courts of law. The scope of FR is therefore wider and may include clinical cases seen in imaging departments, such as road traffic collisions, non-accidental injury, drug smuggling (body packing), and assault. FR may also include imaging of inanimate objects, such as art or jewelry in suspected fraud. However, this article is mainly concerned with the investigation of death, to answer not only “how” but by “what means” the person died, but the other key questions of “who” they were and “when” they died.

Developments over the last 20 years have seen imaging beyond plain film radiography and fluoroscopy, incorporating cross-sectional imaging techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI), which have now become an integral part of many post-mortem (PM, after death) investigations (see Section III, Chapter 32 of this book for an introduction to the CT technique). Many centers around the world have been undertaking research to improve the ability of FR to be an adjunct to, or replace, invasive autopsy. This has led to the slightly different concept of PM imaging.

This chapter will discuss the role and scope of FR and PM imaging and how the different modalities may be used. As post-mortem CT (PMCT) is becoming the internationally favored modality, this will be the main focus.

31.2 Why Do Forensic Radiology and Post-Mortem Imaging?

FR and PM imaging are primarily conducted to assist in identifying the deceased and determining how death occurred (the “cause of death”). Using imaging to estimate the PM interval is possible but imprecise (Rutty and Morgan 2016), and imaging rarely helps with this if the place of death is unknown. Identification is vitally important for the family and friends of the deceased, for psychological as well as legal reasons (Saukko and Knight 2004, Riddick 2011). Identification may be a relatively straightforward process if the deceased is intact, but fragmentation and decomposition will complicate things significantly. One of the first challenges is establishing if the remains are human
or not, and if there is one deceased or several. Identification may be established from DNA, fingerprints, or odontology (a forensic examination of the teeth, including X-rays) if ante-mortem (AM) comparison data are available. Visual identification is not recommended as it is unreliable (Interpol 2014), resulting in misidentifications (Lino and Akoi 2016), and can also be traumatic for relatives involved (Dorries 2004, Interpol 2014). Comparison of PM and AM radiological images may also assist, particularly if there is previous trauma with unique healing characteristics or surgical intervention. Prostheses and medical devices can be located, many of which will have unique serial numbers. Personal effects, watches, rings, and other jewelry may also be identified on imaging, but are insufficient alone to provide an accurate identification.

These techniques are useful if the deceased identity is potentially known, such as in a contained mass fatality such as an air crash with a passenger manifest, or in a missing person search. If there is no clue to identity, imaging can also help in the identification process with age estimation by using primary and secondary ossification centers, dentition which develops in a reasonably predictable time scale (Weems 2011), and calcification of cartilage and erosion of bone with increasing age. Sex can be determined from many skeletal structures, particularly the skull and pelvis, and stature can be estimated from the length of long bones (Trotter and Glesser 1952). The data from a single PMCT scan can be presented in such a way to answer all these questions in a simple report (Brough et al. 2014).

Investigating the “cause of death” involves studying the relevant history and environment, an external examination of the body, and then an internal examination, normally performed by autopsy. This involves macroscopic examination, sometimes followed by the microscopic examinations of bodily fluids and tissues (histology and microbiology) and biochemistry and toxicology testing. The legal investigation may be initiated for a wide range of indications, from a probable but unexpected natural death of unknown reason to an unnatural death suspected to be murder. Sometimes, the actual cause of death may be obvious, for example, in a road traffic collision, and the investigation focuses more on the pattern of injury, giving important information about the circumstances of the trauma, such as speed, use of a seat belt, and site of impact. Imaging is of particular help in this, as bony injuries are easily demonstrated by all imaging modalities. A radiographic survey of the deceased will enable the pathologist to identify and evaluate injuries before the autopsy and differentiate accidental from inflicted injuries. To physically evaluate injuries at autopsy following a road traffic accident, for example, will take a significant amount of time and will be very disruptive to the body. Imaging, and especially PMCT, can considerably speed up this process.

Using PM imaging to delineate patterns of injury can help establish how an injury occurred in the living and deceased and can also help confirm, or refute, the reported circumstances of an incident and improve safety. For example, specific fatal injuries to the head, abdomen, and lumbar spine were recognized in plane crashes and attributed to the use of single “lap belts,” without upper body restraint (Veronneau and Ricaute 2008), and similar injuries have also been seen in car accidents where “lap belts” have been worn (Figure 31.1). Legislation now exists in many countries making three-point seat restraining seat belts mandatory in all new cars. Similarly, following the 1989 Kegworth air crash, the design of overhead lockers in planes was altered to address specific head injuries seen in this accident (Wallace et al. 1995).

Following a traumatic death, foreign objects may be retained in a body, which may not be known about and may be needed as evidence. These may include glass, from windows or a bottle used in stabbing, fragments of metal from car or aircraft accidents, and parts of weapons used in stabbings. These may all pose a risk to the pathology team performing the autopsy, as may sharp bone fragments. Physically locating these objects in a body may be difficult and dangerous during autopsy, but easily done using imaging. In cases of shootings, not only can the bullets, “shot,” or casing be identified, but in some cases the bullet tracks can be visualized. The retained bullets and “shot” can be located for removal, if required for evidence, using plain film radiography or fluoroscopy, but is more readily demonstrated on PMCT. In addition, PMCT has the ability to demonstrate a wider variety of artefacts than plain film modalities, such as plastics.

FR is routine in some institutes and preferable in others. Some institutes, for example, the Victorian Institute of Forensic Medicine, Melbourne, Australia (O’Donnell and Woodford 2008), Centre Universitaire Romand de Médecine Légale, Lausanne (Schneider et al. 2011), and the Institute of Forensic Medicine, Odense, Denmark (Leth 2009) have dedicated CT scanners in the mortuaries, which enable them to scan many, if not all, the deceased who arrive at their units. Elsewhere, forensic institutes gain access to hospital clinical scanners, normally overnight. This,
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There are some natural pathologies that are difficult to identify on PMCT. A non-contrast-enhanced (native) PMCT scan may only reveal the cause of death in approximately 30% of cases, being able to diagnose trauma, cerebral hemorrhage, and aortic dissection, but unable to diagnose pulmonary embolism, coronary artery disease, and pneumonia (Roberts et al. 2012). To address the weakness with arterial disease, PMCT angiography (PMCTA) techniques have been developed (Jackowski et al. 2005, Grabherr et al. 2011, Roberts et al. 2011, Saunders et al. 2011). The introduction of PMCTA improves the ability of PMCT to be a viable alternative to autopsy, and we believe this is also helped by the introduction of ventilated PMCT to improve pulmonary diagnosis (Germerott et al. 2010, Robinson et al. 2014).

“Scan only” PM investigation services are becoming more common. The first in the UK started in 1997 as an MRI service, privately funded by the local community (Bisset et al. 2002). Since then, PMCT has proven to be more practical than MRI for adults, and PMCT services are now available in a few centers across the UK.

31.3 Historical Review

Imaging in forensic investigations started within months of Röntgen discovering X-rays. In the first year after their discovery, X-rays were used in shootings, medical negligence, murder, dental imaging, and attempted murder cases, and their value and potential were realized (see also Section II, Chapter 18 of this book for an historical introduction to radiology). X-rays were first used in a murder investigation in April 1896 in Nelson, Lancashire, UK (Eckert 1984). Elizabeth Hartley was shot in the head four times by her husband but, amazingly, she survived. Her doctor, wanting to locate the bullets, sought the help of the new X-rays, but she was too unwell to move. Undaunted, they moved and reconstructed the X-ray equipment in her home (Thomas and Banerjee 2013). Although the house did not have electricity, they managed using batteries supplied by a local electric corporation. The X-rays were duly taken, and the bullets were located, but unfortunately Mrs Hartley was too unwell to undergo treatment and she died. As Brogdon et al. (2011) observed—“This case can be considered an early manifestation of our tendency to use elaborate procedures and the newest technology, whether or not it will influence the outcome” (Brogdon and Lichtenstein 2011, p.14).

The use of radiographs in court was contentious, and early attempts to use them were refused, with one Judge claiming “it is like offering the photograph of a ghost” (Withers 1931). Photographs were acceptable at the time as secondary evidence and could be explained by witnesses, but the introduction of radiographs required acceptance of this new medical development. It took a further 20 years for radiographs, and indeed radiologists, to be accepted in courts.

The development of FR over the next 100 years was sporadic. Following the initial flourish of activity at the turn of the century, little changed until the forties. Pediatric FR became a distinctly different issue when, in 1946, non-accidental injury was first suggested by Caffey, who recognized a link between unexplained long bone fractures and subdural hematomas (Caffey 1946). Kempe et al. took this a step further, publishing “The battered child” in 1962, suggesting the injuries were caused by a parent or foster parent. They acknowledged the hitherto unrecognized or undiagnosed condition was, in part, due to the reluctance to believe the parents capable, let alone guilty, of abuse (Kempe et al. 1962).

However, is impractical if the institutes are not adjacent to the hospital or the hospital uses all their CT scanners 24 hours a day.

FR has a far wider scope than just assisting with deceased investigations. Clinical imaging for non-accidental injury, assaults, abuse, and road traffic collisions may be part of a legal investigation. Imaging is involved in detecting drugs being smuggled by body packers, whether that is a clinical or PM examination (Figure 31.2). Person and vehicle scanning using X-ray machines by border control agencies to detect contraband and human trafficking may also be considered forensic examinations, as may art and antique fraud detected using X-rays. Imaging can also assist archeological investigations, including the identification of the remains of Richard III (Appleby et al. 2015). FR is not limited to only helping in single case investigations, but has proven invaluable in mass fatality investigations, including the September 11th attack (Harcke et al. 2002) and the MH17 investigation (Khoo et al. 2016).

Imaging has taken PM investigation to a new level and is now seen as an important adjunct to autopsy. It has even been proposed as a replacement to autopsy in certain situations (Dirnhofer et al. 2006, Okuda et al. 2013, Addison et al. 2014, Rutty et al. 2016a). Not all cases are suitable; it is unlikely that courts would be completely satisfied with a “scan only” approach for all suspicious death investigations (Jeffery et al. 2011), but some coroners in the United Kingdom (UK) now accept “scan only” autopsies, particularly in road traffic accident cases. Under UK law, the family of a deceased may request a “scan only” autopsy. The circumstance of the death and the previous medical history must be considered in determining if imaging can provide a cause of death.

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**FIGURE 31.2** 3D (volume rendered) reconstruction of a body computed tomography scan, showing a virtual dissection of the stomach area demonstrating concealed packets. These were packets of powdered narcotics in the stomach of a body packer.
Imaging in mass fatality incidents was first reported in 1949. The SS Noronic, a large passenger liner on a holiday cruise on Lake Ontario with nearly 700 passengers and crew on board, was docked at Toronto harbor when fire broke out at 2:30 a.m. The fire spread rapidly and, despite being docked, exit was only possible via one of five passenger levels using one of two gangplanks. The total number of dead was uncertain with estimates ranging from 118 to 139 fatalities. The problem was that many were so badly burned they were impossible to recognize, or even count accurately. A pain-staking investigation was made to identify the bodies, and comparison of AM and PM X-rays was the sole method of identification in 24 fatalities.

Since then, plain film imaging has, and continues to, provide pathologists with valuable information. There is little doubt the plain film techniques have a role in forensic practice but are limited by two-dimensional images. The introduction of CT in the seventies overcame this, but scepticism limited its use in the forensic field for many years.

The benefits of cross-sectional imaging in forensic investigation were recognized in 1977 when a clinical head CT scan was reported to investigate a gunshot injury (Brogdon and Lichtenstein 2011). First publications on the use of PMCT in the mid-eighties generally looked at single cases or single body areas (Krantz and Holtás 1983, Okuda et al. 2013) and were restricted by the CT technology of the time. Despite the technical limitations compared to the scanners of today, their potential as an alternative to the invasive autopsy was recognized (Donchin et al. 1994).

Key developments in CT scan technology have occurred over the last two decades: spiral and multi-detector CT scanners have allowed faster scanning with improved three-dimensional ability, allowing the body to be viewed in any plane. This has been accompanied by better X-ray generating ability to allow rapid scanning of large body areas and improvements in image reconstruction techniques and image analysis. All this has greatly improved the application of CT in forensic investigation, but probably the biggest change has been availability. In the early nineties, 20 years after the invention of CT, many large towns and cities in the UK would have access to only one CT scanner; the number now could be as many as 10 or more! This availability has led to more research being undertaken into the use and capabilities of PMCT, and use is becoming standard in many places around the world, thanks to its ability to scan a large volume in seconds, portray bone and soft tissues, and its 3D reconstructions.

MRI has also been used in forensic investigation since the nineties. One of the earliest papers evaluated the ability of post-mortem MRI (PMMRI) to detect abnormalities and found PMMRI to be equal to autopsy in detecting gross pathology but that abnormalities smaller than 1 cm were missed, including infarcts and hemorrhage, and microscopic petechiae (which can be a sign of asphyxiation) (Ros et al. 1990). Limitations of the technology at the time may have contributed to these findings. The potential uses of MRI were also investigated with a study on the effects of judicial hanging on the bony and soft tissues of the neck (Wallace et al. 1994). Many assumed death was caused by spondylolisthesis of C2, the so-called “Hangman’s fracture,” but studies of suicidal hangings, undertaken without the benefits of PMCT and PMMRI, had suggested soft tissue injuries were the cause of death. Spinal dislocation with cord transection was demonstrated but also subarachnoid hemorrhage due to damage to the vertebral arteries, confirmed with angiography. These were affected by the position of the knot and the distance the body falls, the drop. Ethical concerns over the use of judicial hanging and the inconsistencies in the causes of death led to the practice being largely proscribed.

Since the initial work, PMMRI research has primarily involved pediatric (Thayyil et al. 2013, Arthurs et al. 2014) and soft tissue imaging with mixed successes (Patriquin et al. 2001, Thayyil et al. 2013), and PMMR may miss around a quarter of the pathologies (Arthurs et al. 2014). However, with additional tests such as biopsy and cytogenetics, PMMR may be able to provide sufficient information when autopsy is declined in pediatric cases (Breeze et al. 2011). One problem with using MRI in the PM field is due to the problems encountered with metallic foreign objects. The inability to exclude metallic objects with any certainty is a potential problem in PM cases. The risk to clinical scanners is great and so a pre-PMMRI screening, most likely by CT, could be required. Possibly more importantly, MRI involves longer examination times, more complexity, and increased costs. CT is therefore more frequently used and so will be the primary focus of this chapter.

### 31.4 Modalities

Adult and pediatric FR should be dealt with confidentially and with the utmost dignity and respect. Ideally, in all cases, as much as is known about the deceased, the circumstances of their death, and any previous medical history needs to be available to the imaging team, prior to starting an examination.

Plain film imaging, dental imaging, and fluoroscopy have been used for many decades. The benefits they may bring are numerous, and they are inexpensive and readily available resources, which can be used in any hospital or mortuary, whether temporary or permanent. They are not without problems, and ideally should be operated by radiographers or technicians with expertise in clinical imaging to avoid suboptimal images, radiographic under- or over-exposure, and poor anatomical positioning (Jefferson 2015). These problems, and those of processing the images (particularly if using photochemistry processing), can be exacerbated if the imaging is being completed away from the radiology department.

The problems of photochemistry processing have been solved by digital processing, but there are limitations of the modalities themselves. Each can only produce two-dimensional imaging and has a limited area that can be imaged at a time. There is also the risk of radiation exposure to those operating the equipment, particularly for fluoroscopy, which must be minimized.

When using digitized images, data storage must be considered. In hospitals, it is likely the storage facility will be the hospital PACS (Picture Archive and Communication System) or DVDs. Outside the hospital, image archiving must be considered to ensure the medico-legal requirements are satisfied. In addition, the ability to store images indefinitely gives imaging an advantage over autopsy. For example, if an investigation needs to be re-opened into a historic case, the images can be retrieved easily from the archive and reviewed, a so-called “virtual exhumation” (Morgan 2010). These images can be transferred anywhere in the world to be reviewed by any expert or interested party.
Pediatrics is generally considered differently to adults and requires pediatric specialist pathologists and radiologists whenever possible. As in clinical practice, the anatomy, pathology, and disease etiology differ from adults and need a different approach. The reasons for undertaking imaging in deceased pediatric cases must be conveyed prior to the examination so the radiographer and/or radiologist can determine the optimal imaging approach. The age of the child and medical history must also be considered when making this decision. MRI is used more often in pediatric FR than adult FR due to its superior ability to delineate soft tissues, but plain film imaging is considered mandatory if bony injury needs to be ruled out (Royal College of Pathologists 2005, American College Radiology 2012). Age is of particular importance when considering bone injury due to the differing fracture patterns at different stages of skeletal development.

Rib, long bone, and pelvic fractures, without an acceptable explanation, are highly indicative of abuse, particularly in children under one year of age (Offiah et al. 2009). Metaphyseal injuries are also highly specific for inflicted trauma in infancy and are most commonly seen in the distal femur and proximal and distal tibia, but also in the proximal humerus (Kleinmann 2008). Imaging for these “bucket handle” or “corner fractures” is therefore vitally important, but they can easily be missed if the wrong modality or poor technique is used. Adherence to international guidance on what to include in a skeletal survey and image quality is essential (Royal College of Radiologists/Royal College of Paediatrics and Child Health 2008, American College of Radiology 2012). Rigor mortis may make positioning difficult and may challenge the most able radiographers to achieve the high-quality images required, but this can generally be overcome with care and time.

31.4.1 Plain Film Imaging

For almost 100 years, plain film X-rays or radiographs were, and still are, very important in FR. Digital radiography (DR) has made radiographic exposure easier and more reliable, and has overcome the problems of photochemistry processing. In addition, the image is produced electronically without having to remove the plate, thus reducing manual handling and increasing productivity.

Plain film imaging can be used in various ways in FR. It can be employed as a screening tool to image the entire “body bag” to determine its contents, or to complete a detailed skeletal survey of a body. A sealed body bag limits the infection risk, but reduces the image quality as the position of each bone is not known and will result in suboptimal images. Care must be taken when completing the imaging, as the limited X-ray plate sizes will necessitate multiple views of an area to ensure the entire region is included. The resultant “jigsaw” of images may make interpretation difficult. In addition, the careful application of anatomical side markers is essential.

A plain film review of the whole skeleton (the skeletal survey) is the “Gold Standard” for the identification of abuse, in living and deceased children, and must be reported by a radiologist (Royal College of Pathologists 2005). In the living, a CT scan of the head is also advocated for children considered “high-risk” or who are of clinical concern (Royal College of Radiologists/Royal College of Paediatrics and Child Health 2008, American College of Radiology 2012). For clinical cases, the survey is essential, in line with international guidance, as 80% of non-accidental injuries (NAI) were found in children under 18 months of age (Mok 2008) and subtle metaphyseal “bucket handle” and, particularly, “corner” fractures may not be seen on other modalities. In deceased cases, when radiation dose is not a concern, a CT scan, in addition to a skeletal survey, could be considered for children under two years and a CT alone for children over two years. (For further information on imaging living NAI cases, see Royal College of Radiologists/Royal College of Paediatrics and Child Health 2008.)

In both pediatric and adult investigations, achieving the required quality of images should be attainable for any radiographer. There are natural differences when dealing with the deceased, and a little forethought in body and equipment preparation may help.

Rigor mortis, the stiffening of the tissues associated with death, causes some problems in obtaining good anatomical positioning. The interval between death and time of imaging, the circumstances of death, and environmental and storage factors will dictate the extent of rigor. Rigor can occur within hours of death and can persist for up to 48 hours and results in the stiffening of muscles. This can be overcome by warming and/or gentle pressure applied to affected joints to straighten the affected areas. Should this not help, high-quality images can also be obtained in the majority of cases by adapting radiographic techniques.

In most cases, the use of pads for positioning, tape for immobilization, and adjustment of tube and plate angulation should suffice. In other cases, more thought may be required. Turning the entire area or torso of the deceased may be required to achieve the ideal image. In pediatrics particularly, turning the child prone can produce images of the lower limbs that are superior to those that could be achieved supine. FR can involve imaging excised parts, such as the ribs to look for subtle rib fractures suspected at autopsy, but not seen on the skeletal survey. High-quality images in this case are clearly paramount and so stabilizing the area, using pads and wedges, is vital. As imaging the entire body to a standard equivalent to clinical practice is vital, if there is any doubt, repeat or additional views should be performed. Should these prove inadequate, imaging using other modalities may be required.

31.4.2 Fluoroscopy

Fluoroscopy is also used in FR to provide an initial survey of the deceased, or provide “spot” films of an area of interest (see also Section II, Chapter 21 of this book for an introduction to fluoroscopy). Real-time imaging is useful as a screening tool, particularly for locating foreign objects. The body and bag are imaged systematically, ensuring the images overlap and cover the entire body and bag. This will demonstrate the contents of the bag, whether an individual is intact or disrupted, if there are commingled remains (parts of more than one deceased in the bag), and if there are any foreign objects (personal effects, hazardous material for the pathology team, or ordnance). The survey should be recorded and individual “spot” images taken, looking at specific areas of trauma or artefacts of interest. Fluoroscopy has two main limitations—the image quality and the size of the image intensifier that produces the images. It is best used as a screening tool, accompanied by dental and plain film imaging (Viner 2011).
31.4.3 Dental Radiography and Odontology

Odontology involves the physical and radiological examination of the mouth for the presence or absence of teeth, their position, size, shape, and signs of decay or repair (see also Section II, Chapter 22 of this book for an introduction to dental radiography). An individual’s dentition is unique and is an excellent means of identification if previous dental records are available detailing the position, condition, and work performed on each tooth. Furthermore, even without previous records, certain signs of wear can suggest age, race, and diet, such as staining from chewing betel nuts, which may suggest ethnicity (Pretty and Sweet 2001).

Although examination and previous dental records alone may suffice, comparison of PM images to AM clinical X-rays is the best way to establish a definite identification and provides a high degree of certainty (Pretty and Sweet 2001). Dental imaging is particularly important in mass fatality incidents. A total of 209 victims of the Lockerbie air crash were identified by odontology (Moody and Busuttil 1994), and in the South East Asian tsunami, odontology provided 79% of the identifications (James 2005). As with all radiographs, image quality can vary, so PM dental images may have to be repeated to match the AM images. Depending on the AM images available, comparison of otherwise hidden identifying features, such as implants, root canal repair, retained roots, undescended teeth, maxillary sinuses, bony trabecular patterns, or surgical plates and interventions, can be used to aid the identification (Figure 31.3).

The odontologists may dictate the views required, but at minimum, these should include peri-apical imaging of the whole mouth. Care must be taken orientating and labeling the film or plate to ensure the correct identification of the teeth. Upper and lower standard occlusals and oblique occlusals may be required to image the maxilla and mandibular dentition, bones, and soft tissue structures. The views may be used to detect impacted or embedded teeth and roots or calcified salivary stones. Bitewing images may also be required to demonstrate repairs to the crowns.

There are two different techniques employed in dental peri-apical radiography. Paralleling technique requires the X-ray plate or detector and the long axis of the tooth to be parallel. The X-ray beam is directed perpendicular to that plane and produces an image of the tooth without distortion. This technique should be used whenever possible to reduce the effects of elongation, foreshortening, and distortion that can occur using the bisecting angle technique. This method dictates that a plate or detector is placed in the mouth behind the tooth and the X-ray beam is directed perpendicular to the line mid-way between the angle of the long axis of the tooth and the X-ray plate. This technique is renowned for being difficult to replicate, which is not helpful when comparison of AM and PM images is crucial.

31.4.4 Post-Mortem Computed Tomography (PMCT) Scanning

Current PMCT bears little resemblance to that first described 30 years ago. The use of PMCT was first reported in the eighties (Krantz and Holtás 1983, Okuda et al. 2013), and a decade later, a study on the use of PMCT first suggested PMCT as a possible alternative to autopsy (Donchin et al. 1994). Since then, PMCT has expanded both in technical complexity and the extent of its use. A true three-dimensional representation of the whole body is now possible, quicker and easier than obtaining whole body imaging using the other modalities. The data can also be reconstructed to produce images for use in court (Jeffery et al. 2011). For the first time in forensic practice, an alternative to autopsy is now viable.

The concept of a virtual PMCT autopsy was discussed in the early Israeli publications (Donchin et al. 1994) and the term Virtopsy® was coined by a Swiss research group (Thali et al. 2003). The early research was primarily in trauma, and PMCT was able to accurately diagnose the cause of death in approximately 30%–50% (Iizuka et al. 2013, Thali et al. 2003, Leth 2009) of cases with various natural pathologies being missed, such as cardiac diseases and pulmonary embolism. As experience in scanning and reporting increased, so did accuracy, to between 75 and 100% in trauma cases (Scholing et al. 2009, Westphal et al. 2012). Whilst highly successful for trauma, for PMCT to be considered a potential alternative to invasive autopsy, it also has to diagnose natural causes of death. Contrast-enhanced images were required, and techniques to achieve this have been developed. PMCT is now an adjunct to some, and an alternative to many, invasive autopsies.

PMCT is irreplaceable to determine if a child took a first breath. (MRI can also be used but with the considerations mentioned above.) Establishing aeration in the lungs, airways, and stomach is vital in a deceased newborn when “neonaticide,” the murder of a child in their first 24 hours of life, is suspected, to ensure the child was not stillborn. Air in these areas, in the absence of resuscitation, means the child has taken a breath and so was a live birth (Guddat et al. 2013). Determining if a child has taken its first breath is difficult pathologically and the tests (e.g., seeing if the lungs float in water) can be unreliable (Barber et al. 2015). These children may have been subject to accidental or intentional airway obstruction, which also can be seen on PMCT (Rutty et al. 2010) (Figure 31.4). Oesterhelweg et al. (2009) have reported similar airway obstruction by natural and unnatural causes in adults. Decomposition changes will affect the appearance and gas content of the body, including the lungs, and so should be given due consideration (Sieswerda-Hoogendoorn et al. 2013).

PMCT is not without its disadvantages, the main one being cost. A CT scanner is significantly more expensive than plain...
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film equipment, but is becoming more widely used clinically and therefore widely available. If a scanner is unused out of clinical hours, the additional cost for a forensic scan is minimal. Interpreting the imaging is more complex than plain film images but pathologists and radiographers, with the assistance of radiologists, can be trained. Dental imaging using CT is problematic as dental amalgam can cause image artefacts, despite modern metal artefact reduction techniques on CT. If this is a problem, plain film dental images or cone beam CT could be required.

Reporting PMCT introduces another element of uncertainty into the discussion. As a relatively new type of scanning, experience is limited. This inexperience probably led to some misinterpretation of imaging signs in early studies, particularly as autopsy control was not used in all studies. With experience and an increasing volume and range of research being published, confidence in the accuracy of PMCT and its reporting is increasing. There are potential pitfalls for the less experienced, as images of the deceased are different to those of the living. Within minutes of death, cells start to break down and fluids start to disperse from vessels and organs, changing the appearance dramatically in some cases, and accumulate in areas not seen in clinical imaging. The abdomen is most obviously affected by gas, due to the high number of naturally occurring bacteria. Gases also accumulate in the vasculature and can mimic fractures in the vertebral bodies. Hypostasis, the break down and settling of blood, is seen in all areas, but is regularly seen in the venous sinuses of the brain, potentially mimicking thrombosis or a subdural hematoma, and in the chest, masking existing pathologies (see ventilated PMCT below). Courses are now being run, primarily in Europe, to teach PMCT principles and reporting.

31.5 PMCT and How to Do a Scan

PMCT, without any body preparation or contrast enhancement, is particularly useful in cases of traumatic injury and can demonstrate trauma in ways 2D imaging modalities cannot. It is now possible for PMCT to replace autopsy in some trauma cases as PMCT can be superior to autopsy in demonstrating some fractures, such as in the spine, base of skull, and face. These may be difficult for the pathologist to visualize, even having seen them on PMCT (Figure 31.5). Significant soft tissue injury, sufficient to cause or contribute to death, can also be seen. Liver laceration, splenic and cardiac rupture are generally all apparent without the use of contrast, although these lesions may not be visible if the subject has died before the laceration can bleed, such as from catastrophic injuries elsewhere. For example, major liver trauma as the cause of death is normally apparent, but liver lacerations in a subject who has hemorrhaged catastrophically from chest injuries, may be missed. The cause of death in such cases is often clearly demonstrated on PMCT and nothing of importance is learnt if an autopsy is performed.

There are changes that occur after death that can mimic pathologies and so need to be understood and recognized. Air in the body, where it would not be expected, may result from traumatic injury, and pneumothoraces and pneumocephalus, not

FIGURE 31.4 Sagittal reconstruction of a computed tomography scan in a neonate found dead. The images show air in the lungs (white asterisk), confirming the child was born alive (the child must have taken a breath). The cause of death was suffocation due to obstruction of airway by forced “packing” in the throat (black arrows).

FIGURE 31.5 Victim of a fatal road traffic collision. The cause of death, due to dislocated cervical spine fracture (white arrow), is immediately apparent on the 3D reconstruction of computed tomography images. These images can be used to demonstrate mechanisms of injury to relevant investigators, such as the police or courts.
always easily seen at autopsy, are obvious on scans. Any penetrating trauma can introduce air into the body, particularly in the agonal moments, and this should be differentiated from a true air embolus.

Air can also be a hindrance, as decomposition gas must be distinguished from naturally occurring gas and air emboli. Decomposition starts immediately after death, and gases may be seen 24–48 hours after death and can be affected by temperature, environment, body size, insect and animal predation (Levy et al. 2010). It has been found that decomposition gas develops in different areas in a predictable pattern, enabling the development of a radiological alteration index (Egger et al. 2012), which enables decomposition gases to be identified.

### 31.5.1 How to Do a PMCT Scan

PMCT is very similar to clinical scanning. It must be conducted with the same precision, care, and attention to detail as a conventional scan. There are different considerations to clinical scans as the radiation limitations that constrain scanning protocols do not apply, but medico-legal restrictions will. The body can be scanned in the body bag, and for forensic investigations, the bag should not be opened except if the body will not fit through the scanner bore. The pathologist should be consulted to determine if the scan is essential and, if so, they should be the one to alter the position.

Before scanning, the radiographer should check what requirements need to be met. Generally, a whole body CT scan is recommended (Royal College of Radiologist/Royal College of Pathologists 2012), which includes imaging the whole bag. This may be separated into head and neck, chest, abdomen, and pelvis, and leg scan (Table 31.1). All should have both bone and soft tissue reconstructions. A separate “angled” brain scan is also recommended, covering the same area as the head and neck scan, which will move any artefact caused by dental restoration and jewelry, which may obscure spinal fractures and posterior fossa bleeds. The scans should overlap to ensure all the body is imaged. Separating the scans in this way makes them easier to manipulate on image analysis workstations.

The head and neck should be scanned in its entirety to the level of T2 to include the entire cervical spine. The chest, abdomen, and pelvis can be scanned as one block, which should start above the symphysis pubis or fingers. The body can be reconstructed if required. The arms and hands should also be included if possible, although these are sometimes omitted in obviously natural death. The leg block should cover from above the acetabulum to below the feet. Depending on the permissible scan length and height of the deceased, the body may need to be turned to scan the legs. This is completed by sliding the deceased back on to the body movement trolley or by rotating the body on the table, if there are at least three people present. The orientation of the scan on the scan console should be changed to reflect this.

If the arms are required and were not included in the chest, abdomen, and pelvis block, the body can be moved across to the side of the scan table to scan the opposite arm, if the width of the shoulders will allow. If the shoulders or arm position will not allow this, the body could be rolled onto the left side to scan the left arm and the right side to scan the right. If the body is rolled,
care should be taken to change the scanner body position so the position markers on the scan images are correct.

In traumatic death, the body may be disrupted and may not be immediately recognizable. Scout views of the contents of the bag may be needed to determine the orientation and position of body parts. If possible, the scan can be completed as described above, but if there is considerable disruption, the scan can be completed in one or two scan blocks. Depending on the size being scanned, one block with a bone and soft tissue reconstruction may be sufficient. If the body parts are larger, two blocks may be required. One could start at the top of the bag and conclude the scan over half way down the bag. The body and bag should be rotated and scanned, having changed the scan orientation, from the bottom of the bag to above the half-way point of the bag. A landmark, whether bony anatomy or other distinguishable point, possibly an immovable foreign object, should be used to ensure there is overlap between the two scans.

If a body area is not scanned in its entirety, the scan should be repeated. If the body position makes the scanning difficult, repeat scans should ensure that all long bones are included in a single scan. Lower leg trauma can present problems, particularly in the presence of rigor, but scanning the femur as one scan and the tibia, fibula, and ankles as another scan, with plenty of overlap of the scans, may be the only way to get the required imaging. In such a case, having the pathologist present during scanning to discuss their requirements can be very valuable.

The scan parameters should be higher than those used clinically. High kV and mA will reduce the artefact caused by having the arms by the sides and improve image quality. The pitch should also be considered to maximize the image quality in the absence of the normal radiation dose restrictions.

Pediatric scans can be completed as described for adults, and the approach will be determined by age. If the child is young, the chest, abdomen, pelvis, and legs can be scanned in one block with a separate brain scan (Arthurs et al. 2015). Separate head and neck and angled brain scans are recommended. However, until its spatial resolution improves, it is unlikely that PMCT will replace the plain film skeletal survey in NAI investigation in under two year olds when metaphyseal fractures need to be identified. MRI may prove to be an alternate means of identifying these injuries (Perez-Rossello et al. 2010).

31.5.2 PMCT Reconstructions

The image reconstructions that are required are a local decision that will depend on the reporting facilities available. Some will be fortunate to have reporting workstations in the pathologists’ and radiologists’ offices, and so reconstructions on the scanner may not be required, as long as the axial images sent to the workstations are of sufficient inter-slice resolution to allow reconstructions on the workstation. Axial “volume” sets, formed with bone and soft tissue reconstruction algorithms, may be all that is required. If only basic image viewers are to be used by the viewing pathologists, then sagittal and coronal reconstructions may be required. The decision will also depend on the size and cost of data storage available. Consideration could also be given to the unusual position of many deceased and the non-conventional images that need to be reconstructed. Automatic multi-plane reconstructions on the scanner, therefore, may not be of much use if inappropriately angled.

31.5.3 PMCT Challenges and Solutions

PMCT faces challenges not seen in clinical scanning. The lack of circulating blood causes vessels to collapse and the appearance of organs to change. Hyopostasis can be seen as sedimentation of the blood on PMCT and may mask pathology, such as pulmonary thromboembolism (PE), a frequent cause of sudden death. PM clots, formed due to the cessation in blood flow, can occlude vessels and cause filling defects that mimic PE. PM blood clots are frequently seen at autopsy, where they are differentiated from PE by their characteristic plasma and blood product layered appearance. This is not always seen on PMCT, and so developing a means of differentiating between PM artefact clot and fatal PE is crucial.

Natural causes of death, particularly coronary artery disease, unless advanced and demonstrated by calcification, are not easily seen nor interpreted. Ruptured aortic aneurysms with significant blood loss may be seen, but the point of bleeding may not be apparent. For PMCT to be able to replace autopsy, these more subtle causes of death need to be diagnosed, leading to the development of PMCT angiography.

Following death, fluids can build up in the lungs and mimic and mask pathologies such as infection and pneumonia. Previously unseen in FR, as the plain film modalities are unable to image the lungs in this way, this caused problems in identifying a cause of death from lung pathologies. A technique of PMCT ventilation was first reported in 2010 (Germerott et al. 2010) and has been developed to simulate clinical lung scanning (Robinson et al. 2014).

31.5.4 Post-Mortem Computed Tomography Angiography (PMCTA)

Means of introducing contrast have developed to image vascular and coronary vascular systems. PMCTA has certain advantages over clinical angiography, particularly for clinical cardiac imaging, as there is no cardiac or respiratory motion. Unlike for clinical cardiac CT angiography, radiation dose is not a concern, and so imaging quality can be improved by using higher scan exposure parameters and scans can be repeated to ensure good-quality images. Contrast media use is not limited by clinical concerns, and so other materials, such as toxic oily compounds, and even air can be used, allowing a “negative appearance” on scans. However, the lack of circulating blood to carry the contrast needed to be overcome.

The first report of PMCTA was in 2005 (Jackowski et al. 2005), and since then, several methods of introducing and circulating contrast through the body have been discussed. These fall into two main methods: whole-body angiography (WBA) and targeted coronary angiography.

WBA was developed in Switzerland (Jackowski et al. 2005) and uses a modified heart lung perfusion pump to deliver the contrast into the arterial and venous circulation. Whilst this technique is successful, there are cost implications and inserting the catheters, for the contrast injection, is not acceptable in all cultures.
In Japan, surgical intervention on a deceased is shunned, and so angiography techniques were developed (Okuda et al. 2013) by pumping contrast through a peripheral vein cannula, placed during AM clinical care, and encouraging circulation using chest compressions in a manner similar to resuscitation techniques (Iizuka et al. 2013, Morgan et al. 2014).

Targeted coronary PMCT angiography was developed in the UK (Saunders et al. 2011, Roberts et al. 2011). Although recognizing the benefits of WBA, both groups realized that this approach may not be practical in the UK for the specific purpose of investigation of natural deaths for Her Majesty’s (HM) Coroner. Angiography targeted to the coronary vessels was developed as coronary artery disease is the most common cause of death in those undergoing an autopsy in the UK and is frequently missed on native PMCT (Roberts et al. 2011). The two groups adopt similar approaches, but use different contrast agents and have different means of administering them.

Each technique has proven successful but also has limitations. Targeted cardiac angiography will not assist in the diagnosis of pathologies in other organs but WBA is more expensive. The identification of PE, blood clots, and lung pathologies are weaknesses identified for all techniques. A plain PMCT scan precedes the PMCTA scan for each technique.

PMCTA in pediatrics has recently started to be investigated. A technique of contrast administration through the umbilical vein in a neonate has been described (Sarda-Quarello et al. 2016) but delivery of contrast may be challenging in the absence of umbilical catheterization (Taylor et al. 2015).

31.5.5 Whole Body PMCT Angiography

31.5.5.1 Swiss Approach

Whole body PMCT angiography was developed in 2005 (Jackowski et al. 2005) using a modified heart–lung machine to infuse the contrast. Two centers in Switzerland are advocating this technique and have developed their approaches through extensive research. Initially, they used a water-soluble contrast, which clearly demonstrated the vessels but caused tissue edema due to extravasation of the contrast into the extracellular space. The Bern group added polyethylene glycol to increase the viscosity of contrast, which solved the problem (Jackowski et al. 2006). The Lausanne group found this may cause fluid to be drawn into the vessel, leading remaining blood to clump together, which may be confused for a thrombus (Grabherr et al. 2015). Initial studies of the lipophilic contrast Lipiodol ultrafluide® and diesel oil perfusate showed promise, and further research led the group to develop their own contrast Angiofil® (Fumedica AG, Switzerland). Together with paraffin oil (paraffinum liquidum) as the perfusate, they found this to be optimal to stop extravasation.

Body preparation can be undertaken in the scan room or can be done in the mortuary. Catheters are inserted in the femoral artery and vein using a Seldinger approach, although some centers are now using an axillary artery and vein approach (Pomara et al. 2015). (Full description of the technique development is described in Jackowski et al. 2005 and Grabherr et al. 2008.) The catheters are secured with tape on the leg. Prior to scanning, the catheters are attached to the heart–lung infusion device to administer the contrast. Three infusions of contrast and scans are completed. A total of 1200 mL of contrast are infused through the femoral artery prior to the “arterial phase” scan. A second “venous phase” scan is after infusion of 1800 mL into the vein. A final dynamic phase involves scanning whilst injecting 500 mL of contrast into the artery. This approach opacifies all the organs of the abdomen and thorax and will reach the extremities in many cases and demonstrates pathologies, such as a ruptured aneurysm (Figure 31.6). The femoral approach will limit contrast opacification on the side of cannulation. This may be overcome, if required, by reversing the direction of the cannulae on the side of the cannulation if required. This technique has been adopted in many centers around the world.

31.5.5.2 Japanese Approach

In Japan, the approaches described in this chapter are difficult as PM incisions are not possible due to cultural concerns, and an autopsy is only permitted if there is suspicion of a criminal cause due to extravasation of the contrast into the extracellular space. The Bern group added polyethylene glycol to increase the viscosity of contrast, which solved the problem (Jackowski et al. 2006). The Lausanne group found this may cause fluid to be drawn into the vessel, leading remaining blood to clump together, which may be confused for a thrombus (Grabherr et al. 2015). Initial studies of the lipophilic contrast Lipiodol ultrafluide® and diesel oil perfusate showed promise, and further research led the group to develop their own contrast Angiofil® (Fumedica AG, Switzerland). Together with paraffin oil (paraffinum liquidum) as the perfusate, they found this to be optimal to stop extravasation.

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FIGURE 31.6 Whole-body angiography of a ruptured aortic aneurysm. An axial image (left) of an abdominal aortic aneurysm showing the rupture site (arrow) and a coronal view (right) showing the extent of the bleed. Although this was suspected on the plain scan, the rupture site could not be seen.
of death (Okuda et al. 2013). The teams therefore utilize lines and cannulae already in place for clinical intervention. After death is declared, with the consent of the family, a PMCT scan is performed, followed by PMCTA.

The cannula, usually in the cubital vein, is connected to a pump injector and contrast is injected at 1.5 mL/s and a dose of 2 mL/kg (Sakamoto 2016). While injecting, two minutes of chest compressions, as described in cardiopulmonary resuscitation (CPR) guidelines, are used to attempt to create a circulation and move the contrast around the body. Although the contrast is injected into a vein, opacification of the arterial system is reported (Iizuka et al. 2013, Sakamoto 2016).

This approach has a great advantage over the other two methods in that the scan is completed immediately after death (Iizuka et al. 2013), despite using clinical scanners. This would not be possible in many centers, as the living would take priority, but this is facilitated in Japan as they have the highest concentration of CT scanners per head of population in the world (Okuda et al. 2013). This approach avoids the problems of extravasation experienced in the Swiss approach, as the permeability of the vascular wall has not increased due to the short time from death to scan (Sakamoto 2016). As discussed, hypostasis and clot formation occur with increasing time after death. With immediate scanning, these are avoided and so problems of discerning clot from PE do not exist.

### 31.5.6 Targeted PMCTA

Coronary artery disease is one of the most common causes of death across the world, and so a means to fully diagnose it was required if PMCT was to be able to replace autopsy. Two groups adopted a similar approach to address the problem. The notable differences between the two groups are the contrast used and the means of administering it. The Oxford group use water-soluble iodinated contrast (Roberts et al. 2011), and the Leicester group use both iodinated contrast and air (Saunders et al. 2011) (Figure 31.7). The Oxford approach goes to lengths to exclude air from the process (Roberts et al. 2011) as they believe it may stop the opacification of the coronary arteries with contrast. The Leicester approach exploits the benefits of air as a negative contrast media to delineate the arteries, which is particularly effective where there is calcification. Water-soluble contrast is used to demonstrate areas of soft plaque encroaching on the lumen. Neither group have seen the tissue edema described by the Swiss, but the quantity and concentration of the contrasts used are lower.

The groups also differ on their means of contrast administration, with the Oxford approach using hand injections (Roberts et al. 2011). After death, as described, the blood settles as hypostasis occurs and vessels collapse in the absence of circulatory pressure. Without pressure, a stenosis or luminal soft plaque encroachment may be overestimated and give false positive results. For these reasons, the Leicester approach uses a CT pump injector (Medrad Stellant pump injector system, Medrad UK Ltd., UK) to administer contrast, whether air or fluid contrast (Robinson et al. 2013). Scanning whilst injecting using a pump injector causes distension of the vessels, mimicking physiological conditions, with the intention of avoiding false positive stenoses. Scanning whilst injecting by hand is not recommended due to the unnecessary radiation dose to the person administering the contrast. As the scan has to be completed after the injection, when pressure is not maintained, there is the risk of vessel collapse.

The body is prepared in the mortuary or the scan room. A catheter is inserted into the left carotid artery through an incision made just above the clavicle. (The technique is fully described in Saunders et al. 2011 and University of Leicester 2016.) The catheter is positioned in the ascending aorta with the tip just above the aortic valve. The balloon on the catheter is inflated using 1% solution of contrast, to hold it in place and to occlude the aorta. The position of the catheter balloon is confirmed on the initial PMCT scan. If the balloon is occluding the coronary ostia, the balloon is deflated, retracted, and re-inflated. Contrast can then be introduced through the catheter at 6 mL/s for 300 mL of air and 3 mL/s for 150 mL of 10% urografin (Urografin® 150 mg/mL, Bayer Healthcare).

![Figure 31.7](image-url) A curved multiplanar reconstruction of a right coronary artery (RCA) and left anterior descending (LAD) artery. During an injection of air (a) and positive contrast (b), the vessel is shown to be patent, despite small areas of the vessel appearing occluded, air and contrast can be seen distal to these points.
Both groups use body rolling and separate injection runs to allow preferential filling of the right and left coronary arteries due to gravity. Rolling onto a right decubitus position also allows any clot that may be occluding the left main stem to move out of the way.

### 31.5.7 PMCT Ventilation

Identifying lung pathology on PMCT is important in ascertaining the cause of death. In clinical cases, a scan is completed on suspended inspiration to clear atelectasis and "dependant" changes (Morgan et al. 2014). PMCT scans of the lungs had previously been effectively acquired in expiratory phase. After death, fluid builds up in the lungs due to livor mortis, which increases with time since death (Shiotani et al. 2011). This pulmonary opacification can mask true AM pathology or can be mistaken for pathology, such as aspiration or contusion (Christe et al. 2010) (Figure 31.8).

In 2010, Germerott et al. published a novel method of ventilating the lungs during a PMCT scan, using clinically placed intubation tubes, continuous positive airway pressure mask, or a laryngeal mask. Whilst helping to clear the lungs of PM artefactual fluid, this method caused gastric dilation, risking purging of the stomach contents and movement artefacts. The use of either mask did not occlude the airway and so had air leaks, reducing the efficacy of the ventilation. The motion artefact issue was resolved by using a different ventilator to deliver continuous positive airway pressure using a continuous positive end-expiratory pressure of 40 mbar, which enabled an inspiration breath hold to be simulated (Robinson et al. 2014). The technique was still prone to gastric dilation as laryngeal masks were used. Rutty et al. (2015) found a definitive airway, and particularly a shortened endotracheal tube (ET) inserted through a tracheostomy incision, the most effective for both adequate ventilation and avoiding the gastric dilatation issue. A technique has also been successfully developed for pediatric use (Arthurs et al. 2015).

A ventilated scan should only be completed after the whole body plain PMCT scan has been done. The scan should cover the entire chest, allowing for the expansion of the lungs from the original localizer sequence. The position of the intubation device must be checked on the plain scan. It is not uncommon, for example, for ET tubes to be in the right main bronchus and so must be pulled back to above the carina to ensure successful ventilation of both lungs. The radiographer or technician performing the scan can reposition this on the scan table. The ventilator tubing can then be attached to the intubation device. The ventilator is turned on prior to scanning and the time for the radiographer to leave the scan room is sufficient to successfully ventilate the lungs. The ventilator is switched off when the scan is completed to reduce the risk of creating surgical emphysema if there is previously unnoticed lung trauma.

### 31.6 Imaging in Mass Fatalities—Disaster Victim Identification

Disaster victim identification (DVI) is the process of identifying individuals who have died as a result of an incident with many fatalities. These may be naturally occurring incidents such as tsunami, earthquakes, hurricanes, or an epidemic such as the Ebola virus outbreak, or manmade, such as large traffic accidents, plane crashes, or acts of terrorism. The process starts with the recovery of the deceased and continues until all are identified and returned to their families. Each country has their own processes, but many follow guidelines agreed by Interpol. The process involves input from all emergency services and forensic experts, sometimes with military support, who are all trained to provide a co-ordinated approach to achieve the identification.

Since its first use in DVI in the SS Noronic disaster in 1949, described above, imaging has been involved many times. Different imaging modalities have been used in the manners described above. The forensic team is led by pathologists, who work closely with odontologists, anthropologists, radiographers, radiologists, and the mortuary team. Their role is to identify each individual and establish the cause of death. This may appear obvious, but in the Japanese Tsunami, a murder had been committed preceding the tsunami and was discovered during the investigation (Lino and Aoki 2016).

![FIGURE 31.8 Lungs before (left) and during (right) ventilation. Post-mortem changes (black asterisk) give the appearance of pathology. This clears on ventilating to reveal the true bilateral effusions with ground glass shadowing.](image-url)
Identification is ideally completed by odontology, DNA, or ridge print analysis (fingerprints). In some instances, radiology alone is used. In the 2001 World Trade Center attack in New York, 188 victims were identified by dental radiographs alone (Centre for Disease Control and Prevention 2002). More commonly, imaging is used in conjunction with the other means of identification. Following the Oklahoma bombing, almost half the victims were identified using imaging and fingerprints or DNA, with an additional 30% only using imaging (Nye et al. 1996).

A full dental radiological examination will be completed to assist the odontologist in comparing AM X-rays and records with the PM images (Middleton et al. 2016). Odontologists can also assist by identifying physical features that suggest ethnicity, wear on the teeth that suggest cultural practices, and dental work, which can be specific to different countries. Imaging is also used to screen body bags looking for fragmented body parts and personal effects, as occurred following the 2001 Pentagon attack (Harcke et al. 2002). The anthropologists assist particularly when bodies are disrupted, by identifying if the bones are human (as animals may also be involved in the incident), identifying which bone is being examined, and the age of the deceased. Without radiology, the only way anthropologists can examine the bones is to “deflesh” them, a time-consuming process, potentially causing more distress to the relatives of the deceased.

Establishing identity can be assisted by identifying unique skeletal features, old healed fractures, and surgical implants such as pacemakers and prostheses, which often have unique reference numbers which can be compared to hospital records. In addition to dental examinations, a complete radiological skeletal survey of the deceased is completed in all cases to facilitate this. This may be done by plain film X-rays, fluoroscopy, or PMCT.

PMCT was used for the first time in a mass fatality in 2006 (Rutty et al. 2007). It has since been used in the 2009 Australian bush fires (O’Donnell et al. 2011), MH17 investigation (Khoo et al. 2016), and the Shoreham air show crash (University of Leicester 2015). PMCT has recently been used in place of plain film modalities, as they can be time consuming (Nye et al. 1996). Additionally, CT is now more frequently used clinically, enabling more opportunity for AM and PM comparison. As CT is able to demonstrate bone, soft tissue, and foreign objects, in a way plain film modalities are unable to, CT offers more opportunity for identification. A cholecystectomy, for example, not demonstrated by plain film would be apparent on CT and potentially aid identification (Morgan et al. 2014).

Imaging in DVI applies the same principles and processes as when dealing with individual forensic cases in a mortuary and/or hospital setting. It is not the same, however, particularly for a larger scale incident, as the logistics, circumstances, environment, and demands on staff are all very different. Taking imaging out of the traditional hospital environment also has problems. Using a heavy fluoroscope on a temporary floor can be challenging, and the radiation protection of the whole mortuary team must be considered. Incorporating PMCT is simpler as it is contained in a lead-lined vehicle, which can operate inside a large enough building or external to it. This may necessitate awnings being erected to ensure privacy. However, the location and type of incident may make this impossible.

In the aftermath of the 2004 Japanese tsunami, the degree of devastation to the infrastructure and the need to treat all the deceased the same, meant imaging could not used (Lino and Aoki 2016).

### 31.7 Conclusion

Forensic radiography has evolved and expanded since its inception and hugely in the last 20 years. Previously being seen as a bonus if a pathologist could have it, it is now routine in many locations as it has been accepted that imaging, particularly PMCT, is better than autopsy at identifying fractures. Through the research undertaken, it has been demonstrated that, in many cases, imaging will add to the information gained at autopsy and the new “Gold Standard” of death investigation is PMCT and an invasive autopsy. In some instances, it is possible for PMCT to replace an autopsy, and in many more cases, dramatically reduce the extent of an autopsy. However, any autopsy can be extremely distressing for the family and friends of the deceased, and it is hoped that further development of PMCT will enable imaging to replace autopsy in the majority of cases in the near future.

### REFERENCES


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