The Evaluation of Computerised Tomography for its use in Forensic Pathological Investigations

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By

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ABSTRACT

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by Dr Amanda Jeffery

The prospect of an autopsy examination of a loved one is often upsetting for relatives. Despite public perceptions of pathologists, many doctors entering histopathology training do not aspire to undertake autopsy examinations. As many pathologists cease autopsy work following completion of training and the option of an autopsy-light curriculum of UK pathology training is proposed, the future of autopsy practice is unclear.

A few research groups, worldwide, have started investigating expansion of the role of post-mortem imaging. The replacement of invasive autopsies by post-mortem imaging is proposed by some as a socially acceptable solution to future autopsy service provision.

The benefits of post-mortem computed tomography (PMCT) have been championed but few authors have taken a more critical approach. This thesis critically examines the capabilities of PMCT in the fields of mass fatality investigation and ballistics/projectile deaths. It assesses its ability to replace the invasive components of a forensic post-mortem and the acceptance of such a procedure by the end users of the report.

PMCT provides valuable additional information which informs and enhances the autopsy examination. It can form part of the permanent medico-legal record which can be revisited long after body release. The images produced have great potential to revolutionise the demonstration of injuries to end users including HM Coroners, the police, and other legal professions and more importantly lay jurors. PMCT is particularly valuable in the investigation of mass fatalities. It is also of great assistance in the investigation of projectile trauma both as part of the autopsy examination and as a terminal ballistics research tool.

Whilst PMCT has a lot to offer death investigations, there are still areas where it cannot compete with the autopsy examination. This is particularly true of certain soft tissue abnormalities. With standard PMCT, vascular abnormalities such as traumatic defects, thrombosis and atherosclerosis cannot be reliably detected as circulating contrast media cannot be seen. Parenchymal defects in organs and cartilage, including penetrating wound tracks cannot be reliably discerned in all cases.

At present, PMCT cannot provide all of the answers that the police and legal profession have come to expect from autopsy examinations. The legal profession is not ready to accept the current uncertainties that surround a technique that is very much in its infancy. Therefore, it is unlikely that PMCT will replace the autopsy as the gold standard in suspicious death investigation in the near future. It may have the potential to replace the invasive component of some coronial autopsies in particular some road traffic deaths. It does have great potential as a pre-autopsy screening tool and as a valuable adjunct.

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Dissemination of Research

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CHAPTER FIVE

ABSTRACT:

- Rutty G.N, **Jeffery A.J**, BouHaidar R, Robinson C (2006). **The first reported use of multi-slice computered tomography for mass fatality radiological investigation** XXth Congress of the International Academy of Legal Medicine. Meeting proceedings OTI4

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CONTENTS

INTRODUCTION

CHAPTER ONE- **THE BACKGROUND**

CHAPTER TWO - **THE CURRENT STATUS OF POST-MORTEM AND FORENSIC COMPUTED TOMOGRAPHY –** A REVIEW OF THE LITERATURE

FIREARM & PROJECTILE DEATHS

CHAPTER THREE – Terminal Ballistics

CHAPTER FOUR - Computed tomography of projectile injuries in animal models and human forensic cases

THE FUTURE

INTRODUCTION

Chapter One : The Background

1.1 Introduction

In 1994, it was proposed that computed tomography might address the declining number of post-mortems due to increased clinical commitments of pathologists and ethical or religious considerations. In 1997, at the request of the local Jewish population, an MRI service was set up in Manchester in the United Kingdom as an alternative to the invasive post-mortem procedure. In the British Medical Journal, the radiologists reported achieving a confident cause of death in 87% of cases but the radiology was not correlated with the autopsy findings [2]. This work highlighted the potential for the development of non-invasive imaging-based post-mortem examinations [3]. Since then, concerns have been raised as to the validity of these suggestions [4]. In May of 2008, the Manchester experience was communicated to the general public within a local newspaper article entitled 'Body scans instead of post mortems' [5]. In July of the same year, the topic was raised in the House of Commons and the Lord Chancellor and Secretary of State for Justice, Jack Straw, announced that he was in discussion with others regarding rolling out this service to the rest of the United Kingdom [6]. As UK government considers "rolling out" an autopsy imaging service across the country, questions remain as to whether there is sufficient validation of the accuracy of radiology in detecting pathology and cause of death, and whether the imaging meets the needs of the medico-legal system.

1.2 POST-MORTEM RADIOLOGY

The post-mortem examination has been described as the ultimate surgical operation [7]. Few surgeons would attempt a complex surgical procedure without prior sight of some form of radiological imaging. However, the vast majority of post-mortem examinations undertaken within the United Kingdom, do not make use of this valuable adjunct.

The post-mortem examination is one of the main focuses of the forensic pathologist. Shortly after the advent of radiology in November of 1895, the forensic value of radiology became evident. The first use of radiology in a homicide case in the UK was in 1896 in a case of murder-suicide [8]. This refers to a murder followed by suicide of the perpetrator. In this case, the victim was shot four times to her head with a handgun and the assailant, her husband, subsequently drowned himself. The victim survived just over two weeks and radiographs showed that the projectiles were not amenable to retrieval.

In modern practice, forensic pathologists undertake radiology in a range of circumstances [9, 10]. These include:

- **Identification –** where a body is unidentifiable by other means.
- **Firearm deaths** – where location and retrieval of projectiles is of forensic importance.

- **Child abuse / Non accidental injury** – skeletal surveys are crucial for the detection of recent and historical skeletal trauma.
- **Barotrauma or suspected air embolism** – such entities can be difficult to demonstrate at post-mortem examination.
- **Traumatic subarachnoid haemorrhage -** contrast angiography is a recognised method for examination of the integrity of the vertebral arteries.
- **Other complex cases** where the examination and interpretation is compromised by destruction of the body e.g. fire damage, decomposition, dismemberment, or fragmentation.

Wilhelm Conrad Röntgen's original discovery of 'X-rays' has revolutionized medicine. The humble radiograph has developed significantly over the years with cross-sectional imaging using computed tomography and magnetic resonance, now gold standards in clinical radiology. However, the forensic pathology community has been slow to embrace the new technology available, with many still relying on traditional 2-dimensional radiographs.

While MRI has been considered as a form of post-mortem radiology, the prolonged time taken for whole body imaging, the financial impact and inherent problems with metallic foreign bodies have limited its large scale use in post-mortem investigations. [11]

1.3 COMPUTED TOMOGRAPHY

Computed Tomography (CT), or computerized axial tomography ('CAT' scans), was developed in 1972 by Godfrey Hounsfield and Allan Cormack as a means of producing cross sectional images through the body. Both shared the 1979 Nobel Prize in medicine.

Unlike traditional plain film radiography which used a photographic plate, the technique involves passage of a rotating collimated x-ray beam through the body and subsequent electronic measurement using a circular array of x-ray detectors. With original CT scanners the body moves in increments between x-ray tube rotations, acquiring information in a 'slice by slice' manner.

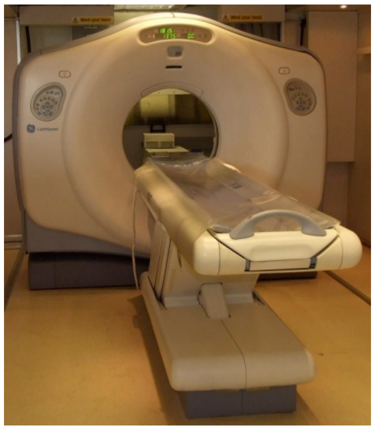


Figure 1.1 – CT Scanner

The spatial resolution (sharpness) of the image in the x and y planes (transaxial plane) depends on the number of detectors, rotation speed and electronic post processing. The resolution in the z plane (longitudinal axis) depends on the collimation and thickness of the detectors.

There have been several developments in CT technology over recent years including:

- Greater output capacity of the x-ray tube (heat capacity)
- The achievement of contiguous rotation of the x-ray tube and movement the patient (spiral CT)

- The advent of multiple arrays of detectors which can image multiple 'slices' in one rotation (multi-slice or multi-detector CT: MSCT or MDCT)
- More powerful and sophisticated computers enhancing image reconstruction.

As a result, rapid whole body imaging is possible with a nearly perfect 3D acquisition (i.e. the resolution in the z plane is almost as good as in the x and y planes: isotropic imaging). This allows manipulation of the images and review in any desired plane (multi-planar reconstruction or MPR). Locally, the last 15 years has seen the time taken to scan an average body length reduce from 4 minutes to 6 seconds.

The CT scanning process produces a significant amount data. This data can be processed in different ways to exploit those features that will be most useful to the practitioner.

The first step in the processing of the data is application of an iterative algorithm known as the algebraic reconstruction process (ART). However, this acts as an estimate and includes inherent errors.

A mathematical filter can be applied to the data before to enhance the edges of the scanned object. This is called filtered back projection (FBP). Complete 'de-blurring' of an image produces a very high resolution image but also produces image noise (graininess). This graininess makes differentiation of soft tissues structures more difficult. Filters used are therefore a compromise between resolution and noise creation. Different filter algorithms may be used to enhance different features within the image such as a hard algorithm which produces edge enhancement for better bone and lung images or a soft algorithm that provides better soft tissue contrast.

The result is an image with considerably improved contrast between structures, compared with 2D radiography, due to lack of overlying structures and the ability to resolve structures in all planes.

The image in a particular scan plane is made up of a matrix of pixels (up to 1024 x 1024 small volumes). These are presented as a calculation of their attenuation coefficient for x-rays in that voxel, in relation to the attenuation coefficient of water. In this scale (Hounsfield units) water is 0, bone can be 400 to 1000 HU and air about -1000 HU.

The resultant image is digitally displayed on a monitor, or printed films may be produced. A CT image may include a range of HU values from -1000 to 1000. As the human eye can only discern around 16 shades of grey, tissues of interest that are only a few HU different may not be discerned. Therefore images are visualised with control over the range of HU values depicted as black to white. For example a window setting with centre at 30 and range of 300 would be useful for soft tissue imaging but if the range were increased to 1000, apparent soft tissue contrast would be reduced but the difference between bone and metal foreign bodies would become more apparent. The image is formed from a matrix of 2D picture image elements (pixels).

In practical terms, the first image produced is known as the scout image (figure 1.2). This is used to define the target area for scanning. This is a 2D image akin to standard radiography as seen to the left.

Figure 1.2 – Scanogram or 'Scout' image

Multiple axial slices can be viewed as is routine in clinical practice and the data can be reconstructed to produce 3-dimensional images (Figure 1.3). Post processing manipulation can also allow virtual dissection of the body (Figure 1.4).

Figure 1.3 - 3D reconstructions showing bony detail only

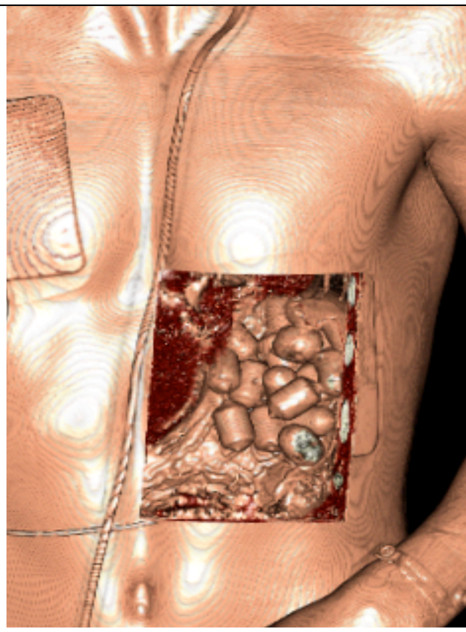


Figure 1.4 - Virtual dissection revealing multiple small drug packets in the stomach of the deceased.

Chapter Two: The Current Status of Post-mortem Computed Tomography - a review of the literature

2.1 Introduction

The field of post-mortem computed tomography (PMCT) is relatively new and is expanding rapidly, replacing more traditional forms of radiology as novel applications evolve. The capabilities of PMCT have been championed within the literature with many suggesting that it has the potential to replace some invasive post-mortems in the future [12-16].

A research group in Switzerland have coined the term 'Virtopsy®' to represent the concept of the virtual autopsy [11, 17]. Within the UK, the Ministry of Justice, Ministry of Defence, Department of Health and the Home Office have worked together to compile a group of experts to push forward research into the non-invasive autopsy. As well as in the scientific community, there is also lay interest and the idea of rapid, non-invasive examination of the dead is being championed by several religious groups. However, most of the current literature pertains to individual case reports rather than a true assessment of whether a virtual autopsy would be fit for medico-legal purposes.

In May of 2005, the Victorian Institute of Forensic Medicine (VIFM), Victoria, Australia, installed a 16-slice CT scanner within their mortuary facility [18]. This was funded by the Victorian State Government because of the scanner's potential to enhance Victoria's counter-terrorism capabilities [19]. Over 15,000 bodies have been scanned and their published experience is anticipated.

Within Victoria, PMCT has proven to be a valuable adjunct in cases where next of kin have objected to post-mortem examinations and when death certificates have been scrutinised and deemed to require further evidence. It has also facilitated cases of '*inspection and report*'. This is similar to the Scottish system of '*view and grant*' where a cause of death is provided by the pathologists following review of the information of the case together with an external examination but with the advantage of adding radiological evidence [20].

The principal questions asked by HM Coroner in relation to the death of an individual are who they were and when, where and how they came to their death. In most cases, the main focus for the pathologist is 'how' they came to their death. However the post-mortem examination may play a crucial role in the identification of unknown individuals.

2.2 WHO? - IDENTIFICATION

Accurate identification is critical as it allows appropriate repatriation of the deceased individual, funeral organisation and provides closure for friends and relatives. Visual identification by relatives is not always possible, particularly when there are no clues as to the identity or when the condition of the body makes it inappropriate or impossible. Indeed, a third of visual identification of the victims of the 2002 Bali bombing by relatives produced misidentifications [21]. Radiographs are a well established method of human identification.

If ante-mortem radiographs are available, they can be compared to post-mortem radiographs of the deceased. A number of anatomical structures have been investigated for these purposes with many considered as unique as a fingerprint. The most well recognised being dental characteristics, cranial sinuses, cranial sutures and mastoid air cells.

The unique morphology and permanence of the frontal sinus has made it an important tool in the armoury of the forensic anthropologist when attempting to identify skeletal remains. PMCT has been shown to be a potentially useful alternative to plain radiography when ante-mortem scans are available for comparison [22, 23]. A case report has also demonstrated successful identification of an unknown corpse by correlation of multiple features within the lumbar spine [24].

Comparison of ante-mortem and post-mortem radiographs is facilitated by obtaining standard clinical radiographs from the deceased that match the orientation of the ante-mortem (clinical) radiographs. It can be difficult to achieve identical post-mortem orientation due to rigor mortis and disruption of the body.

It is easier to compare two pieces of radiological information of the same modality for example two radiographs or two sets of CT data rather than comparing a radiograph with CT. However if the only ante-mortem records available are traditional x-rays, multi-planar reconstruction (MPR), post processing manipulation and reorientation of CT generated images can overcome this problem [25]. Researchers are also developing computer software to assist comparisons between different radiological modalities [26].

In addition to the natural skeletal anatomy, other features may assist. These include pathology such as osteoarthritic changes and historical fractures or medical interventions such as surgical implants. The presence or absence of, for example, a dynamic hip screw, may immediately narrow the field of enquiry.

PMCT has excellent potential in this area as it can demonstrate the anatomical features of the skeleton, natural or unnatural bone pathology and medical implants or prostheses [27]. CT also has the advantage of providing more detailed soft tissue information.

In the same way that the presence or absence of medical prostheses may be used to narrow down potential identity matches, the presence or absence of normal anatomical structures such as the appendix, gall bladder or spleen can play a similar role. The soft tissue definition of CT allows such features to be recognised without invasive examination. Evidence of more subtle medical interventions such as the presence of coronary stents may also be identified if the appropriate algorithms are used.

The ability to accurately examine the skeleton in varying orientations in a non destructive manner, paves the way for new applications of PMCT.

In cases of marked decomposition, anthropological measurements may be taken from the skeleton of the deceased without time consuming, and potentially damaging, de-fleshing of the bones [27]. The potential, therefore, exists for anthropological indicators of age and sex to be obtained from non-destructive PMCT [28-34]

Anthropologists have used CT scanning to obtain important data from archaeological remains to avoid destruction of mummified corpses such as Otzi, the iceman discovered in Tyrol in 1991[35] [36]

Reconstructed 3D data from skulls may also be used in the process of facial reconstruction [37, 38]. Ante-mortem CT scans have already been used to gather information regarding the variable thickness of facial soft tissues in different racial subgroups [39].

2.2.1 Dental identification

Forensic odontology is a more established means of identification. The dentition of the deceased may be correlated with prior dental records and radiographs or, in their absence, photographs of the deceased smiling. This is traditionally achieved by physical examination of the dentition by odontologists and contemporaneous or subsequent comparison with available dental records. It is important to remember that all modes of dental identification are, of course, fundamentally dependent on the existence of dental records for comparison. The absence of prior dental records caused significant difficulty in the identification of the victims of the Asian Tsunami on Boxing Day of 2004 [40].

Limited availability of forensic odontologists and the need to limit the number of individuals present at mass fatality event, produces the need for radiography; a permanent medico-legal record which can be used for remote reporting and kept for subsequent comparisons. The radiography undertaken must permit detailed examination of each tooth, root and surrounding bone. This level of detail cannot be achieved with simple radiographs of the skull. Dental radiographs traditionally consist of multiple periapical views each showing the adjacent teeth, roots and association bone and 'bitewing' views which show the occlusal surfaces of the teeth. This can be technically difficult when dealing with a 'non-compliant', deceased patient. Panographic radiographs (those showing the entire maxilla and mandible) can be undertaken but specific panographic machines are required to image supine patients. With standard clinical machines, the x-ray tube rotates around a standing or sitting patient.

In mass fatality situations, the use of conventional radiographs to record dentition can be particularly time consuming with radiography becoming a rate limiting factor in body processing. Software packages are available for CT scanning that allow presentation of the dental images in multiple formats to allow comparison [41]. It has been proposed that PMCT could attain more detailed dental imaging than plain radiographs within minutes, avoiding the need for the presence of odontologists within an already overpopulated temporary mortuary facility and superseding the conventional radiography [42]. Others have, however, expressed concerns over the apparent high error rate resulting from streak artefact, despite the use of an extended CT scale and the difficulty in differentiating some dental materials such as ceramics from the native dentine and enamel [43].

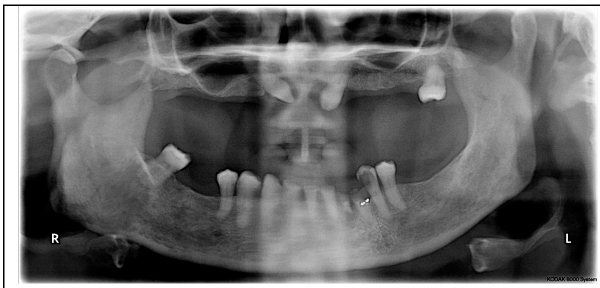


Figure 2.1 - Radiographic Orthopantomogram (OPG)	Figure 2.2 - CT OPG

2.2.2 Mass Fatality Radiology

In mass fatality scenarios, identification of individuals becomes one of the primary objectives of the investigation for all parties concerned. The current standard approach, as used in previous incidents such as the terrorist bombings in London in July 2005, involves moving fatalities through up to three separate radiology stations; standard radiography, fluoroscopy and dental radiography. PMCT may in the future provide an all-encompassing radiology facility, acquiring all the necessary data in one, more time efficient, station [44]. Truck mounted CT scanners could be driven to the area by road or containers could be airlifted into place and have the potential to provide a quick, permanent record of individual characteristics for future comparison. The application of PMCT to mass fatality scenarios is discussed in more detail in Chapter 5.

2.3 WHERE & WHEN?

The place of discovery of a body may not necessarily be the place of death. In the majority of cases this will be ascertained from witness statements, scene investigation and circumstantial evidence, rather than invasive pathological evidence. The case is similar for estimation of time since death and there is extensive research into estimating this, when circumstantial evidence is not immediately available. This includes the use of temperature, biochemistry, entomology, and muscle excitability [45-47]. These investigations are largely non-invasive and could be undertaken in addition to imaging with minimal, if any, damage to the body.

As invasive pathological examination has limited capabilities in determining where and when a person has died, it would appear that radiological investigations are unlikely to be able to assist further in these areas at present. There are a number of changes that are noted as normal variants in PMCT. These are simply a result of the pathophysiology of the process of death and are discussed later in this chapter. Many of the changes are related to gaseous decomposition and hypostasis (gravitational vascular congestion) within the organs. This is particularly evident within the portal veins of the liver. In the same way that many authors attribute a timeline to the external changes of decomposition, there exists further scope for research in this area. However, the ever present variables that affect the accuracy of other methods of estimation of time since death would equally apply to PMCT findings.

2.4 HOW? – CAUSE OF DEATH

2.4.1 Natural Deaths

One of the main drawbacks of forensic PMCT as a form of virtual autopsy is the current inability to detect certain natural causes of death with any degree of certainty. In particular the inability to confidently diagnose cardiac causes of death, pulmonary thrombo-embolism and many acute strokes is a major limitation. The vast majority of medico-legal post-mortems reveal natural cardio-respiratory causes of death. Even in unnatural deaths, PMCT might beautifully demonstrate the presence of traumatic injuries in a pedestrian road traffic collision, for example, but miss the fact that the deceased may have collapsed into the path of the vehicle due to an acute coronary thrombosis. This would have important legal consequences for the driver of the vehicle. Similarly sudden cardiac deaths can be precipitated by stressful situations such as otherwise minor physical assaults or burglary in those with pre-existing cardiovascular disease. Objective evidence of such cardiovascular disease would be required for any prosecution to proceed.

Although calcification of the coronary arteries can be demonstrated, any pathologist undertaking post-mortem examinations will be aware that non-calcified coronary arteries may be significantly stenosed and become thrombosed while some severely calcified vessels are remarkably patent. Likewise, coronary artery calcification scoring has received great interest in clinical radiology [48-50] but is now considered by many to be a flawed prognostic marker [51-53]. Multi-slice and electron beam CT have been shown to provide excellent images of the coronary circulation in the clinical setting but in cadavers similar quality images have required contrast infusion of explanted hearts [54, 55]. These ideas are all still in the research phase and at present accurate assessment of the coronary vasculature remains impossible with non contrast PMCT.

The appearance of the myocardium in the post-mortem period may be altered by relative hypostasis and decomposition. It has been argued that MRI can differentiate between post-mortem and ante-mortem clotting and that areas of myocardial infarction can be visualised [56, 57]. To date, no such claims have been made by those utilising CT technology.

Therefore, whilst radiology may have the potential to replace a post-mortem examination, one has to consider the additional information gained from direct visualisation of the structures and the supplementary investigations undertaken by pathologists for example toxicology, histology and microbiology.

The organs are routinely weighed at the time of post-mortem. The weights may then be compared to standardised tables of weights expected for that particular sex, weight and height. In practice these weights often add little to the interpretation of the macroscopic findings except arguably, the heart and brain, where an excessive weight will alert the pathologists to the potential of underlying cardiac disease and brain swelling, respectively. There is a single paper which has investigated the ability of PMCT and post-mortem MRI (PMMRI) to provide accurate assessment of organ weight [58]. It showed excellent correlation between both CT and MRI estimations of organ mass and those found at post mortem with some limitation in decomposed cases where there was gaseous degradation. It is important to note that the paper presented a correlation rather than an agreement with the measured weights. New image-based reference ranges would need to be produced to account for the variations present. The paper also concentrated on the liver and spleen alone which are largely homogenous and therefore technically easier to measure than the more complex structure of the heart and brain but less relevant to assessment of significant life threatening pathology.

While toxicological samples may be taken by needle aspiration, further consideration is required for microbiological and histological examination. CT guided needle biopsies have been proposed and preliminary research would suggest that the amount of tissue that can be harvested is sufficient for histopathological assessment [59]. It is important to note, however, that there was no autopsy correlation of this work. In clinical practice, CT guided biopsy is regularly performed for many body areas [60]. Fluoroscopic CT (acquiring continuous scans in 'real time' whilst the operator introduces the biopsy device) is rarely required. Most radiologists do a CT scan of the area, prepare the line of biopsy and then advance the biopsy needle using intermittent small area scans to confirm the accuracy of the needle placement. This removes radiation dose to the operator, who can leave the room for the intermittent scans. Many may consider the needle autopsy approach inadequate but in cases where there may be a high infection risk to the pathologist and mortuary staff, it may still have value.

2.4.2 Unnatural Deaths

Computed tomography is used clinically in cases of trauma. It is therefore unsurprising that it can be of value in assessing traumatic injuries in the deceased [13, 15]. The published literature is, however, dominated by case reports which tend to provide an overview of the positive achievements of the imaging rather than displaying a more critical review of the findings.

a. <u>Firearm Deaths</u>

The use of radiology in the location of projectiles within the body is commonplace in modern forensic practice. It is easy to appreciate the advantages of three-dimensional imaging over multiple two-dimensional traditional x-rays.

Conical bevelling of the skull is used in conjunction with the external wound appearances to differentiate between entrance (internal bevelling) and exit wounds (external bevelling). This feature is illustrated in Chapter 3. Where multiple firearm injuries are present to the skull or when it is not possible to otherwise differentiate between an entrance and exit, Puppe's Rule may also be applied in attempt to ascertain the order in which they were inflicted. Puppe showed that a fracture line produced in the skull will halts when it intersects a pre-existing fracture line thus making it possible to reconstruct the sequence of injuries [61].

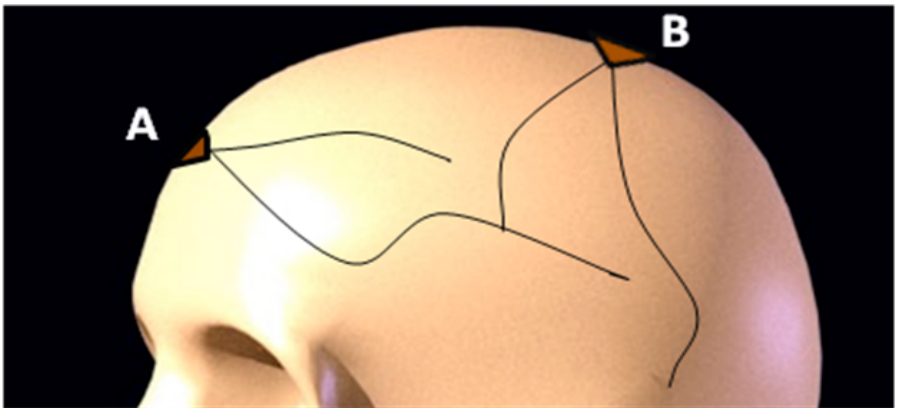


Figure 2.4 - Diagrammatic representation of two impact points to the skull (A&B) and their associated fracture lines. Application of Puppe's rule to these fractures indicates that impact A preceded impact B as one of the fractures associated with B stops at its intersection with a fracture radiating from impact A.

CT can demonstrate both bevelling and application of Puppe's rule to fracture patterns [62, 63]. It is also argued that the track of the projectile through the brain can be determined but this appears to largely depend on aligning the entrance and exit wounds and pattern of bone fragmentation rather than demonstrating the track itself [64, 65]. It is important to remember that following the passage of a projectile or the removal of a penetrating weapon, some soft tissues such as brain will collapse obscuring the track. Bleeding into the defect may however reintroduce the tissue density differentiation that is required to visualise the true path of the injury.

It has been suggested that gunshot residues may be detectable using computed tomography and that their presence within the soft tissue of a victim may be used to ascertain the range of shot [66, 67]. The authors acknowledge that the assessment would be dependent on the weapon and ammunition used but do not consider the artefactual introduction of external foreign material and projectiles into the wound from an intermediate target. Modern primers are also lead free making them less radio-opaque and reducing the universal application of such techniques.

b. CT use in Military trauma

There is increasing use of post-mortem computed tomography in cases of military trauma. Following pressure from families and the refusal of permission for invasive post-mortem procedures, the Israel Defense Forces Medical Corps commenced PMCT scanning. Their preliminary findings showed that PMCT used in conjunction with conventional post-mortem examination revealed more details than either method used in isolation [68].

Specific problems they encountered included defining multiple intersecting projectile paths and insufficient coverage of limbs due to the limitation of the field of view of the scanners. When assessing projectile paths in the mortuary, bodies may have to be manipulated to assess the possibility of projectiles traversing limbs and re-entering the body. This is not easily achievable during the CT scan process [69].

c. Paediatric Non-Accidental Injury

The skeletal survey has been an essential part of the assessment of non accidental injury in children for some years. It has been shown in animal studies, that CT scans may overestimate the number of fractures present depending on the fracture orientation in relation to the orientation of the scanning plane [70]. However due to the high fracture detection rate, Cattaneo's work suggests that a cranial CT scan should be undertaken in children with head injuries in line with the recommendations of the American Academy of Pediatrics [71]. One specific area in which CT was shown to have a lower rate of fracture detection than conventional x-ray was the ribcage which was believed to be a consequence of the tangential slices viewed in conventional CT reporting. This work highlights the value of combining multiple forms of examination to reap the most accurate results.

Shaken baby syndrome remains an area of great controversy in forensic pathology. Contrast enhanced PMCT imaging of the bridging veins, the proposed source of the classical subdural haemorrhage, has been put forward as an adjunct to the post-mortem [72]. As this involves needle puncture of the fontanelle prior to direct observation of the contents of the skull, this may not meet with widespread support from pathologists. Re-bleeding occurring within an older subdural haematoma originally due to, for example, known birth trauma or witnessed accidental injury may be suggested by defence barristers as an alternative explanation to a prosecution's claim of multiple subdurals of different ages caused by separate incidences of non-accidental injury. In CT scans, fresh haemorrhage appears bright (high attenuation) due to the haemoglobin present but as the haematoma matures it loses density relative to the adjacent brain. Re-bleeding of subdural haematomas, without significant trauma, is thought to be a result of the fragility of the small vessels within the maturing haematoma [73]. Acute bleeding within a pre-existing subdural therefore can produce a mixed or layered appearance on CT. It has been shown, however, that variations in the density of subdural haematomas seen on CT scanning cannot reliably be interpreted as re-bleeding in the setting of a chronic subdural

[74]. Greenberg at al suggest that the variations seen within the setting of pure acute haemorrhage may result from partial clotting with adjacent liquid blood [75]. As such, histological examination is required when timing of the bleed is crucial.

It has been demonstrated that post-mortem congestion within the posterior cranial fossa may be mistaken for pathology in infants because increased density in the area of the tentorium is used clinically as an indication for traumatic subarachnoid haemorrhage. [76] Due to the number of cases examined, this post-mortem artefact is now easily recognised in children and adults alike by those involved in PMCT scanning within University Hospitals of Leicester (Figures 2.5 & 2.6).

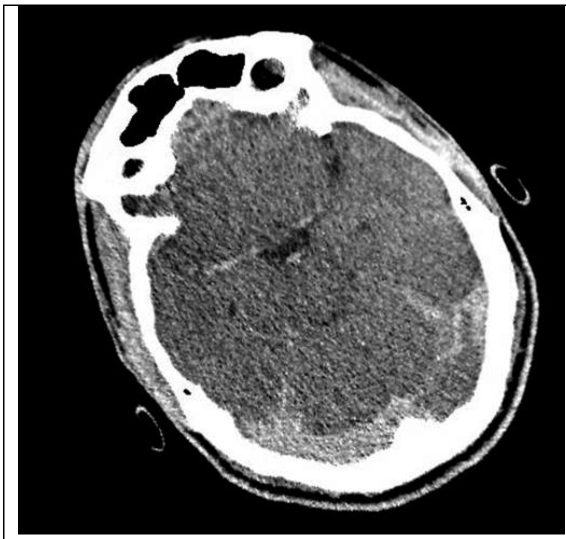
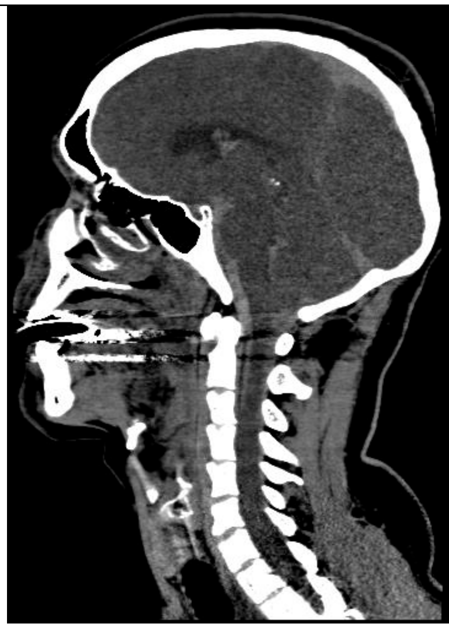
	

Figure 2.5 – Post-mortem venous congestion within posterior cranial fossa	Figure 2.6 – True subarachnoid haemorrhage characterised by increased density of blood beyond that seen in pure vascular congestion present in regions that do not correlate with venous sinus anatomy.

d. Sharp force injuries

The forensic application of CT in a stab injuries has been reported [77, 78]. These reports however, involve ante-mortem CT scans with use of intravenous contrast media injection and one with the knife left in-situ. In the latter, there is no apparent consideration of the implications if the knife had been removed from the wound. The position of the wound track and its effects are understandably easier to ascertain if there is a weapon in-situ and a functioning circulation. In forensic pathological practice the circulation is absent and the same is often true of the weapon. The wound track collapses and fills with blood making visualisation of the track difficult if not impossible. Although the scans may be able to show the clinical sequelae of the injury, whether or not they can provide the forensically relevant information that could be obtained through post-mortem examination such as an accurate measurement of track depth and detailed features such as serrations on bone, amongst others, remains to be proven. A recent article has shown how contrast can be instilled into a wound channel to highlight the wound track showing its size and direction. However, the wound tracks used in the demonstration are encased by soft tissues. Care would be required to prevent the production of false tracks within already damaged tissue. Such a method would also be less helpful when the wound tracks have traversed a natural body cavity e.g. the pleural cavity, before progressing to the heart [79].

e. Head injury

The position and morphology of fractures to the skull are regularly assessed by forensic pathologist to differentiate between falls and blunt force assaults. Multi-planar and 3D imaging can demonstrate these features in a sterile manner for jury members with the adjunct of digital overlays of potential weapons used in cases of assault.

Forensic pathologists are also asked for opinions in cases of assault where the victim has survived. In such cases the clinical CT scans may provide important forensic evidence [80].

Forensic examination of head injury usually involves not only a thorough post-mortem examination but also specialist neuropathological examination. At present neither PMCT or PMMRI can assess findings in the scalp or temporalis muscles as accurately as naked eye observation and many small lesions such as thin film subdural haemorrhages and contusions are easily missed in imaging [81].

f. <u>Air Embolism</u>

Radiology is an excellent method of confirming air within tissue and the cardiovascular system. Demonstration of an air embolism at post-mortem is not impossible but requires specialist techniques which would not be undertaken if the entity was not given prior consideration. PMCT is an excellent modality for the identification and quantification air embolism assuming gaseous decomposition is considered [82, 83]. In deaths due to decompression sickness, PMCT and PMMRI imaging are more successful in identifying gas bubbles in the meningeal vessels than post-mortem examination [84]. It is important to remember, however, that if a person dies from an unrelated pathology whilst diving, so called ‘off-gassing’ of the tissues on ascent of the body will still occur so the presence of arterial gas does not necessarily indicate arterial gas embolism due to barotrauma [85]. Whilst taking this pitfall into consideration, the Royal College of Pathologists in Australia recommends the use of CT in the post-mortem examination of diving fatalities [86].

g. <u>Fatal pressure on the neck</u>

PMCT is able to show fractures of the hyoid bone and laryngeal cartilage but in order to ascertain whether this occurred prior to or after death MRI scanning has been suggested as CT alone cannot reliably show areas of associated soft tissue haemorrhage [87]. The use of CT and MRI in clinical forensic medicine is attracting great interest as it is suggested that radiological imaging of a surviving victim can prove the severity of trauma to the neck in the absence of external findings thus assisting in prosecution of the assailant [88]

h. <u>Other Complex Cases</u>

In cases where decomposition or destruction of the body by other means such as fire makes external evidence of injury difficult to identify, PMCT may be invaluable in highlighting areas of internal trauma prior to internal post-mortem examination [89, 90]. However, in cases of decomposition, more needs to learnt about the imaging appearances of gaseous decomposition and other changes such as adipocre; a wax-like substance formed by the anaerobic bacterial hydrolysis of fat [91].

The lack of ability to comment on the efficacy of surgical interventions may necessitate internal examination of those who have died following surgical intervention.

2.5 FOREIGN BODY INTERPRETATION

The ability to detect radio-opaque materials like metals is unquestionable. However, the presence of non-metallic foreign bodies needs further consideration. It is our experience in the East Midlands Forensic Pathology Unit that glass is clearly visible (Figure 12). There are clinical examples of wooden foreign bodies that have been missed on CT [92]. The ability to detect different substances on CT images (image contrast) depends on the difference in electron density (similar to density) of adjacent materials and their size.

A foreign body which finds itself within a tissue of a similar density to itself will be difficult to detect.

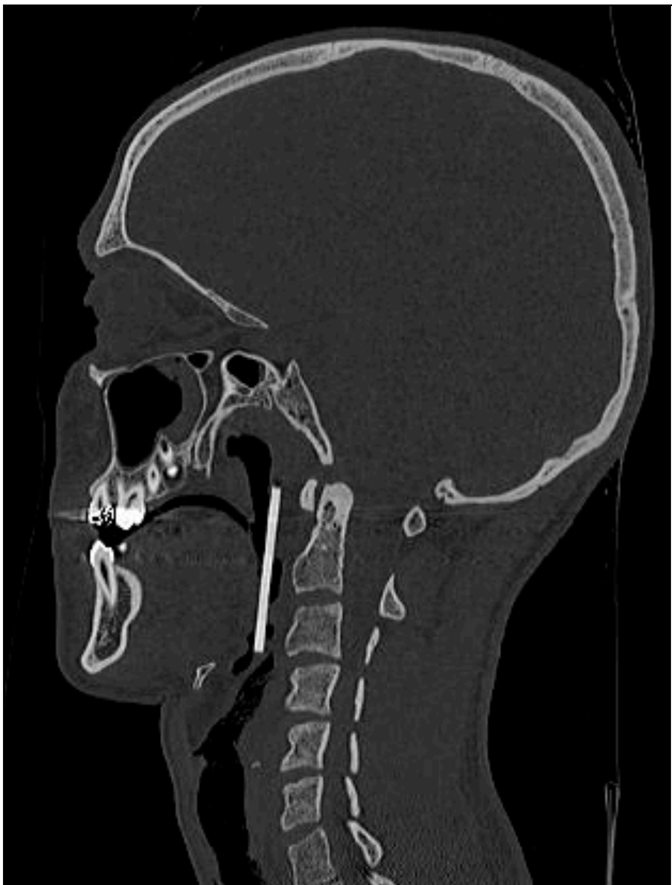


Figure 2.7 - Glass in the pharynx following an assault.

Wooden objects have been shown to appear as hypodense areas on CT scans, which can be misinterpreted as air and also as hyperdense areas if left in-situ in the longer term [93]. These considerations are of particular importance when dealing with injuries caused by explosions. The explosive device may disperse metal or non-metallic components for example plastics and body parts may themselves become secondary projectiles [94, 95].

Some investigators have commented on the varied radiological appearances of ammunition components [69]. Even with prior radiological investigation, small fragments of projectile may elude even the most thorough of pathologists. If CT were able to identify which of the fragments were likely to be of most forensic importance, this would focus the efforts on the fragments of most value.

2.6 NORMAL VARIANTS IN PMCT

In the United Kingdom there is a collaboration of forensic radiographers – International Association of Forensic Radiographers (IAFR) [96] but at present there is no equivalent body of clinical radiologists trained in diagnostic imaging and specializing in forensic imaging. While post-mortem CT remains a relatively new venture, it is vital that those undertaking the scans share their experiences with others. There are a number of changes that occur to the body after death. While the knowledge base is still growing, simple post-mortem artefacts may be mistaken for ante-mortem injuries or pathologies.

Figure 2.8 - Hypostasis (dependent congestion) seen within the lobes of the lungs.

Visceral hypostasis is evident in PMCT particularly within the lungs (Figure 2.8) [97]. The process of hypostasis may also explain areas of hyper-attentuation seen in the region of the tentorium mentioned previously in relation to infants but also commonly seen in adults. Recognition of this apparently normal post-mortem change will prevent mistaken diagnoses of traumatic meningeal haemorrhage.

An apparent post-mortem change identified on CT is hyper attenuation of the aortic wall [98]. Although causes such as atherosclerosis and arteritis have been identified in clinical situations, it was noted in 100% of the post-mortem cases in the particular study. The authors suggest that this may be due to the loss of blood pressure and relative condensation of the fibrous components of the vessel wall and blood dilution following peri-arrest resuscitation attempts.

Dilatation of the cardiac chambers has been recognised in PMCTs undertaken following cases of cardiac arrest but it is unclear whether this is truly post-mortem artefact or the consequence of fluid resuscitation and ensuing cardiac failure [99].

Air has also been reported within the hepatic portal vein on PMCT and although this may be seen in the presence of intra-abdominal pathology, it may simply represent a post-mortem change or artefact produced by artificial respiration during attempts at cardiopulmonary resuscitation or gaseous production by gut bacteria [97, 100, 101].

Many of the unusual findings seen in post-mortem CT involve post-mortem decompositional gas production. As part of this work, within the East Midlands Forensic Pathology Unit, it has been noted that air trapping is often present within the vertebral bodies apparently outlining the fine vascular networks present (Figure 2.9).

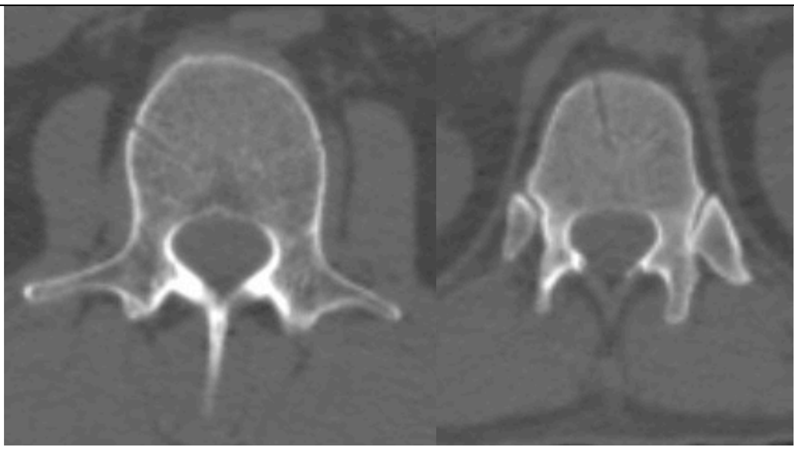


Figure 2.9 - Examples of post-mortem artefact within the vertebrae.

This observation is supported by the work of Rotman et al who used CT scanning to identify air pockets and similar patterns in the donor bone graft which had been confused with lytic pathology when viewed with conventional radiography. The authors consider this to be a post-mortem phenomenon arising as a consequence of decomposition [102].

2.7 COMPUTED TOMOGRAPHY USE BY ALLIED PROFESSIONALS

Ballistics & Explosives

A ballistics expert may be required to demonstrate / reconstruct events for court purposes. This has traditionally been achieved through diagrammatic representation. It has been shown that synthetic skull brain models can be produced with non invasive CT imaging of the internal effect of the passage of the projectile [103, 104]

There are also computed tomography based scanners marketed for airport security services for the detection of explosives and weapons within baggage[105, 106].

Forensic Veterinary Radiology

With the yearly increase in reports of animal cruelty [107], forensic veterinary pathology is a growing field. In the same way that PMCT may assist in the examination of suspicious human deaths, it may provide important information in animal subjects [108].

2.8 CONCLUSIONS

While the literature regarding post-mortem computed tomography is growing, there is still much to learn. Although, there are undoubtedly many advantages to adding sophisticated imaging to the post-mortem procedure there needs to be more critical assessment of the limitations of CT before we can consider it an alternative to the post-mortem examination. We also need to consider whether radiological examination is robust enough to meet the requirements of the judicial system.

2.9 THESIS STRUCTURE AND AIMS

Having summarised the introduction of computed tomography to post-mortem practice, this thesis outlines the potential for expansion of the use of computed tomography in forensic practice. It concentrates on two areas where other forms of radiology are currently utilised, namely firearm deaths and the management of mass fatality scenarios.

Chapters three and four highlight value of computed tomography in firearm death investigation. The first of these chapters focuses on its potential use in science of terminal ballistics. This is then followed by a study of CT capabilities in animal models and human cases with an illustrated review of the study findings.

Chapter five outlines the theory and logistics of mobile computed tomography use in mass fatality scenarios. This is followed by the application of this knowledge in a mass fatality case involving a multi-vehicle collision and six fatalities.

The final chapter includes a comparison study of invasive and non invasive approaches to eight forensic cases, considering the differences in findings of fact and causes of death along with the importance of histology to the interpretation of the case. The acceptance of PMCT by the end-users of post-mortem reports, in particular the medico-legal community, is then assessed ultimately considering whether the potential exists for post-mortem CT to replace invasive post-mortems.

FIREARM AND PROJECTILE DEATHS

CHAPTER 3: TERMINAL BALLISTICS

3.1 INTRODUCTION:

There is a long tradition of the use of radiology to assist with the forensic analysis of cases where foreign material is present within the body. In cases of firearm death, it has been used primarily as a tool to identify projectiles and precisely locate them to aid retrieval.

Firearms can be loosely grouped into rifled weapons, for example, handguns, rifles, and air weapons, and non-rifled weapons, such as shotguns. The damage caused depends on the velocity and characteristics of the projectile, as well as the body tissues involved. [109]

3.2 RIFLED WEAPONS

Rifling of a weapon refers to the presence of spiralled grooves within the barrel. This causes the projectile to spin as it passes through the barrel and increases the accuracy of shot. The term rifle is generally used to describe a long barrelled weapon with rifling. Smaller weapons or handguns, such as revolvers and pistols, also have rifling, but the shorter barrel will generally result in reduced bullet velocity. There are many types of ammunition available for these weapons. However, in broad terms there is a shell containing the propellant into which the projectile sits. The shell is ejected from the weapon and is not present within the wound (Figure 3.1).

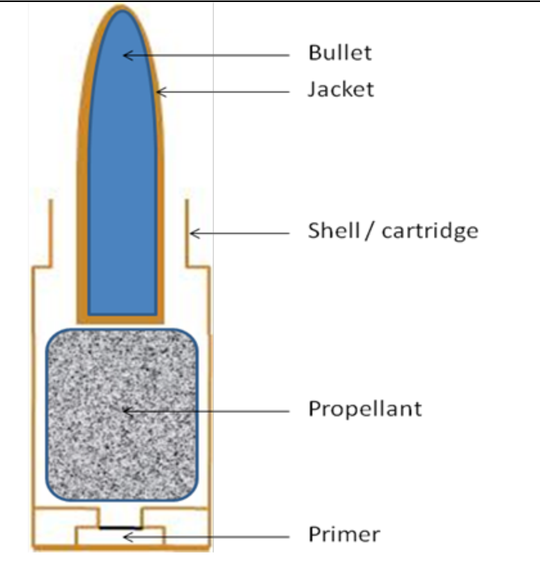


Figure 3.1 - Diagrammatic example of components of rifle ammunition

The projectile itself may be a single or composite metal bullet with or without a jacket. The jacket may cover the whole bullet, such as for military ammunition (full metal case or jacket, FMC), or be partial providing a soft bullet tip. The bullet (and jacket where present) may be present within the body, but this is dependent upon the velocity at which it is travelling and the distance of the body from the muzzle of the weapon. In the case of a high-velocity FMC bullet, the bullet may be intact with little deformation, such as a standard AK 47 bullet, or demonstrate fragmentation of the jacket such as for M16 rifle bullets. This fragmentation may affect radiological interpretation as it can mimic a second projectile (Figure 3.2). Where the weapon is not known and details of the ammunition are required to assist in the search for a weapon, invasive techniques may become essential to allow projectile retrieval. The rifling pattern, in particular, can be used to match a projectile to a suspect weapon (Figure 3.3).

A bullet that does not deform or hit bone can pass completely through the victim. In the case of a non- or partially jacketed bullet there is likely to be considerable deformation, increasing the soft-tissue damage caused by the bullet. This type of bullet is more likely to remain within the victim [109]. There is a variety of specialist rifled weapon ammunition, which the radiologist and forensic practitioner may encounter. An example is the THV (tres haute vitesse, very high speed) bullet, which was originally produced in France for use by the police. It is intended to be light weight, high velocity ammunition. The conical point allows easy penetration, even of soft body armour and the abrupt widening slows it down suddenly, stopping the bullet within its target, preventing injury to bystanders. The hollow tipped bullet works in a similar way, mushrooming on contact (Figures 3.4 & 3.5). CT can thus be used to consider the shape and type of projectile within the body.

		
Figure 3.2 - Example of projectile fragmentation	Figure 3.3 - Rifling marks on the jackets of two projectiles	Figure 3.4 - Example of the mushrooming effect

	
Figure 3.5 - Mushroomed hollow point,	Figure 3.6 - Expanded 'Black talon'

This may be a great importance when considering ammunition such as the controversial 'black talon'. This is projectile that splays sharp barbs causing maximum tissue damage and poses a significant health and safety risk for the surgeon or pathologist.

If the projectile passes through other objects, for example, the metal door of a vehicle, prior to entering the body, parts of the object may also enter the body and mimic fragmented projectile or bullet jacket [110].

The interpretation of a projectile path may be further complicated in the case of multiple projectiles fired in different directions [69]. Where cases involve multiple intersecting projectile paths it can be difficult to attribute specific wound tracks and damage to individual entrance and exit wounds. This is not a problem that is unique to radiological interpretation. In military ambush cases, it can be very difficult for the pathologist to define individual wound tracks.

The damage that a projectile causes is dependent upon the amount of kinetic energy that the projectile carries with it and how much of this energy is transferred into the body, which in turn depends on the structure of the projectile and the distance of the target from the weapon. When a projectile penetrates the body it delivers kinetic energy to the surrounding tissues producing both permanent crushing of tissue in its path and a temporary radial displacement of the tissues, known as a temporary cavity. The tissue then collapses back to form a permanent cavity or wound track. Consequently, the damage to the tissues surrounding the permanent cavity may be greater than anticipated on inspection, such as in cases of spinal cord damage without direct injury to the cord [111]. This is clinically significant for those treating the patient as the surgical debridement required may be greater than simply the wound tract. The pattern of injury to the organ will be dependent upon the elasticity of the connective tissue infrastructure [109]. Thus, a projectile may pass through the relatively elastic tissue of the lung and result in a clearly defined entrance and exit wound whereas, if it passes through the liver or brain there may be substantial organ disruption.

Fragmentation handgun ammunition, such as Magsafe or the Glaser Safety Slug, comprise an outer copper jacket, a tip made of epoxy resin or Teflon, and contain birdshot pellets [112]. They are designed to fragment on contact, which causes rapid transfer of kinetic energy with resulting superficial destructive wounds but decreased depth of penetration. They can thus be used within confined spaces, such as aeroplanes, to incapacitate individuals without risk of collateral damage. Therefore, on CT examination, the appearance of birdshot pellets does not necessarily indicate the use of a non-rifled weapon (Figures 3.7 & 3.8).

Airguns are another example of rifled weapons. The pellets can enter soft tissue and depending upon the site of the body may enter internal cavities, such as the head or chest resulting in fatal injuries (Figure 3.9) [113].

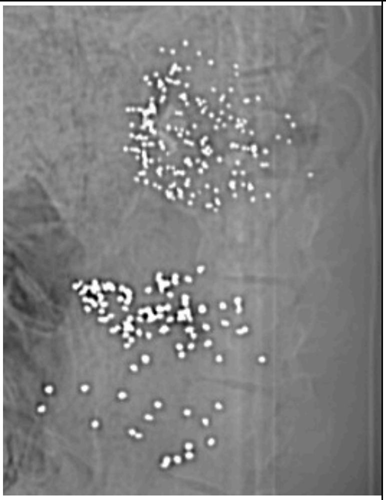
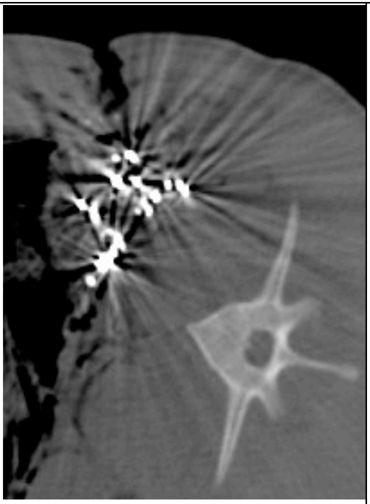
	

Figure 3.7 - Scout image showing Shotshell (Upper) and Glaser safety slug (Lower) ammunition	Figure 3.8 - Axial image of Glaser safety slug.	Figure 3.9 - Scout image of an intra-abdominal air pellet.

3.3 NON-RIFLED WEAPONS

Shotguns are an example of a non-rifled weapon. A shotgun can comprise one or more barrels in varying configurations, such as side by side and over and under. The bore of the barrel is smooth with no grooves. The shotgun was traditionally used as a hunting weapon, which produces a conical stream of pellets that disperse over an ever widening area at increasing distances from the weapon. This projectile dispersal increases the chances of hitting prey. The illegal shortening of the barrels to produce a ‘‘sawn-off shotgun’’ is principally done to assist in concealing and carrying the weapon and has little affect on the pattern and spread of the pellets. The ammunition of a shotgun is traditionally a cartridge consisting of a cylinder of plastic or cardboard with a metal disc or cup at the base. The cylinder carries a charge, wadding, and a number of pellets. Close range shotgun wounds may contain pieces of wadding in addition to the pellets.

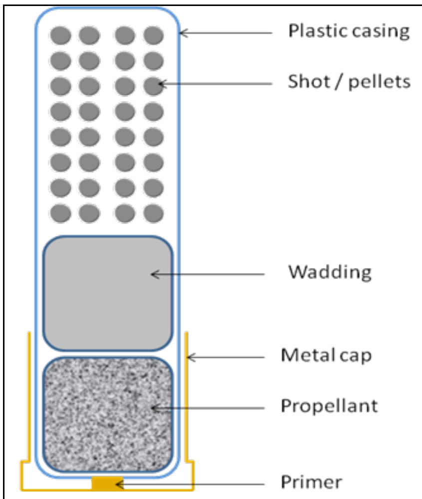


Figure 3.10 - Diagrammatic example of components of shotgun ammunition

Figure 3.11 - Examples of differing forms of wadding

3.4 PROJECTILE INJURIES FOLLOWING EXPLOSIONS

Explosions can result in multiple injuries to many victims at once [114]. As well as causing strain on clinical services they may also cause strain on forensic services. The speed of scanning in multiple fatalities is an important advantage of the use of MDCT in this situation [115]. Although explosions by themselves are destructive particularly to the head, lung, GI tract and the skeleton, they can produce flying debris which in turn, causes further injuries [94, 116-119]. The shrapnel may be pieces of the explosive itself, the container or timing device or surrounding objects such as vehicles or masonry. The body may also contain other person's tissue or bone. The resulting projectiles can therefore be metal, wood, glass, plastics or human tissue. Due to the varying contrast between these substances and soft tissue they may be difficult to visualise using conventional radiology due to overlapping structures. The 3-D imaging approach of CT avoids this problem making low density foreign bodies easier to identify.

3.5 ARROWS

Fatalities caused by arrows of all types are uncommon with scanty single case reports described within the literature. Those that are described, both within clinical and pathological literature, usually relate to crossbows rather than leisure, hunting or longbows [120]. Most cases are suicidal or accidental with few homicides reported [121]. Radiology plays an important role in these deaths. When the arrow remains in situ, usually in the head, neck or chest, there is no difficulty for the pathologist as to what has caused the pathology but a CT scan of the arrow in situ helps visualise the track. Dissection of the track with an arrow in situ is complicated and hazardous but removal allows organs and tissues to move complicating interpretation of the course of the injury. If the arrow has been removed from the body prior to its discovery, the entrance wound can resemble that of a rifled weapon [122]. It may not be until the body is imaged that the absence of a projectile and exit wound raises the possibility of an impaling injury such as that caused by an arrow.

3.5 SPECIFIC INJURIES CAUSED BY PROJECTILES

Bone may be damaged without direct impact due to the dispersal of kinetic energy as described above. A variety of fracture patterns may arise as a result of passage of the projectile. Typically, when the projectile passes through the bone, there is a conical shaped injury with so called ‘‘bevelling’’ seen to the inside of the entrance wound and outside of the exit wound [123]. The skull structure is made up of an outer and inner table. Once one of those is breached, the remaining table is left relatively unsupported and therefore the second 'table' to be damaged has a broader defect.

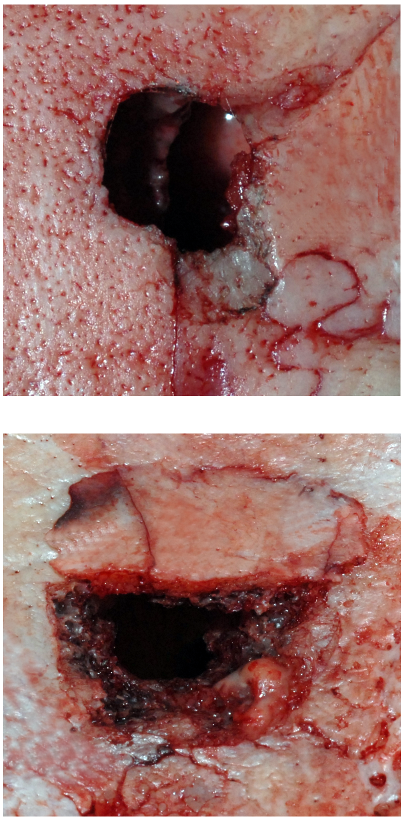
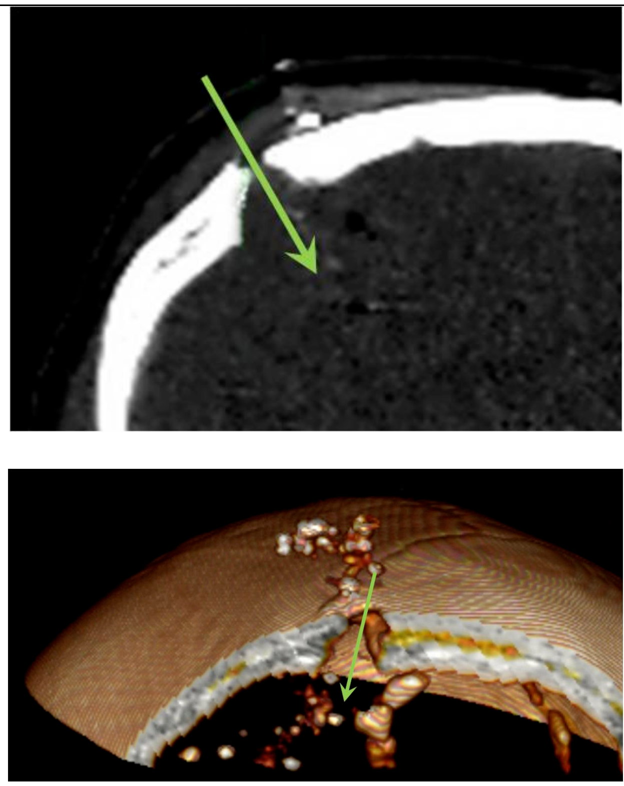
	

Figure 3.12 - Bevelling of the skull evident at post-mortem examination. Entrance wound showing external (upper) and internal (lower) views.	Figure 3.13 - Bevelling demonstrated using PMCT. The arrows show the general direction of the projectile.

Metal may be present on the bone surface (lead wipe). Projectiles may for example strike the skull and deflect away, i.e., they do not penetrate the cranial cavity. This can result in the so-called ''keyhole'' injury where there is both internal and external bevelling to the injury. Finally, due to the transfer of energy, bony fragments may now travel in the approximate path of the projectile, resulting in secondary projectile injuries. An apparent firearm exit wound may represent the exit of a bone fragment rather than pieces of the projectile itself.

Vessels of all calibres may be damaged by the projectile with resulting internal and external blood loss for example haemothorax, haemopericardium, or haemoperitoneum. In the case of pellets, these may enter the blood vessels and travel to a distal site, i.e., a projectile embolus [123, 124]. Cadaveric vascular injury may not easily be visualized without the use of contrast medium, which is as yet not routinely used in post-mortem CT.

3.6 The investigation of terminal ballistics

Terminal ballistics concerns the behaviour of the projectile within the target including the effects of a projectile when it strikes and enters a human being (wound ballistics) [125, 126].

Traditionally, investigation of the cavitation and wound track produced by the passage of the projectile and its fragmentation has been achieved with the use of soft tissue simulants, which include ballistic soap or ordnance gelatine blocks.

The information obtained from these investigations is used to assess whether ta weapon and its ammunition meet with national and international regulations such as the Geneva Convention and to guide surgical intervention in victims.

High-speed photography of shots into semi translucent simulants has been used to aid the analysis of the effects of the passage of the projectile. However the absence of a truly transparent simulant necessitates a destructive method of examining the internal cavity. The block is used as a mould, producing a cast of the cavity. Retrieval and examination of the cast requires disruption of the original block. The use of ballistic soaps and gels together with high speed photography has revolutionised wound ballistics allowing the examination and quantification of the temporary cavity. This information generated can be used to guide surgeons dealing with firearm victims, for the assessment of humane and inhumane ammunition and to reconstruct the events of a firearm fatality [127-129]. The use of computed tomography in terminal ballistics could replace this approach.

The use of CT for terminal ballistic analysis was first described by Korac et al. However, since their original papers, CT technology and volume rendering software has developed significantly. This work shows that CT, in turn, can revolutionise ballistic analysis allowing more information to be gathered from the analysis of the blocks without the need to open the blocks as illustrated.

3 8 AIMS AND OBJECTIVES

This chapter expands on this work exploring the use of MSCT as a rapid, non-invasive tool for the analysis and demonstration of terminal ballistics. It seeks to determine whether the current labour intensive and destructive casting technique can be replaced by CT scanning with graphical demonstration of the cavity without destruction of the gelatine block.

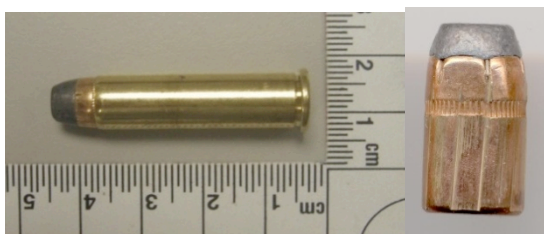
Two studies were undertaken. The first assesses the ability CT to examine gelatine blocks and makes a qualitative comparison with traditional techniques. The second study was performed as a quantitative assessment of the agreement between CT and traditional cast techniques.

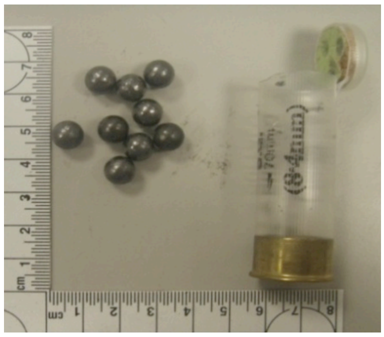
3.9 MATERIALS AND METHODS

3.9.1 Study 1:

Four glycerine based ballistic soaps were purchased; each measuring approximately 17 x 17 x 26cm (http://www.victoriasoap.se). A single firearm was discharged into each block from a distance of 15cm by an experienced forensic firearm officer.

Table 3.1 - Weapons and Ammunition Used in Study 1

Weapon	Ammunition
S&W revolver model 66 	.357 Magnum JHP (jacketed hollow point, 10.27 g 360 m/s 

Weapon	Ammunition
FN FAL rifle 	7.62 x 51 mm FMJ (Full metal jacket, 9.43 g 810 m/s)  
SA80 rifle 	5.56 mm FMJ (Full metal jacket, 3.56 g 960 m/s)  
12 gauge shotgun 	SG shot (9 shot; lead 3.71 g 270 m/s) 

Following discharge each block was imaged; 2 blocks were imaged using a mobile CT scanner and the other 2 using a hospital based static scanner. Both scanners were GE Lightspeed 16-detector CT scanners with Microsoft® Advantage workstations. The images produced included anterior-posterior and lateral scout views undertaken at between 120-140KV and 250-300mA (block dependent) and a 'spiral' scan using either a 1cm x-ray beam slice thickness and 16 x 0.625 mm detectors, or a 2cm x-ray beam slice thickness and 16 x 1.25 mm detectors, with subsequent slice reconstructions interleaved at 0.625 or 1.25 mm respectively. The CT images were saved to optical and compact disc and post-processed using Voxar 3D imaging software (Barco, Kortrijk, Belgium). Post-processing included creating multi-plane reconstructed images (thin slices in the axial, coronal and sagittal planes) and 3-D reconstructions.

3.9.2 Study 2:

Three further glycerine based ballistic soaps were purchased from the same supplier. A single firearm was discharged into each block by an experienced forensic firearm officer. The weapons and ammunition were as shown below.

Table 3.2 - Weapons and Ammunition Used in Study 2

Weapons & Ammunition
.223" CZ BRNO


Weapons & Ammunition
.357 Magnum 
12 gauge Shotgun with #5 shot 

The scans were performed on a Toshiba Aquilion 64 slice MDCT scanner with a beam thickness of 3.2 cm creating 64 x 0.5mm volumetric data. Scan parameters were 120KV and 300mA with a rotation speed of 0.75. The CT images were saved to compact disc and post-processed using Voxar 3D imaging software (Barco, Kortrijk, Belgium).

Plaster casts of the temporary cavities were then produced using crownstone casting media. These were then left for 24 hours to ensure that the casting medium was completely hardened before its removal. The blocks were cut open longitudinally using a simple large kitchen knife releasing the casts. The widest diameters (in the left to right plane) of the casts were measured using Lyman callipers at 2cm intervals from the entrance site. The callipers had a stated accuracy or certificated uncertainty (linear scale) of ±0.01mm. However, the widths of the casts exceeding 10cm were beyond the clearance of the callipers, necessitating an estimation of the deficit using the calliper scale. The error for measurements over 100mm was increased to an estimated 5mm. The casting process and measurements were undertaken by ballistic officers.

These measurements were repeated using Voxar 3D software by the author without reference to the previous measurements. The measurement facility on this software gives measurements rounded up to 0.1mm. Measurements were undertaken on the scout and MPR views using window, level and cine facilities to ensure that the diameter was in fact the maximum diameter in that plane.

3.10 Statistics and analysis

Measurements for the 3 techniques; calliper, CT scout and MPR images were tabulated. Prior to agreement analysis measurement error was correlated for all data with the magnitude of the measurement. If magnitude of error is proportional to magnitude of measurement then data transformation is required before assessment of agreement. The variance, within subject standard deviation (wSD) and repeatability of the measurements for the 3 techniques was then calculated using calliper measurement as the 'gold standard'[130].

3.11 RESULTS

3.11.1 Study 1:

a. Digital Measurement

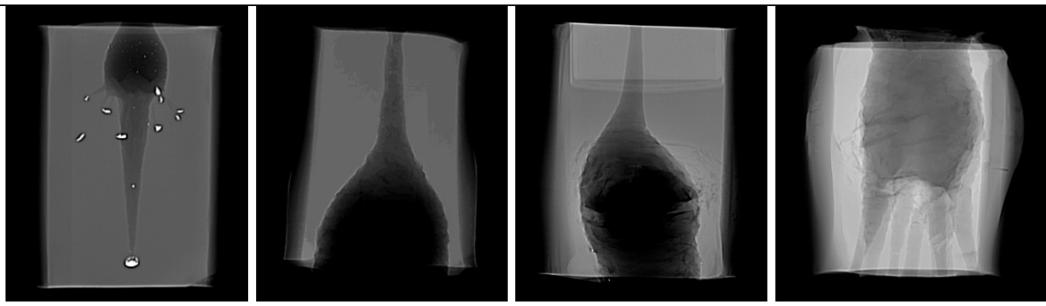
In this study, the voxel sizes are 0.5 x 0.5 x 0.125mm for blocks 1 & 2 and 0.5 x 0.5 x 0.625 mm for blocks 3 & 4. Theoretical accuracy of measurement taken using the digital software is therefore ± 1-2 mm.

b. 'Wound' Cavity Examination

The S&W model 66 .357 Magnum JHP jacket fragmented and the projectile remained in the block, whereas the other 3 type of projectiles all exited the blocks.

i. <u>Scout Images</u>

The AP and lateral scouts provided quick visualisation of the morphology of the temporary cavity and the position of retained projectile fragments. It became quickly evident that in situations where multiple projectiles were present, multi-plane reconstructed images were required to correctly identify the number of fragments and their positions.



S&W revolver model 66 **FN FAL rifle** **SA80 rifle** **12 gauge shotgun**

Figure 3.14 - Scout images of each block:

ii. Multi-planar Images

The advantages of CT over conventional radiography are that by viewing the scan in both scout view and multi-plane reconstructions, it is possible to measure the distances travelled by the projectile fragments and also the angle of dispersal from the centre of the entrance ‘wound’. Example measurements generated from one of the blocks are shown in Figures 3.15 & 3.16.

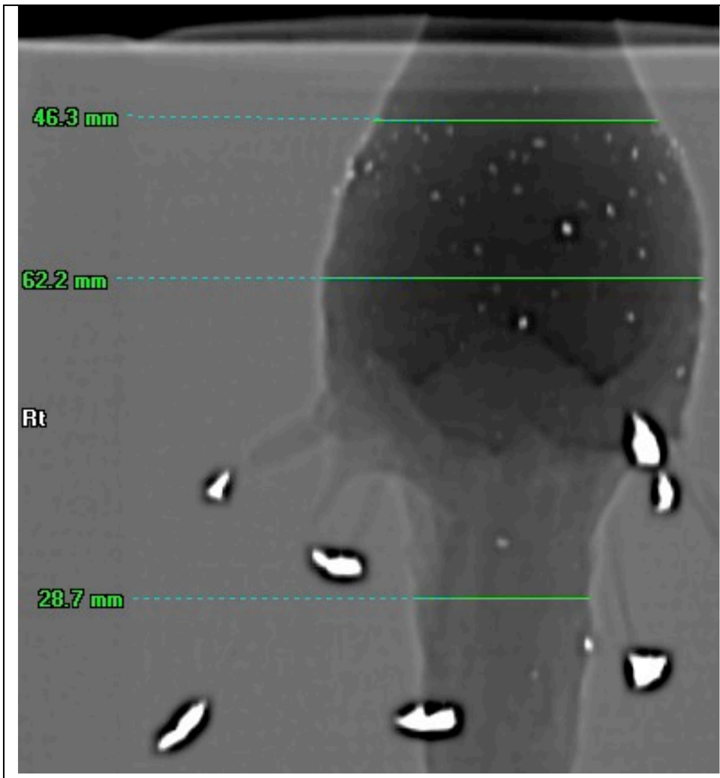


Figure 3.15 - Cavity diameter measurements

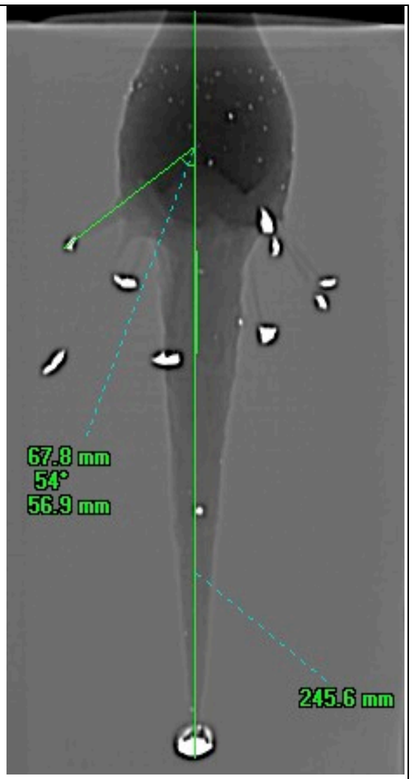
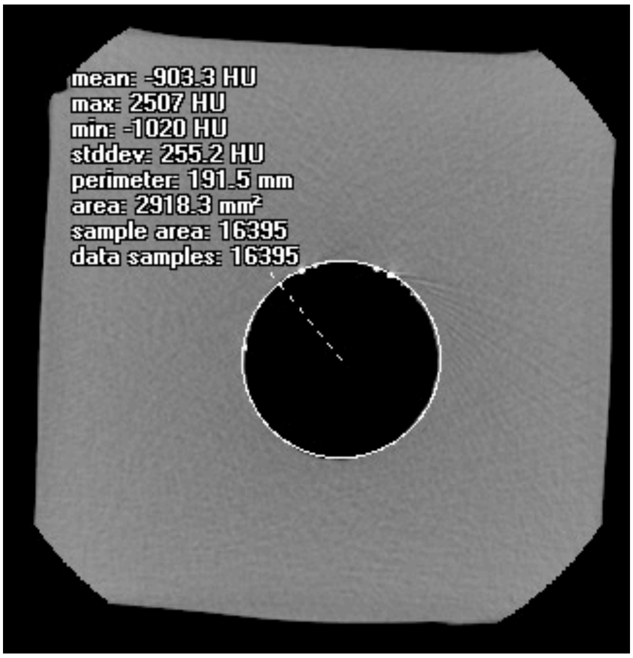
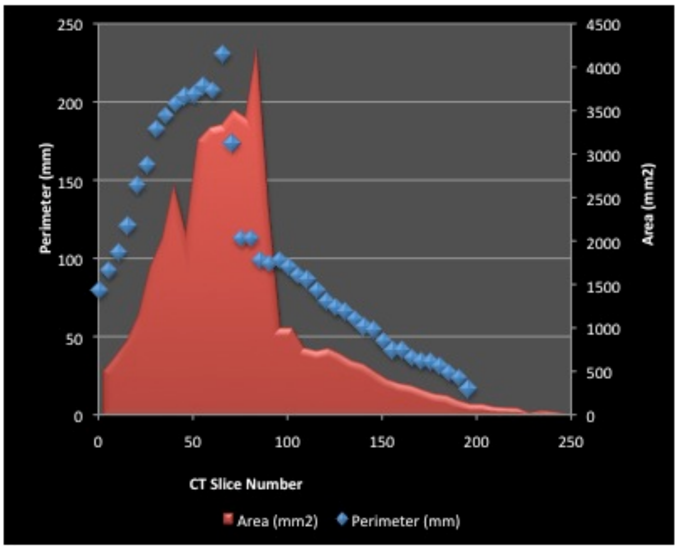


Figure 3.16 - Projectile penetration and angles of dispersal.

It is also possible to take measurements of the diameter and cross-sectional area of the cavity at different levels within the block. The standard levels can be set by examining an image at a given slice interval. An example of this is shown in Figure 3.17, where the measurements are taken every 6 slices (equivalent to every 7.5mm for 1.25mm and 3.75mm for 0.625mm slices).





Slice number	Perimeter (mm)	Area (mm^2)
1	79.3	500.9
6	91.8	670.6
11	103.4	851
16	120.5	1155
21	146.3	1703.1
26	159.3	2020.1
31	182.5	2650.7
36	191.5	2918.3
41	198.6	3139.8
46	203.2	3287.1
51	204.3	3320.1
56	209.6	3494.6
61	206.9	3406.2
66	230.3	4220.6
71	173.2	2386.7
76	112.2	1001.8
81	112.2	1001.8
86	98.6	774.3
91	96.4	740.2
96	98.3	769.6
101	94.3	708.3
106	88.8	628.2
111	86.1	589.3
116	79.3	500.9
121	72.3	416
126	68.1	368.9
131	65.9	345.3
136	60.8	294.7
141	56	249.9
146	54	232.2
151	46.8	174.4
156	40.9	133.2
161	40.8	132.6
166	35.9	102.6
171	34	92
176	33.3	88.1
181	30.9	30.9
186	26.6	56.2
191	23.4	43.5
196	16.3	21.1

Figure 3.17 - Examples of cavity measurements

iii. Three dimensional volume rendering

The final assessment is the examination of the block in 3D. Using the thin interleaved reconstructed slices, a 3D model of the block can be made. Image manipulation allows for viewing of the external surfaces, 3D cross-sections of the block in any plane and the air space within the cavity. The latter can replace the casting process and prevent destruction of the block itself allowing it to be kept for evidential purposes or revisited in the future. The block itself can be removed just to consider the projectiles or endoscopic “tunnelling” views can be used to create 3D fly-through views to travel through the block from one end to the other showing the internal features of the cavity. Examples of these features are shown in Figures 3.18 - 3.21.

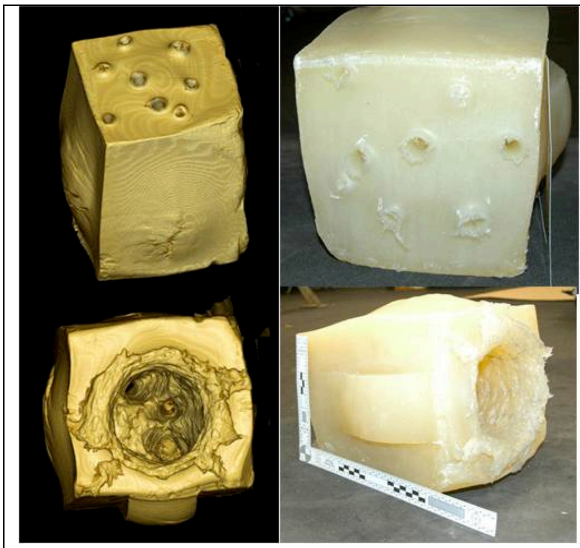


Figure 3.18 - Surface reconstructions of a block (left) shown alongside digital photographs (right).

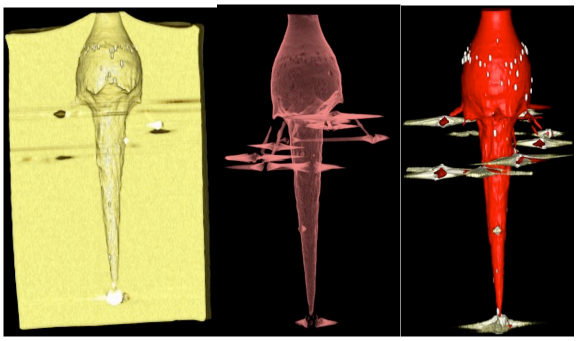


Figure 3.19 - 3D reconstruction of block showing virtual dissection and varying representations of the cavity

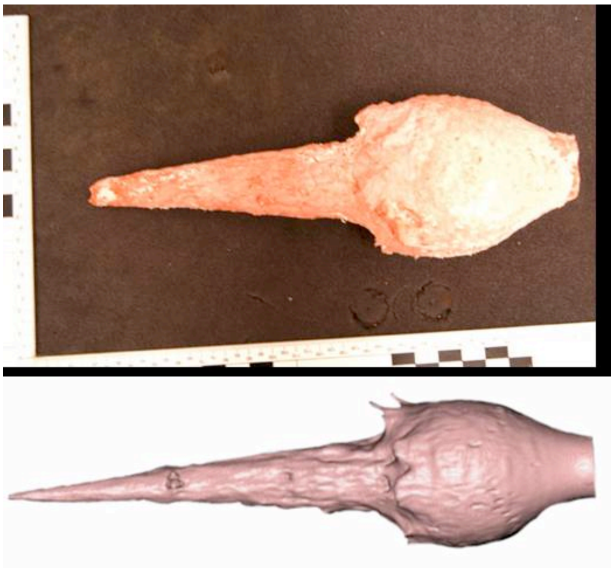
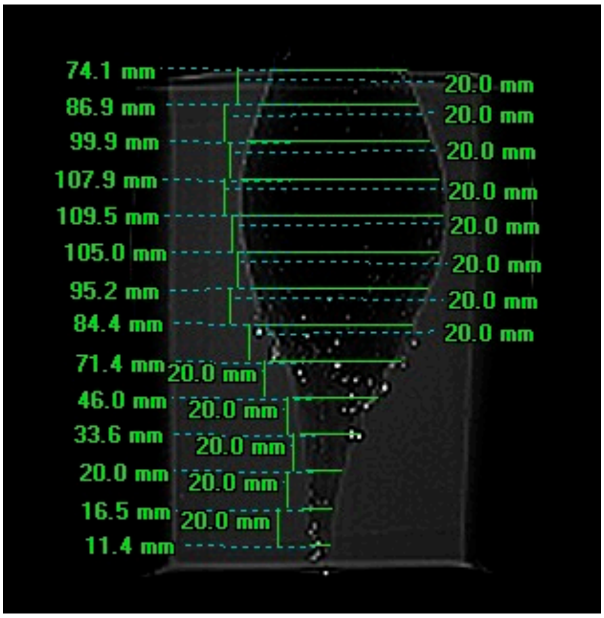


Figure 3.20 – Hand made cast (top) with CT generated virtual cast. Reproduced from Rutty et al 2008 with permission [131]	Figure 3.21 - Images showing pattern of projectile dispersal only

3.11.2 Study 2: Quantitative results

Examples of the CT measurements undertaken are shown in figures 3.22 & 3.23 below:



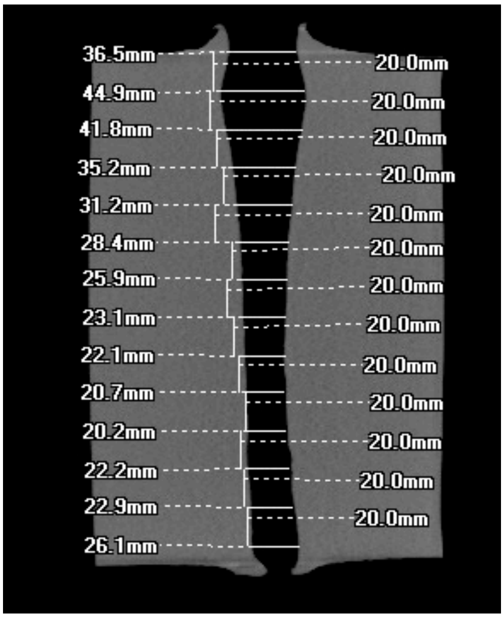
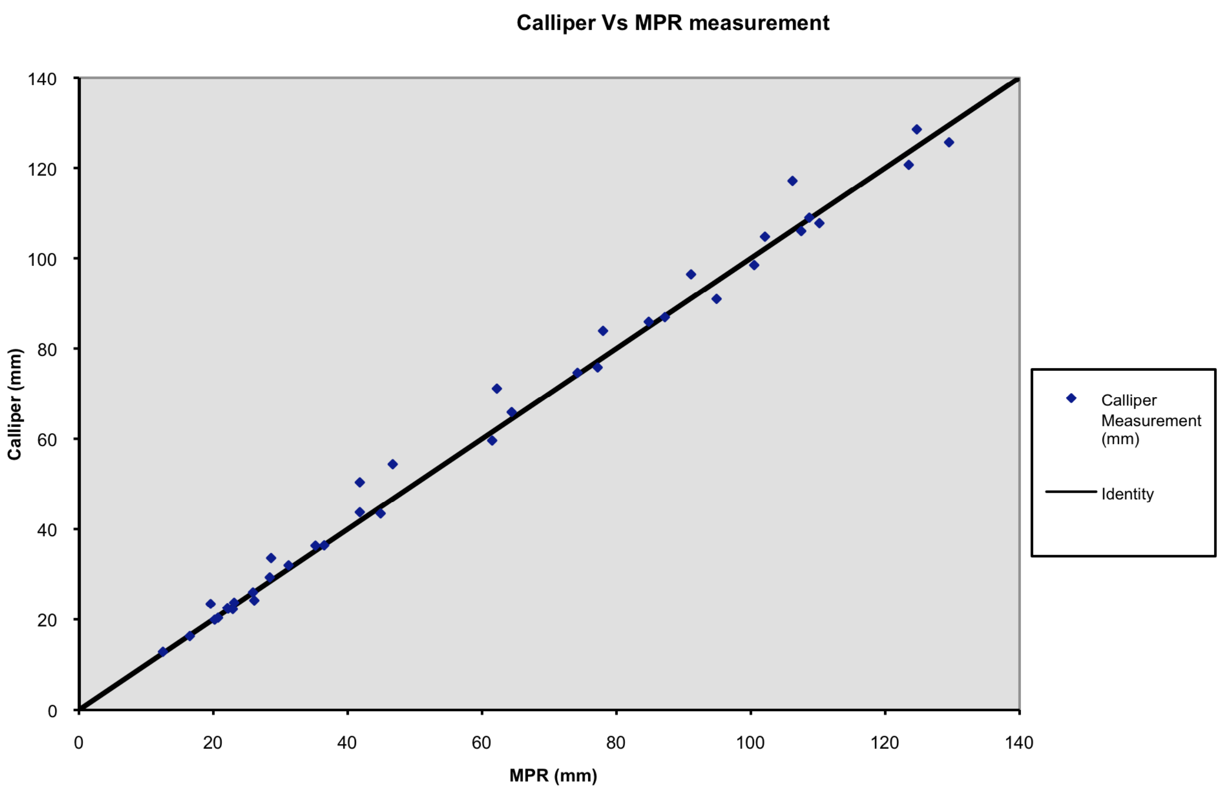


Figure 3.22 - Measurements undertaken on scout view	Figure 3.23 - Measurements undertaken on MPR view

The measurements obtained with the callipers, CT scout and CT MPR views are presented in tabular forms in Appendix A.

Not surprisingly there is excellent statistical correlation between the techniques as we were measuring the same dimension (Chart 1).

Chart 1 – Correlation of MPR and Calliper Measurements



There was a relation between measurement error and the magnitude of the measurement for MPR (and scout CT) Vs calliper measurements with correlation coefficients of 0.38 (95% confidence interval 0.07 – 0.62) and 0.43 (95% CI 0.13 to 0.7) (Chart 2). This trend was not seen when data was transformed to percentage change.

Chart 2 – Difference between MPR and Calliper Measurements in relation to magnitude of measurement

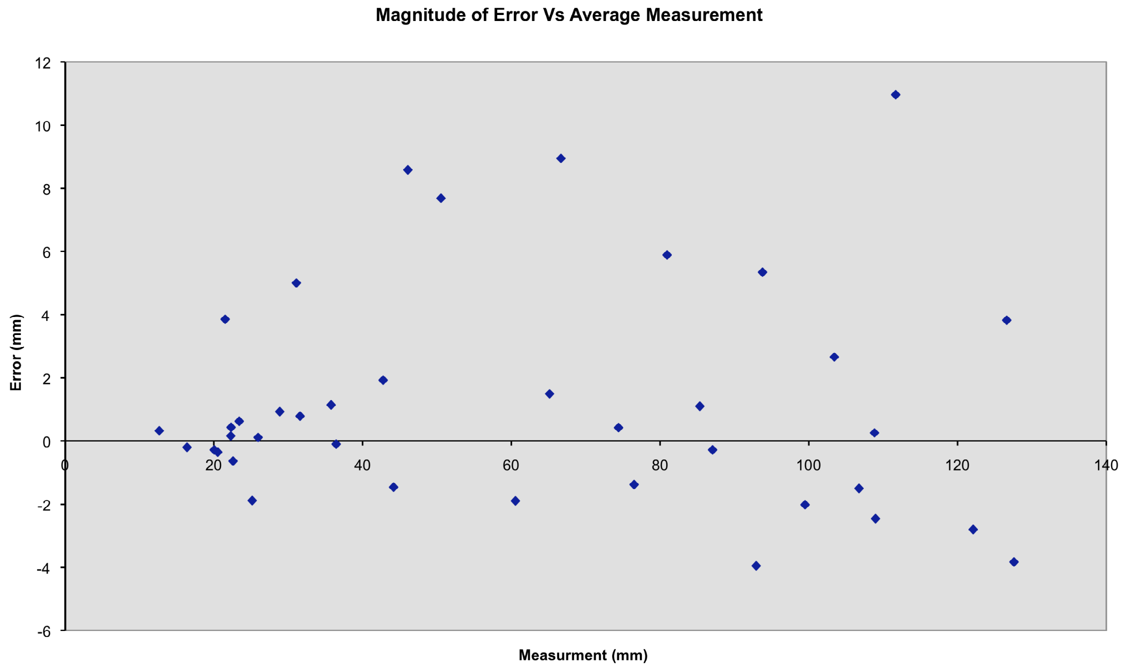


Table 3 shows the mean error in measurement, the within subject standard deviation and the 95% repeatability. It can be seen that measurements will generally agree to within 12%

There was a slight tendency for calliper to measure greater than the MPR (average 1.2mm p=0.04) and for the Scout to measure greater than the MPR (average 1.0mm p=0.02).

Table 3 – Calculated Error Margins (* p<0.05)

MEASUREMENT METHOD	MEAN DIFFERENCE (mm)	WSD %	REPEATABILITY %
MPR VS CALLIPER	1.2*	4.4	12.3
SCOUT VS CALLIPER	0.2	4.6	12.7
MPR VS SCOUT	1.0*	3.5	9.6

3.12 DISCUSSION

CT scanning allows excellent visualisation of temporary cavities within ballistics soaps. 3D volume rendering can portray the cavity in many different ways and CT software can also allow objective measurements in multiple planes.

As expected the narrowest range of variation is seen when comparing the two different CT modalities. Whilst it can be argued that the measurements should be identical when using the same technology, the variation can be explained by comparing the more crisp outlines of the MPR views to the overlapping and less distinct contours on the scout views. Small variations between the three different modalities are to be expected due to the irregularities of the margins of the cavity and the logistical difficulties in measuring the corresponding points on the cast with the cavity.

Of the two CT techniques, comparison of the MPR views with the calliper technique produced the narrower range of variation. The 95% confidence interval of the variation, was about 12%. Measurements using the soap are technically more demanding, requiring casts to be made of the cavity, and occasional difficulties in applying the callipers to the diameter of interest. It is therefore likely that the increase in variability of calliper Vs CT measurement as compared to scout CT Vs MPR CT measurement is due to problems with the cast and calliper technique. The calliper readings are generally slightly greater than CT measurements. This is not surprising as it is very unlikely to gain a calliper dimensions *less* than the true dimension of the cast. CT measurements also provide a simpler opportunity for area and volume measurements.

The ballistic soaps are used because the material is considered to be a close comparison to the soft tissue of the human body. However, there has been little in the literature regarding an actual comparison between the cavities produced in the soap blocks and those seen in actual patients. Whilst the ballistic soaps remain a rather crude estimate of the damage produced by a firearm and its ammunition, a 12% variation is likely to be of little consequence.

It is also possible to consider the entire wound tract and projectile dispersal paths both in 2 and 3-dimensions without destruction of the soap block. As the blocks ultimately dry out and shrink after a month or so, the CT data and images provide a permanent record of the projectile path for research purposes. This technology can therefore replace, or at least compliment, traditional casting of the cavity. The information can also be used to illustrate the effect of different calibres of weapons to courts using modern information technology such as scout views, 3-D and fly-through tunnelling. The digital reconstructions could also be superimposed on standard anatomical 3-D bodies to provide a ‘virtual’ demonstration of potential wounds from shots to different areas of the body.

It is therefore proposed that the extended use of CT and volume rendering software within the field of terminal ballistics, will be of great benefit to firearms officers, crown prosecution service, jurors and surgeons alike.

CHAPTER FOUR: COMPUTED TOMOGRAPHY OF PROJECTILE INJURIES IN ANIMAL MODELS AND HUMAN FORENSIC CASES

4.1 INTRODUCTION

Radiology has played a significant role in firearm related death investigation for many years but many pathologists still rely on traditional radiographs and currently CT is not routinely performed across the UK. The main reason for undertaking radiology in such cases has been the location of foreign bodies/projectiles which may be of evidential value. However, with the advances in imaging techniques, CT scanning can provide much more useful information than traditional radiographs.

4.2 AIMS AND OBJECTIVES

This chapter considers the capabilities of post-mortem CT as an adjunct or replacement of the invasive post-mortem examination, in penetrating projectile injuries. Using animal models and human cases, the abilities of PMCT to discern 1, the wound tracks, 2, the internal damage and 3, the projectile position are investigated.

4.3 METHODS

4.3.1 Animal Models

Three whole porcine cadavers and an adult German shepherd dog were donated to the forensic pathology unit, Leicester, following lawful euthanasia. Each animal was suspended on a metal frame with the left side of the body exposed to replicate a normal standing position to orientate the skeleton and internal organs in as normal an anatomical position as possible. Each cadaver was then shot at differing ranges up to 5m away using a variety of weapons and ammunitions. See Appendix C for the complete list. All of the weapons were discharged by trained ballistics officers on licensed premises adhering to strict health and safety protocols. Each entrance wound was labelled and photographed following the discharge of the weapons. Following the discharge of each group of weapons each cadaver was examined using a mobile GE light-speed 16-detector CT.

4.3.2 Human cases

The East Midlands Forensic Pathology Unit began undertaking post-mortem examinations of forensic cases in 2002. The investigations are undertaken as part of police investigations into suspicious deaths under the authority of Her Majesty's Coroner. Ethical Permission is also granted for research imaging of human cadavers. Most of the earlier human images were undertaken using a Philips Intera single detector spiral CT system that was subsequently replaced with multi-detector CT.

4.3.3 CT examinations

Radiation dose is not a concern for post-mortem scanning but there are still limitations on the minimum slice thickness that can be obtained related to the required speed of scanning and tube heating limits. These issues are less of a concern on new 16 slice MDCT where whole body 1.25mm (and even 0.625 mm at slightly lower signal to noise ratio) scans are possible in a practical scan time. Further, narrow scan collimations can create thousands of images putting stress on image analysis software. An ideal CT examination comprises 2 'scout' views (AP and lateral), the orientation of the bodies (supine / prone etc.) is checked on the 'scout' images to allow correct orientation to be programmed into the scan software. A 'spiral' scan was performed, using a 2cm x-ray beam slice thickness and 16 x 1.25 mm detectors, with subsequent interleaved 1.25 mm slice reconstructions. The CT images are reviewed either using GE advantage windows workstation or Voxar 3D imaging software (Barco, Kortrijk, Belgium).

The scans were initially reported alongside a radiologist experienced in whole body CT imaging blind to the knowledge of the weapon and ammunition used and the external examination findings. The images were then reported again with external photographs and in the presence of the Firearms officer involved in the discharge of the weapons/ammunition. An analysis was then made of the ability of CT to demonstrate 1, wound tracks, 2, internal damage and 3, projectile position.

4.4 RESULTS OF IMAGE REVIEW

The details of the weapons discharged on each animal and the subsequent CT findings are shown in tabular form in appendix D. For ease of reference, the numbered firearm discharges are included within the text.

4.4.1 Animal 1

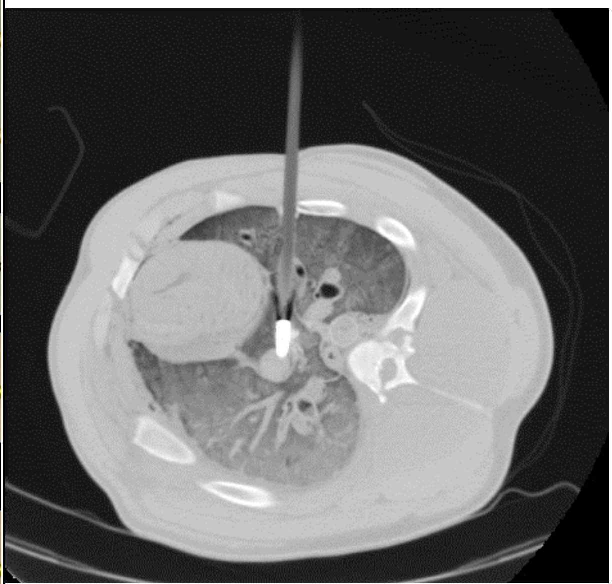
Animal 1, canine, was subject to 6 shots from rifled weapons with varying ammunition. The presence of surface hair obscured a number of the skin entrance and exit wounds. Where skin wounds were present, it was not possible to differentiate between entrance and exit wounds without associated bony injuries or bone fragment dispersal. With the presence of the ballistic officer who had discharged the weapons and photographs documenting the position of the entrance wounds attempts were made to match the CT findings to the projectiles. The passage of two projectiles through similar areas of the body complicated the assessment of the individual wound tracks such that no definitive wound track could be found for one of the projectiles (Discharge 4). It was also not possible to differentiate between two discharges (Discharges 5 & 6) using the CT scan but it is important to note that these were caused by an automatic rifle and were therefore two firearm discharges in quick succession in the same area of the body. It is likely that a pathologist undertaking a post-mortem examination would have encountered similar difficulty.

4.4.2 Animal 2

In the case of animal two, porcine, a single rifled firearm was used to allow assessment without intersecting paths (Discharge 6). The remaining weapons were a shotgun with varying sized shot and bows with arrows or bolts. Projectiles from all of the weapon discharges remained within the body.

As the arrows remained in-situ during the CT scanning process, it was possible to visualise the wound tracks in great detail. During the review, the radiologist was able to discern three distinctly different shaped arrow tips.

From sketches of the arrow tip shapes undertaken at the time of the initial review, the ballistics officer was able to identify the arrow/bolt. As seen in the images below, the shape of the metal objects was much clearer on the scout image than the axials.

	
Figure 4.1 - Scout image showing CT views of arrowheads alongside digital photographs.	Figure 4.2 - Axial CT image showing arrow in situ

The use of one rifled weapon assisted in the tracing of the wound track which was easily identified. The varying size and number of shot was evident in the CT scan and it was possible to provide angles of pellet dispersal. The skin wounds were easier to identify in this case due to the relative absence of surface hair.

4.4.3 Animal 3

Animal Three, porcine, was subject to a range of more specialist weapons and ammunition including air weapons, converted blank ammunition and a number of ammunition types designed to 'mushroom' and remain within the body.

There was only one weapon discharge that could not be accounted for. This was one of the air weapons. Following discussion with the ballistics officer it became clear that very superficial penetration may have resulted in the projectile dropping out of the subcutaneous tissue during movement of the body. As with case 1, the use of production of multiple wound tracks meant that is was difficult to differentiate between two tracks produced within the same region. This was the case for discharges 8, 9 and 10 where the cavitation produced by the latter may have simply obliterated or superimposed on the former.

On the initial radiological review of discharges 13 and 14, the lack of any apparent retained projectiles within the body led reviewers to believe that the projectiles must have exited; although exit wounds could not be found. During discussion, it was highlighted that the ammunitions used in these discharges were designed to fragment on impact and that they were unlikely to have exited the body. Review of the images showed that the debris within the peritoneum, although initially considered to be minimal, was likely to represent the fragmented projectiles.

The shape of the THV projectile, discharge 15, was clearly seen radiologically despite the slight distortion of the tip.

4.4.4 Animal 4

Animal Four, porcine, was subjected to a number of different ammunition types including fragmentation handgun ammunition and shotgun ammunition.

On initial review only 10 weapon discharges could be accounted for. This was because one of the pieces of rifled ammunition (discharge 1) became masked amongst a shower of shotgun shot (discharge 8). On secondary review, a 1.5cm metal fragment was seen lodged in the spinal column at the level of T1/T2 in close proximity to the collection of shotgun pellets.

4.4.5 Human Cases

Three human firearm deaths were identified in the archive. The exact nature of the firearms used was not recorded in every case and thus have not been included.

CT was able to demonstrate bevelling to entrance and exit wounds in the skull allowing reconstruction of the direction of shot. As the human subjects were alive at the time of wound infliction, it was also possible to demonstrate the vital reaction in the affected tissues and organ systems.

In one of the shotgun wounds to the head, due to the extensive fracturing of the skull, it was not possible to ascertain a definitive entrance wound. Both the left side of the face and the roof of the mouth were suggested by the reviewing radiologist as possible entrance wounds. Later correlation with the external appearances confirmed a clear entrance wound to the skin of the left side of the head with associated sooting.

In case three an occipital tumour was documented at post-mortem but not seen on the PMCT scans despite review. This was believed to have been obscured by the artefact caused by the metallic fragments present and the poor resolution of the scans.

4.5 Key Conclusions of Results

1. Entrance and exit wounds are often difficult to determine particularly when there are no associated bony injuries.

2. Wound tracks are difficult to determine, particularly when multiple tracks exist.

3. Determination of entrance and exit wounds and wound track assessment would be greatly assisted by access to external examination findings and/or photographs.

4. Those reporting the images benefit from the knowledge of firearms, ammunition and recognised patterns of injury, for example execution style wounds.

5. When projectiles are retained, they are readily identified.

4.6 DISCUSSION

In both the animal models and human cases, all metallic projectiles remaining within the bodies could be identified, although on initial review some of the individual projectiles had become masked by others. This was particularly the case where individual projectiles had come to rest within a field of shotgun pellets. Although it is possible to distinguish a single, rogue projectile from a mass of relatively uniform shotgun pellets, this is not always easy. Hatton rounds, as used in discharge 10, are traditionally used to breach doors and consist of a semi-solid, frangible projectile which fragments on impact. These will not necessarily fragment uniformly and could easily mask other ammunition. In some cases projectiles had sufficiently unique features to allow the ballistics officer to identify the specific ammunition type from the radiological appearances alone. This included all of the arrow tips, the varying size of shotgun ammunition and the THV ammunition.

The ability of CT to discern, in detail, the nature of the projectile, appears to be dependent on its structure. Where, the projectile holds its shape, there may be unique features that point towards a specific type of ammunition. The initial assessment is best carried out using the scanogram view as metal artefact is produced by the reconstruction of the axial slice; a process which is not required to produce the scanogram image. However, when there is marked distortion or fragmentation, it is not possible to give reliable interpretation on the ammunition. Due to potential distortion occurring on impact, the dimensions of

the projectile seen on CT cannot be used to indicate the size of ammunition used.
The main features that could not be determined were the presence of sooting or charring of the entrance wounds. This is extremely important information as it can be used to differentiate between entrance and exit wounds when other features such as bone bevelling are not present. This means that the external examination must remain part of the post-mortem examination of projectile fatalities

The intersecting paths of projectiles present within the animal models made interpretation difficult but patterns of bony injury assisted with the direction of projectile paths. It was possible to discern some skin defects on PMCT, but this became difficult when they had been obscured by matted hair and or blood. CT could not match naked eye examination for differentiation between the surface appearances of entrance and exit wounds.

Correlation with the external appearances and ballistic expert opinion proved to be essential to gain the most accurate results. Latter correlation with external injuries made it possible to link residual projectiles to their entrance sites and to link entrance and exit wounds with their associated wound tracks. It became quickly apparent that some knowledge of classical wounding mechanisms is vital. For example a projectile delivered to the head in an execution style killing may be recovered from the pelvis or have a distant exit site in the model used.

In our experience, the shotgun wadding is not easily identifiable on CT imaging. The dispersal pattern and position of the pellets, however, can be easily demonstrated on CT. The use of axial and 3D imaging can illustrate this far better than traditional 2D plain radiographs.

In the case of the arrows, using the scout, axial and 3D images, it was possible to identify the type of an insitu arrow head, the site of the head in relation to the internal structures, the injuries caused by the passage of the shaft, and the distance the arrow had penetrated the body (Figures 4.3 & 4.4). The observations are equally as applicable to any solid rod inserted into a body for example impaling injuries.

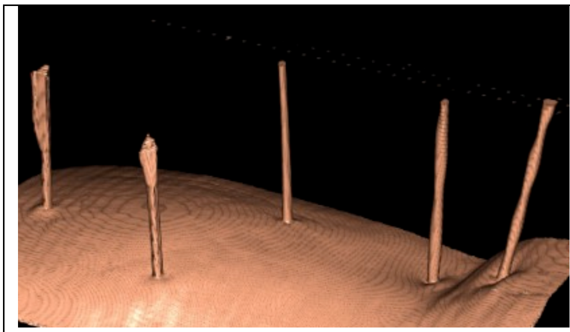


Figure 4.3 - 3D surface reconstructions (arrows in situ) provide a sanitised alternative to photos and a more accurate alternative to body diagrams.

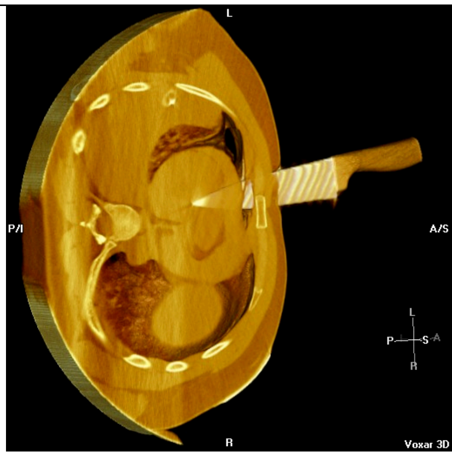


Figure 4.4 – 3D dissection showing a knife passing through the edge of the sternum and into the pericardium & heart resulting in a haemopericardium.

The resulting pathology of projectile injuries, for example haemothorax or pneumocephaly, will all be identifiable on CT as well as skeletal injury and if CT angiography is used, damage to principal vessels.

4.7 CONCLUSIONS

The use of radiology in the investigation of a firearm injury is standard practice. The main objectives, both clinically and forensically, are to ascertain the exact position of any projectile, the path the projectile has taken and the extent of the damage caused along its course.

The 3D capability of MDCT is of particular importance in the assessment of foreign bodies as it allows more accurate location than plain radiography and allows more detailed assessment of damage to the internal structures.

The absence of foreign material is equally as important as it suggests the projectile may have traversed the body and exited or in the case of an arrow, have been removed. In order to accurately assess CT imaging of projectiles, in both clinical and forensic contexts, a working knowledge is required of the variety of projectiles in circulation and their characteristic injury patterns.

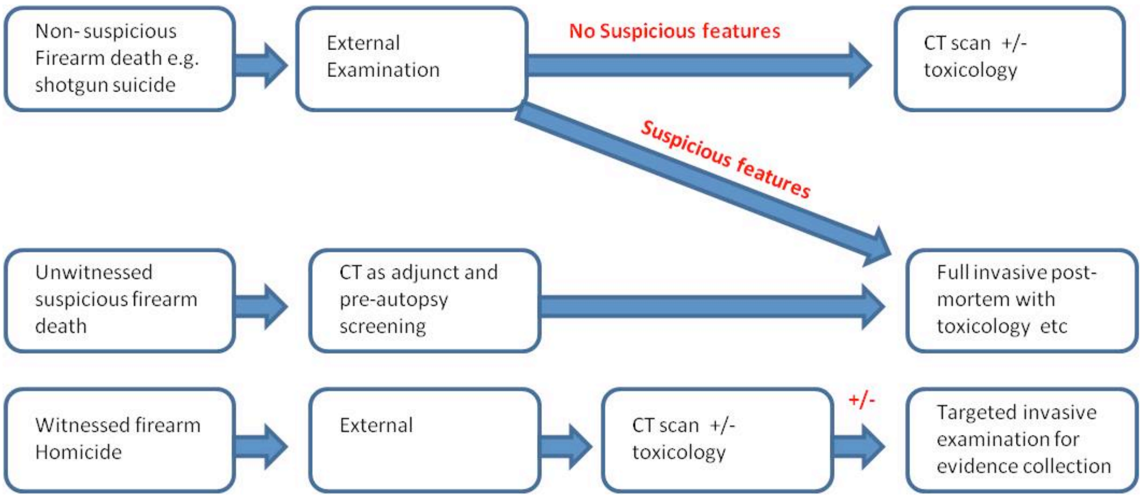
CT can provide us with valuable information in victims of projectile injuries in both clinical and forensic cases. In living victims the information provided can be used to direct further investigations and management, as well as providing evidence for potential future prosecution. In the deceased, where witness statements are often lacking, it may help piece together the circumstances surrounding the death and provide valuable information for the criminal investigation. It is important that the reporting radiologist has the information from external examination as entrance wounds can be hidden by matted hair or clothes on CT images. The information can be presented in 2D or 3D using a variety of imaging methods depending upon the volume-rendering software available. All of these images can be stored as original raw data on a variety of storage media. The images can be produced in court as either traditional still images or in movie format. The use of high-quality, sterile imagery, removes the use of autopsy photographs in court.

CT cannot replace all the information that autopsy can provide, and in most cases CT should only be considered an adjunct to forensic autopsy [1]. However, in certain circumstances a non-invasive approach becomes a possibility with an external examination, toxicology, and trace evidence collection by the pathologist and subsequent CT scan. In cases of fatal injury, if there is a witnessed or captured event (for example, CCTV) or the circumstances were those of a suicide or accident where the cause of death is only attributable to the projectile, then the amount of information that can be gathered from CT questions the need to undertake an invasive autopsy [12, 132].

While recovery of retained projectiles may be necessary to match rifling patterns to a suspect gun, there is little that can be gained from the examination of shotgun pellets. The aim of such examination is to identify the cartridge type so that again it could be matched to others found in the possession of a suspect. For this reason the nature of the wadding and the size of the pellets are of interest.

Where there is potential forensic value in retrieval of projectiles, the relevant part of the body, at least, would need invasive examination although the remaining body could be imaged with MSCT.

The following flow diagram is a suggested approach to the investigation of firearm cases:



The final post-mortem report will probably remain the remit of the pathologist, but the radiologist will contribute significantly to this and may find themselves giving expert evidence in courts of law in areas that they have previously not encountered [10].

MASS FATALITY INVESTIGATIONS

CHAPTER FIVE: THE ROLE OF MOBILE COMPUTED TOMOGRAPHY IN MASS FATALITY MANAGEMENT – A Local Trial

5.1 INTRODUCTION

Radiology serves a number of purposes in mass fatality investigation. When considering the management of a mass fatality event the cause of death may be apparent, but further information is required that can be provided by imaging. It can reveal foreign bodies which may pose a health and safety hazard to those handling and dissecting the body. It can also accurately pinpoint the position of material for retrieval if considered of evidential value. Imaging may also help with victim identification, a primary aim of the post-mortem examination. Within a disaster/temporary mortuary, depending upon the nature of the incident including environmental, medical, industrial, vehicle, or terrorist related, three different types of radiology are traditionally deployed [133, 134]. The first is fluoroscopy, used at a screening stage prior to autopsy examination; the second is plain radiography, principally used for pathological and anthropological assessment and the third is dental radiography. This requires up to three different types of radiological equipment to be present outside their normal environment, with sufficient personnel to operate them, with subsequent health and safety implications.

5.1.1 Fluoroscopy

Mobile fluoroscopic imaging units require the operator to be next to the body during the process to manipulate the machine down the body length capturing images as necessary during the procedure. This investigation takes at least 15 minutes. The bag may have to be opened to manipulate the body in order to obtain a good image plane, exposing the operator to the contents and sights within. As a radiation source this requires a 'controlled' radiation area to be set up which may be difficult in a temporary mortuary. The images are then often interpreted by a pathologist who is not specifically trained in reporting radiographic images. Fluoroscopy's primary use is a screening device for the detection of metal fragments or projectiles in bodies, hidden weaponry and personal possessions. It provides limited soft tissue and bony information prior to post-mortem examination. The findings are usually communicated verbally without the production of a formal written report.

5.1.2 Plain Radiography

This may be digital or analogue and is a second radiological source within the temporary mortuary requiring a second team of radiographers. Multiple images are undertaken from varying angles and the bag is usually opened to allow optimum positioning of the remains for imaging purposes. The images may be interpreted by radiographers and or forensic pathologists. A few radiographers may be trained in reporting of radiographs, but pathologists may only have radiology experience from their basic medical training. Again, a formal radiology report is often not generated. This examination is used principally for imaging of bones for pathological and anthropological assessment.

5.1.3 Dental Radiography

This uses specialist dental x-ray equipment or plain x-ray equipment. It forms a third radiological source within the temporary mortuary. This work is normally undertaken by the odontology team rather than a radiography team.

All of these three modalities require their own electrical power supply and must be undertaken undercover in dry conditions.

5.2 MOBILE COMPUTED TOMOGRAPHY

The use of a mobile CT scanner for forensic purposes, as opposed to diagnostic clinical work, was first reported in Japan [135]. Due to the lack of access to clinical scanners in Japan, they described the use of mobile CT for forensic autopsy investigations. The paper concentrates on the use of CT imaging in autopsy practice rather than their experience with the use of mobile CT. Since then the Virtopsy® group have published two theoretical papers speculating on the use of CT for mass fatality investigations. The first briefly raised the idea of CT-enabled dental identification for mass fatality incidents [42]. The second, more detailed paper, considered the potential of CT as a screening tool for mass fatality investigations, using the Interpol Disaster Victim Identification (DVI) forms and illustrating how CT could be used to acquire the information required for these forms [44].

Although mobile CT scanners have been described for clinical use in remote circumstances, and for examination of the dead where static hospital scanners have not been available, no previous peer-reviewed paper or internet based report has been identified detailing a trial of the use of a mobile CT scanner at a disaster/temporary mortuary following a mass fatality vehicle incident [135, 136]. In this chapter, the use of mobile CT is demonstrated in a local road traffic incident which resulted in multiple fatalities.

When managing radiology within a mass fatality mortuary, issues related to radiology equipment sourcing, numbers of trained and accredited operational personnel, the radiological risks to those working in the immediate environment and accurate image interpretation must be considered. A 6-month trial of mobile computed tomography by the Forensic Pathology Unit, University of Leicester, was funded by the Home Office. Through a series of exercises, this allowed more detailed consideration of all of these aspects.

5.2.1 The Mobile CT Scanner: Logistics

A mobile CT scanner is a vehicle composed of two parts; the tractor, i.e. the part that pulls the trailer, and the trailer, which containers the scanner. It is a long heavy vehicle weighing in the region of 34 tonnes (scanner—26 tonnes, tractor—8 tonnes) with a turning circle of 12.5 m, a height clearance of approximately 4 m and a total working length of 16 m including clearance for the air conditioning unit (http://www.alliance/interim.com/site_planning.htm). The trailer functions independently of the tractor so the trailer can be taken to the site by other means, for example by rail or by airlifting via mountings in the roof. Forward planning is required in relation to its arrival at a site, which could be the scene of an incident or a permanent or temporary mortuary, as the pad on which it functions must be level and composed of “road surface” quality material. Hydraulic suspension is used to support and level the trailer on four bases, rather than the wheels, when it is on site. It can operate indoors (as long as it is vented) or outdoors, 24 h per day, in all weather conditions. Depending on the site the unit can be connected to an electricity supply or can be adapted to run using a diesel generator (a single fuel tank lasts for approximately 1.5 days of continuous operation). Once sited, the trailer side walls can be extended increasing the available work area in the scan room. The scanners have hot and cold running water as well as air-conditioning. Two radiographers trained in CT are typically required for operational deployment.

Following the initial setting up of the trailer, calibration checks have to be completed on the scanner. If the unit is delivered without the generator running it will take 4 h for the generator to warm up. However, units delivered with the generator running reduce this time to approximately 20 min. The scanners have a bore size of 700 mm with a maximum field of view (FOV) of 500 mm. The gantry will tilt ±30° and the weight limit of the table is up to 205 kg/450 lb with a maximum scan length of 1.4 m. The four-channel detector scanners have a typical configuration of a 1-cm beam width divided into four 2.5-mm slices. The 16-channel detector scanners have a typical configuration of either a 1-cm beam width divided into 16 slices measuring 0.625 mm or a 2-cm beam width divided into 16 slices measuring 1.25 mm (faster mode) e.g. GE lightspeed 16.

Both have a scan rotation speed of up to 2 rotations per second. The 16-channel detector scanner can scan approximately 4–6 cm of body per second. The maximum scan length of 1.4 m could therefore be achieved in less than 30 s for the 16-slice machine. This can be further improved with the new 64-channel MDCT machines, which can achieve a whole body scan in approximately 10 s. Images are in a 512 × 512 matrix at a resolution of 0.5 × 0.5 × 0.625 mm (improved to almost 0.5 mm^3 in a 64-channel MDCT).

5.2.2 Record Keeping and Continuity

As in the clinical setting, a request form with patient details or unique identifying number should be completed before radiology is undertaken. This form provides the radiology facility with details of the examination required and allow the reporting radiologist to enter comments in relation to the results of the examination. This form also acts as part of the chain of evidence of a police investigation.

The Association of Chief Police Officers' (ACPO) books used in body identification detail whether or not radiology has been undertaken, but do not currently provide a mechanism for relaying results of the investigation and important health and safety advice to those undertaking the post-mortem examination. If a separate all inclusive radiology station is envisaged, there must be communication between this station and the operators within the mortuary facility.

5.2.3 Scanning Process

As with other forms of imaging, mobile CT is a clinical diagnostic machine. Thus, although CT is relatively new to the world of forensics, mobile CT protocols are already widely used in clinical medicine for a wide range of applications. These protocols simply need adapting to the needs of post mortem imaging. The following section relates to experience gained with GE lightspeed® plus 4- and 16-channel multi-detector mobile CT (MDCT) scanners with Advantage Windows workstations. DentaScan® software (GE Healthcare, Chalfont St. Giles, UK) was used for consideration of dental identification.

Protocols for post-mortem MDCT are similar to clinical protocols, but with two clear differences. First, rapid scanning in clinical situations is useful for obtaining images free of breathing artefacts, but this is unnecessary for forensic scans. These rapid scan protocols are, however, useful if multiple cases are scanned in a mass fatality. Second, clinical protocols are based on a compromise that occurs because any increase in image quality, either by decreasing slice thickness or increasing the intensity of the X-ray beam, results in an increase in radiation dose. Although this is clearly not an issue in forensic practice the same factors also cause an increase in the "heat-loading" of the X-ray tube, which can limit the volume that can be scanned without pausing for cooling. This is a particular issue for the older four-channel detector platforms.

5.2.4 Data processing & remote reporting

Anything from 300 to 4,000 images can be produced depending on scan resolution. These images conform to a DICOM standard (http://dicom.nema.org), but can also be stored as JPEG or AVI files. The DICOM format contains additional patient information and image data which is lost in other file formats. Data archiving is possible on optical disc, CD and more recently DVD, one forensic case will typically fill a single CD in DICOM format, and in some cases more than one disc is required.

In the ideal circumstances, all radiology should be reported by appropriately trained specialist. While it would be unwise to introduce more specialists to an already overcrowded and potentially chaotic scenario, this may still be achieved via remote reporting. The images may need to be sent by telephone, WIFI or satellite communications. The trailer has a telephone line and can be connected to an LAN wireless system for remote reporting. However, this is a time critical step and the larger the data files, the longer it takes to send and report. Secure internet transfer and remote reporting is now commonplace (tele-radiology) but a rapid and secure link between the mobile scanner and a suitable tele-radiology system is required

5.3 CIRCUMSTANCES OF LOCAL TRIAL

In early 2006, a 5 vehicle road traffic incident occurred on a two lane road in the early morning which resulted in 6 fatalities. The incident involved a medium sized lorry (1 fatality), 3 Long Heavy Goods vehicles (no fatalities), and a minibus (5 fatalities, 2 survivors). Three passengers were ejected from the minibus resulting in significant body disruption and co-mingling of body parts over a stretch of the carriageway. Due to the degree of body disruption and the anticipated difficulty of body identification and body part re-association, a mass fatality disaster plan was put into action by the police on the authority of Her Majesty's coroner.

During the initial scene assessment undertaken by the forensic pathologist, senior investigating officer, senior body recovery officer and coroner's officer it was decided that the radiological examination of the bodies prior to examination at the disaster mortuary was justified. The mortuary used was stand alone, secure, isolated and purpose built within a hospital grounds and was commandeered for the storage and examination of the victims of the incident. It was converted by the mortuary teams to an internal floor plan and flow process which followed a typical disaster mortuary setup. This mortuary however had no radiological services.

5.4 AIMS AND OBJECTIVES

The aim of this trial was to consider the contribution of computed tomography to a mass fatality incident, appraising the logistics of arrangement and the scanning process whilst also assessing the information gained.

5.5 METHODS

5.5.1 Deployment of the Mobile Scanner

At 1335hrs on the day of the incident a private medical radiological company was contacted and a mobile CT scanner was arranged to attend the disaster mortuary. The scanner and staff came from different parts of England and were all on site by 2000hrs with the scanner been set up and operational by 2035hrs i.e. a time elapse of 8.5 hours between request and being operational. It was sited at the back of the mortuary on a road quality tarmac area adjacent to the body reception area with sufficient space allowed for the funeral vehicles to drive up and park adjacent to the scanner. The site was private and secure. The environmental conditions during operational use were that is was night, windy and raining.

The scanner was a GE light-speed plus 4 channel multi detector CT scanner with Advantage Windows workstation. It was operated by 2 CT radiographers with 2 APTs (Anatomical Pathology Tecnologists) responsible for the movement of the body bags through the scanner. The whole process was overseen by the chief pathologist in the presence of the coroner's officer and a number of operational observers. The morticians wore mortuary scrubs and gloves. The radiographers did not come in contact with the body bags so wore their normal operational clothing. The bodies and parts remained inside the bags at all times. The bags were not opened at any point thus removing the need to break continuity of evidence seals. All bags were opaque so the contents were not seen by non mortuary staff. All Disaster Victim Identification

(DVI) paperwork remained taped to the outside of the bag at all times. The DVI unique numbers were used as the reference identification numbers for the CT scan images. Continuity of evidence records were kept throughout the scanning process.

5.5.2 Scanning Process

A total of 38 body bags – 6 adult size body bags and 32 bags containing body parts ranging from limbs to multiple fragments of human tissue greater than $5cm^3$ were retrieved from the scene and conveyed to the mortuary by three funeral vehicles. With the exception of one body, all other bags were placed into refrigerated storage (primary body storage) on arrival at the mortuary. On this occasion, as it was the first time that this approach had been attempted and due to the nature of the event, all six adult body bags but only 3 body part bags were imaged by CT. All material was subject to autopsy examination the following day (day 2) with DNA samples taken from all pieces estimated at greater than $5cm^3$ for identification and body part re-association purposes. All DNA profiling of material recovered at autopsy and thus all body part re-association was completed by close of work on day 3.

The first body was taken straight from the funeral vehicle and placed onto the CT trolley. It was placed onto the CT lift accompanied by a single APT. The lift was raised and the body taken into the scanning suit. Two morticians then transferred the bag from the trolley onto the CT table with the head positioned adjacent to the scanner. As the diameter of the scanner orifice was 700mm the body bag was secured around the body using tape to ensure that it passed through without difficulty. The body bag was then scanned as outlined below, before being removed by 2 morticians back onto the trolley and, via the lift, taken from the scanner to the body storage area where the second body was retrieved and the process repeated.

5.5.3 Imaging

The imaging followed the Leicester forensic pathology CT protocol at that time. Thus the imaging was undertaken to consider the following issues:

- Cause of death
- Documentation of soft tissue/organ and bony injuries
- Documentation of natural disease
- Presence and location of identifying items; personal possessions, unique identifying items such as surgical implants
- Health and safety; hidden weapons, infectious disease, bone trauma, vehicle parts
- Autopsy planning
- Collection of imaging evidence

In addition to these the following could also be considered:

- Dental identification – not specifically considered on this occasion
- Presence, nature and location (x,y,z) of projectiles; not relevant in this case although the presence of vehicle parts inside the bodies was considered
- The examination of non-animate materials

The body bags were first subject to head to toe antero-posterior and lateral scout images or ‘scangrams’. This is a 2-D image of the body performed for all CT scans enabling localisation to plan further imaging and has a similar format and appearance to a standard plain film x-ray. These images were performed using standard clinical settings and took approximately 8 seconds for the whole body scan. No pre-positioning of the body occurred due to the novel circumstances under which these scans were performed. Whole body axial scans were then undertaken. Scanning parameters were based on standard clinical protocols. As radiation dose is not relevant ideally axial scans should be performed at the highest possible resolution to achieve the narrowest possible reconstructed slice thickness. However, this creates two potential problems. Firstly increasing the resolution involves increasing the ‘heat load’ on the x-ray tube. This is rarely a problem in clinical practice with newer machines, but can delay the start of the next scan due to increased cooling time where turnover is rapid. Secondly increasing resolution increases the number of images and overall size of the electronic image file. This could be a problem where instant distant reporting of the images is required. The relation of scan thickness, exposure factors (heat loading) and reconstructed slice thickness is complex for multi-detector CT. A range of reconstructed slice thicknesses is available usually from 0.5 to 10mm. A compromise of an intended reconstructed slice thickness of 2.5mm was made but, due to ‘tube heat loading’ factors and the novel environment, one of the scans was performed at low mA and only reconstructed to a 10mm slice thickness*.

The raw data was deleted prior to radiology review preventing further reconstructions. This is less likely to be an issue for future scanning as modern scanners use an increased number of detectors and the X-Ray tube have higher heat capacity. Each scan took only a few minutes to achieve. An initial review of the scanogram, axial and 3D images was performed by both a radiographer and the chief pathologist on-site. All images were stored to a dedicated master optical disc with additional CD copy burnt on site. All images were saved in Dicom format. Hard film images can also be produced on-site but were not used on this occasion.

5.5.4 Image Review

All of the remains recovered from the incident were examined with full invasive autopsy the following day. All images were reviewed by a radiologist experienced in whole body CT imaging and a trainee forensic pathologist.

* In retrospect, other strategies should have been used such as increasing the KV or slowing the rotation speed in order to reduce mA.

A typical report was performed by first reviewing scanograms and the axial CT images. 3-D reconstructions were then performed focussing on bone and soft tissue algorithms.

Prior to this event, reporting forms were designed. Initially these forms were constructed in line with the design of pre-existing ACPO format such that they could be considered for inclusion in their ACPO book for use at mass fatality and CBRN incidents (Appendix E). The form could be used in digital or hard copy form. The form is colour coded in line with the other ACPO forms. Forms have been designed for whole bodies, skeletons or body parts. It features the universal ACPO body identification code box and has both diagrammatic and free text sections for use by the reporting radiologist. The form also details the way in which the images have been stored and the individuals involved in the scanning and reporting process

Through discussions between the local pathologists and radiologists, it became evident that for the purposes of comparing the detail that could be gained from PMCT with a full autopsy examination, a more structured report form was required.

The radiological findings in all of the scanned cases were recorded using the newly designed forensic CT reporting form (Appendix F). This included the following main headings:

- General Review including skin and subcutaneous tissues
- Foreign Bodies / Personal Effects

- Musculo-skeletal System
- Cranium, Facial Bones, Spine, Axial and Appendicular Skeleton
- Central Nervous System
- Cardiovascular System
- Respiratory System and Airway
- Abdomino-pelvic Organs including upper GI tract

The more structured approach was used to direct the radiologist to specifically comment on areas that would be discussed in a typical post-mortem report. The images were reviewed initially without reference to the post mortem reports and the findings were documented ('blind review'). The final post-mortem reports were then reviewed alongside the CT reports. A comparison was made and in cases of discrepancy, the CT images were revisited.

5.6 RESULTS

Failure of standard image archiving checks, due to the novel environment under which this study was performed, led to the archiving of an incorrectly reconstructed data set for the first case scanned (in fact a large proportion of the body was not demonstrated in the reconstructed volume). Under standard operating procedures this data is easily recovered from the original scan electronic raw data. The initial data set is normally only stored for a few days. This was unavailable at the time of formal image review so the case was excluded from analysis. The remaining five bodies were successfully scanned and hence full comparisons could be made. For complete bodies the whole scanning process could be achieved by an experienced team in approximately 10 - 15 minutes. Body parts could be scanned individually or as multiple bags in one session at a faster rate.

It was possible to give accurate causes of death for all five of the whole bodies using the CT images, although this was largely evident even with external examination in 4/5. A table showing both the positive findings that were in agreement between CT and invasive examination and features that were only identified with one or other of the methods are presented in Appendix G. In some cases, secondary review of the CT scan with the knowledge of the post-mortem findings allowed recognition of subtle findings that had initially been overlooked. Details of foreign bodies present are excluded from the table but are discussed below.

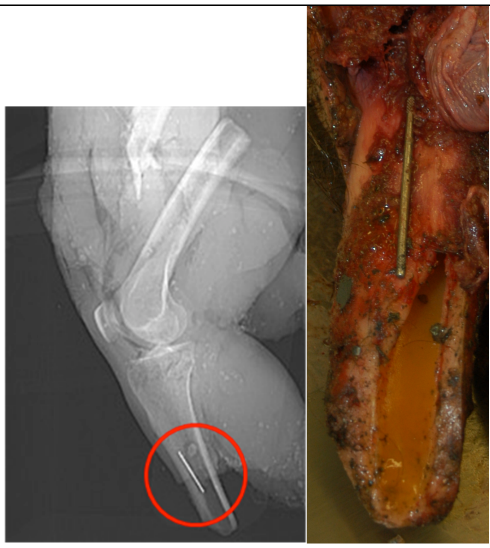
5.6.1 Surface Detail

As expected the surface reconstructions undertaken could not compete with the level of detail that could be ascertained from a direct visual external examination. Large skin lacerations and significant soft tissue haematomas could be seen but small lacerations, glass injuries, minor bruises and superficial abrasions could not be reliably identified.

5.6.2 Foreign Bodies

All potentially hazardous foreign objects were identified and radio opaque personal effects could also be seen including keys, coins, a lighter and packet of cigarettes. The identification of the cigarette packet on 'blinded' review shows that CT can detect low density foreign bodies.

However although all metal foreign bodies could be detected and glass fragments were well seen, not all plastic personal effects were demonstrated. Reconstruction of the images also allowed potential non personal identifiers such as boot tread to be resolved.

		
Figure 5.1 – Set of keys visible on scout/scanogram	Figure 5.2 – Foreign body seen on scout (left) with image from post-mortem (right).	Figure 5.3 – Detail of boot tread.

Whilst these may seem of little use, when an external examination can occur, they may be invaluable in contaminated bodies where it may be preferable to gain as much information as possible to avoid the necessity of opening the body bag.

5.6.3 Skeletal Injuries

The skeletal system was well represented in the CT images. In all but one case, every fracture demonstrated by autopsy was identifiable when present within the scanned area. The exception was a case reconstructed at 10mm slice thickness in which rib fractures could not be seen due to the poor image resolution. Several fractures were revealed by CT scanning that were not appreciated on autopsy. In these cases the images were re-reviewed to ensure they were true fractures and the presence of fractures was confirmed. These fractures included stable, posterior cervical vertebral, maxillary, nasal, and scapular fractures.

5.6.4 Cerebral Injuries

The CT images of the central nervous system, in 3 of the 5 cases where the brain was intact, tended to yield more detailed information than the post-mortems reports; which did not include formal forensic neuropathology. The images showed subarachnoid haemorrhages reliably. CT was able to demonstrate loss of grey-white matter differentiation and loss of sulcal definition in 2 cases, providing good evidence of life threatening brain trauma causing oedema and onset of increased intracranial pressure.

5.6.5 Chest Injuries

Imaging of the chest was able to identify pulmonary contusions in all cases in which they were confirmed and was able to provide reliable evidence of pleural fluid collections and pneumothoraces (Figure 5.4).

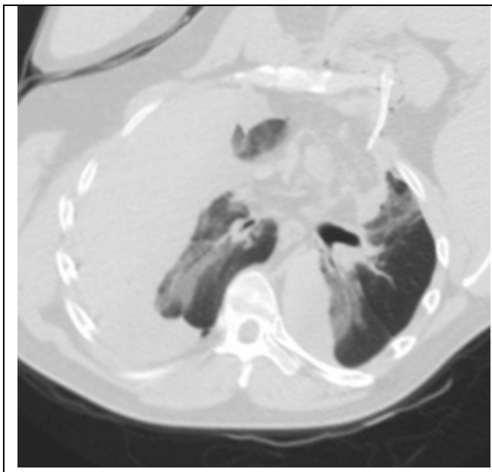


Figure 5.4 – Left sided chest trauma with rib fracture puncturing heart and resulting in haemothoraces.	Figure 5.5 – Partial 3D reconstruction highlighting the rib fractures.

When present, blood could also be identified within the airways. Blood could be distinguished from other fluids by its increased density (as shown by measuring the Hounsfield number of the region) [137].

The main area in which discrepancies were found was the mediastinum. At post-mortem, 3 of the cases showed cardiac tears, 2 showed valvular damage and 3 showed aortic damage (tears or transections) one of which had an associated oesophageal tear. It was not possible to confidently diagnose these entities despite revisiting the images. However, the presence of these significant injuries could be inferred due to the presence of their consequences of haemopericardium and haemothorax. The aorta was also noted to have collapsed in 3 of the cases of aortic rupture / cardiac laceration. This supports other researchers' work which suggest that it may prove to be a useful sign of death due to rapid exsanguinations although our subsequent work has shown this to be false [138]. There was therefore agreement in all cases where cardiovascular or lung trauma was a significant cause of death.

5.6.6 Abdominal Injuries

The assessment of minor liver lacerations was compromised by the presence of intravascular air, a normal post mortem finding. Further image quality was also degraded by post mortem gaseous distension of bowel causing 'streak' artefact in the images. It was possible to demonstrate large lacerations, generalised trauma and disruption to abdominal organs. However some of the smaller lacerations were missed. CT was sensitive to free air and fluid although in one case free fluid measured at 200mls on autopsy was not seen on the original report but detected around the spleen on review.

5.6.7 Time Management

Although assessing all organ systems for potentially fatal injuries could be performed within minutes full image review took approximately 1 hour per case due to the extensive injuries.

5.7 Discussion

Over the last few years it has become increasingly recognised that radiology has an important role within the disaster mortuary environment [139, 140] [141]. However, depending upon the nature of the incident, up to three different radiological modalities may be required. Although a variety of radiological investigations should be available within modern forensic practice, there is at present an international trend to move away from the use of fluoroscopy and plain radiography within both routine and forensic autopsy practice with the gradual increased use of CT. It was shown on this occasion that the single modality of CT can potential undertake roles of plain radiography and fluoroscopy at a single time generating both soft tissue and bony images in AP, lateral, axial and 3 dimensional views within short time periods which can be reported on-site or by distant tele-reporting (not tested on this occasion), exhibited, backed-up and stored. The data presented here suggests that CT may be adequate as the sole imaging investigation in this setting.

Acting as a one-stop radiology station, the scanner limits the number of individuals exposed to radiation sources. It is equally as capable as fluoroscopy of identifying foreign bodies with the added advantage of detailed 3-dimensional location. The more detailed axial images provide bony detail and improved soft tissue detail from which the cause of death may be determined. Imaging of the teeth with application of appropriate volume rendering techniques allows for potential dental identification. In the event that an explosive device is present on the body which can be detonated by x-rays, the CT room will provide some protection to the operators compared to the use of fluoroscopes or plain x-rays. The images can be interpreted on site or remotely transmitted for interpretation by a qualified radiologist.

The scanner can examine single body bags or multiple fragment bags all at the same time without the necessity for manual manipulation of the parts or the machine at slices as thin as 0.625 mm. The bags do not have to be opened at any time removing the exposure of the operator to the sights within the bag or the possibility of cross contamination of evidence for example in an explosive scenario. Continuity of evidence is maintained at all times.

Although MRI could also be considered for use in both permanent and temporary mortuaries, there are problems related to the availability of both fixed and mobile technology and related to the scanning of bodies or body parts containing metallic material [132] [142].

Computed tomography, can theoretically be used in all circumstances including at the scene of the incident itself. The scanner and operational suite are mounted within a long heavy goods vehicle that can theoretically be taken anywhere where there is a road quality surface. To date we have operationally used mobile CT scanners outside permanent and temporary mortuaries, on a road during a simulated mass fatality exercise as well as within a building (with the generator exhaust vented externally). They can be adapted for air lifting or driven into a plane for transportation to distant sites. They run on diesel generators but can use electrical supplies. The one utilised in the incident is equipped with the scanner, imaging suite, telecommunications facilities for distant (tele-) reporting, hard film printing, optical and CD burners for data storage and air conditioning. As there are fleets of mobile vehicles within the country, acquisition of a fully staffed, up to date, fully serviced vehicle should be possible 7 days a week, 365 days a year. As the unit is self enclosed there are no external radiological health and safety issues unlike the use of fluoroscopy and plain x-ray although normal safe operating procedures within the vehicle must be adhered to. Following the work undertaken in Leicester, an agreement has been made between the Department of Health and the Home Office that at least three mobile scanners, currently used for clinical purposes, could be redistributed for post-mortem scanning in the event of a mass fatality.

One important issue raised by this review is the need for a robust, well trialled protocol for CT scanning in such events to avoid data loss. The body scanned and reconstructed at 10mm slice thickness had rib fractures which could not be discerned on the CT images due to poor resolution. Narrow slice thickness and hence resolution of the scan images is therefore important to detect subtle injuries and allow good 3-D reconstruction. Scanning at high resolution is therefore important but this must be offset against potential delays due to CT X-ray tube cooling and potentially large image file sizes if immediate distant reporting is required. For this reason it is recommended that the scanner should be at least 4 channel (4 slice) and ideally 16 channel (16 slice) or better. It is recommended that the primary intended slice thickness for the reconstructed images be set to ≤ 2.5 mm. This is generally the setting that determines the X-ray tube current setting and therefore the balance between quality of images and 'heat loading' on the X-ray tube. Secondary image reconstructions can then be made to aid 3-D reconstructions and thicker slices to allow wireless transmission of images for instant distant specialist opinion.

The body does not have to be in a perfect anatomical position as the scan can be adjusted to take into account of, for example, bodies that are on their sides and use computer software to re-orientate the reconstructed images. However, it is important that the correct body habitus is recorded following the initial scout scan when possible. The default for CT scanners is head first in the supine position. As the bags are opaque this cannot always be achieved. It is recommended that after the first scanogram is performed details of the body position are corrected in the CT scan console. The scanogram can then be repeated and all subsequent images will correctly identify right, left, anterior and posterior without having to reposition the body bag. This is particularly relevant when scanning body parts as mirror images produced during image processing may be misleading when determining laterality especially in the case of limbs.

Subsequent to this trial a local standard operating protocol has been introduced for mobile scanning. This follows:

- A standardised operational protocol for the movement of the bodies on and off the scanner and individuals roles within the scanner in relation to scanning, image interpretation and data backup.

- Where possible bodies are scanned in a head first supine position. If this is not possible the position is checked on the initial scanogram images and the correct position data is then loaded onto the scan console without changing the body position. The scanograms are then repeated and imaging continues. Full head to toe images should be generated in both AP and lateral views. Where necessary, the body bag may need to be rotated with separate scan of the lower limbs. In such cases, it is essential to ensure that the change of orientation is taken into account
- Bodies or body parts are then scanned at optimum resolution. In the case of this mass fatality scanning an intended reconstructed slice thickness of $\leq$ 2.5 mm is suggested. However this is variable depending on the CT platform used and, if speed of throughput and electronic data transmission are not limiting factors, then the highest possible resolution should be used.
- All image reconstruction and image archiving should be checked before the end of the scan session. Where possible all the CT scan image data including the pre processing data should be stored until expert review has been performed.

Reporting of images was time consuming. Many of the discrepancies in this study can be explained by the sheer volume of abnormalities in these cases as shown by the number of CT misses subsequently detected on review. Generally CT performed well at identifying bone and lung pathology. In many cases CT was superior to autopsy at identifying fractures. This fits with previous autopsy experience, where fractures in bones that are not routinely dissected out such as the vertebrae, are difficult to detect. Although rib and hyoid fractures can be identified on thin section CT they are easily overlooked, whereas at autopsy direct visualisation and palpation assists detection.

Although vascular tears could not be seen they could be inferred in all cases by surrounding haemorrhage. Therefore it is unlikely that significant vascular damage could occur without significant related abnormality on the CT images. Although aortic transection has been described previously in post mortem studies on CT in the case described the aorta was completely disassociated which was not a feature in this study [143].

It is possible that all the relevant information required for the investigation could be acquired in 10-15 minutes reporting time, which would be typical for a clinical report. A further detailed report could be requested at a later date if required; 'virtual exhumation'.

Through this incident it was possible to illustrate for the first time the use of mobile CT in mass fatality investigations. The widespread adoption of mobile CT in the future for the investigation of mass fatalities could remove the necessity to have multiple radiological sources within a mass fatality mortuary, offering superior, faster, contamination free examinations of both bodies and body parts, which can be electronically stored as a permanent record.

RADIOLOGICAL REPLACEMENT OF THE MEDICO-LEGAL POST-MORTEM?

CHAPTER SIX: COMPUTED TOMOGRAPHY VS THE INVASIVE EXAMINATION: A COURTROOM FEASIBILITY STUDY

6.1 INTRODUCTION

Although the discovery of x-rays caused great excitement in the scientific and medical communities, it is important to note that the legal profession remained somewhat sceptical and questioned the use of radiographs in courts of law. As early as 1915, it was argued by one judge that a radiograph alone could not reach the accepted evidential value of a photograph due to the inaccessibility of the image to the layman[144]. However, he did accept the testimony of an expert in the field.

While the main focus of research has been on the abilities of computed tomography to detect pathology, the literature lacks investigation of the viability of a radiological replacement of the internal examination within the legal arena. If PMCT is not accepted by the legal profession, much of the research may have been in vain. If the crown prosecution service is unable prosecute a case with CT scan evidence, the demand for invasive post-mortem examinations in forensic cases will remain.

6.2 AIMS AND OBJECTIVES

This chapter seeks to assess the viability of a non-invasive approach to forensic post-mortems. The information gained and lost by this method is considered alongside the likelihood of acceptance by the medico-legal profession.

6.3 METHODS

8 cases were selected from the routine forensic caseload to represent a variety of causes and modes of death. A larger number of cases would have been advantageous but during initial search of the archive of post-mortem CT cases, it became apparent that it was inappropriate to compare incomplete scans and older CT technology with the full invasive post-mortem procedure. The resolution of some of the older scans was not sufficient to detect un-displaced fine fractures and fine organ and vascular injuries and could not therefore be subject to fair comparison.

The whole body post-mortem CT scan was intended only to replace the internal aspects of the post-mortem examination report. As documented in the previous chapters, the surface rendering that can be achieved with reconstructed CT scans cannot currently compete with naked eye examination when examining external appearances, marks and injuries. The circumstances of the case, scene details where available and external examination findings were all provided to a Specialist Registrar in Radiology prior to their examination of the whole body CT. Such information would have been available to the pathologist undertaking the original internal examination. These details, together with scene and external photographs and the radiologist's findings were conveyed to a consultant pathologist with forensic experience. The results of some toxicological sampling were also made available but only those that could conceivably be retrieved without opening the body. Although histology is routinely undertaken as part of the forensic pathology investigation, this was not included in the CT reviews. The consultant pathologist was then asked to compile all the information available, formulate the comments and conclusions routinely provided in a forensic post-mortem report and provide a cause of death where possible.

6.3.1 Study One

The first part of this study involved a comparison of the completed non-invasive report with the actual post-mortem report that was issued. This included a comparison of the factual findings of the CT scan with those of the invasive examination and of the causes of death given. The absence of histology in the non-invasive cases was also considered in light of the information provided by the histology report.

6.3.2 Study Two

The non-invasive reports were sent to medico legal professionals representing the full range of end users of medico legal reports including a police officer, HM coroner, high court judge, barrister and solicitor. CT images were included where it was felt that they demonstrated salient findings. By means of a questionnaire (Appendix H), their opinions were sought as to effect of the absence of invasive procedures such as histological and stomach content sampling, whether there were any significant omissions from the reports and whether the reports enabled them to complete their role in the medico legal system. In addition to the formulated questions, free text responses were encouraged regarding the advantages and disadvantages of adoption of the new non invasive approach into practice. These free text comments were then analysed using a phenomenological approach. This is a recognised qualitative research methodology [145]. Many surveys seek opinion by asking the subject to rate their level of agreement with a statement on a scale of 1 to 5. This however gives no background information as to the reasons for their opinion. A phenomenological approach prevents the stifling of opinion and over generalisation of the responses. The aim was to discover all contrasting opinions and individual perceptions rather than to present the most commonly held opinions. The free text comments underwent a themed content analysis. Themes were identified by collating similar comments from all respondents.

6.4 CASE PRÉCIS

Case one:

An elderly female recovered from a house fire at her home address and pronounced dead on arrival at hospital. The seat of the fire was just inside the front door and the police believed that the source had been pushed through the letter box.

Case two:

An elderly male found deceased and lying in the middle of a main road. He was believed to have been run over having possibly already been lying in the road.

Case three:

A middle aged female found deceased beneath a train between the rails, in close proximity to a railway bridge having been seen beforehand crouched across the track. The police were considering a number of possibilities as to how she came to be there including the possibility that she may have been pushed from the bridge.

Case four:

A young male seen to have an altercation with another male on his doorstep before collapsing to the ground. He was admitted to hospital with stabs wounds to his chest and died despite resuscitation attempts.

Case five:

A young male found deceased and heavily charred within the ground floor hallway of a block of flats by a fire crew having distinguished a fire. The body was in close proximity to the burnt out remains of a stolen motorcycle.

Case six:

A middle aged male reportedly found deceased by partner halfway down the stairs in a seated position. Having originally believed to be a natural event, the body was removed to the mortuary whereby a member of mortuary staff identified a ligature mark around the neck. At the time of the examination it was unclear whether this was a homicide or the partner had released and removed a ligature to hide a suicide.

Case seven:

A teenage male found deceased, lying across the pavement and road having sustained blunt force trauma to the face and head together with incised and stab wounds to the head, face and neck. Broken glass, a piece of wood and a metal bar were all found within the vicinity.

Case eight:

A teenage male found with a shotgun injury (buck shot) following an altercation between rival gangs. He was admitted to accident and emergency and surgical attempts were made to save his life.

6.5 RESULTS

6.5.1 Study 1: Comparison of Invasive and non-invasive approaches

a. Pathological Findings

The main differences in the findings of fact are detailed in the table included in Appendix I.

The main findings successfully demonstrated in both procedures included traumatic fractures, the effects of traumatic injuries such as haemothoraces, pneumothoraces and surgical emphysema, and natural conditions such as fatty liver disease. While no quantification of the haemothoraces was provided in the CT reports it was possible to state whether these were clinically significant.

Although the effects of, for example, stab wounds, could be demonstrated it was not possible to routinely define individual tracks, track depths and directions. In case 7, where the wound track primarily involved soft tissues, rather than body cavities, the air tracking through the tissue allowed an estimation of depth which varied from that provided at post-mortem examination by only 0.8cm. Despite this, the significant vascular injury that had ultimately led to death and associated vagus nerve trauma could not be identified.

While stab wounds affecting bone could be easily demonstrated, those passing through the costal cartilages were not identified. Equally, an ante-mortem fracture to the thyroid cartilage was also missed.

In the firearm case, a more destructive insult than a stabbing, areas of parenchymal damage and contusion to the internal organs were more readily identified but medical intervention such as sutures could not be commented upon.

In the fire deaths, important features such as sooting to the lower airway and oesophagus and heat damage to the laryngeal structures could not be identified. Areas of deep bruising to the soft tissues and organs, also, could not be ascertained unless significant haematomas had formed.

The PMCT examination generally provided greater detail regarding fractures of the pelvis, posterolateral spine and limbs which may not be easily demonstrated at invasive post-mortem examination. It also identified a hemiathroplasty which was not documented in the invasive post-mortem report.

The CT examinations did however, produce some equivocal findings. This included possible nasal fractures, air in the cranial cavity suggestive of a skull fracture and possible inhalation of blood that could neither be confirmed nor refuted.

In three of the eight cases there was a false positive reporting of intracranial haemorrhage. This is now a recognised artefact of post-mortem congestion of the brain and venous sinuses. There was also the report of a depressed fracture of the frontal bone in one case which was not substantiated by post-mortem examination. A retrospective review was not undertaken as this was not the purpose of this chapter.

b. Cause of Death Comparison

In 5/8 cases the cause of death provided using CT in replacement of the invasive internal examination was identical to that given following the invasive post-mortem examination. 2/8 cases showed slight variation. In first of these cases alcohol intoxication was included in part Ib of the original cause of death but not in that of the non-invasive approach. In the second, a fire death, the original pathologist included burns in addition to the inhalation of the products of combustion in part Ia of the cause of death but burns were not included in the cause of death in the non-invasive report. These variations appeared to result from the different approaches and opinions of the reporting pathologists in regard to the toxicological evidence and interpretation of the external examination rather than the effects of the replacement of the internal examination. Thus 7/8 causes of death could be considered unaltered by the absence of an internal examination.

In one of the cases there was a significant difference between the causes of death provided by the different approaches. This was in case 7, a case of stabbing, in which the ‘invasive’ post-mortem examination gave the cause of death as “Stab wound to the neck” while the non-invasive approach resulted in “Inhalation of blood following glass wound to neck”. While these may not appear immediately incongruous, the first had suggested death had resulted from blood loss caused by vascular injury whereas the PMCT was unable to demonstrate a definitive vascular injury but did show possible inhalation of blood thus leading the pathologist down a different route. Although this represents a failing of the PMCT approach, with a different pathological process being provided as the cause of death, arguably the outcome is unaltered – providing evidence of a homicide.

c. <u>Contribution of Histology</u>

Whilst CT guided biopsy can be undertaken to allow histological examination, this further complicates and lengthens the examination. In each of the eight cases, histological samples were taken during the invasive post-mortem examination. Review of the reported histological findings showed that in 5/8 cases, histology made no significant contribution to the case. Thus the absence of the histology in the non-invasive approach in these cases was not detrimental to the interpretation.

In the lung histology of two of the cases, fire related, soot was confirmed within the peripheral airways. In each of these cases the absence of this information did not affect the case interpretation as positive toxicological results had confirmed inhalation of the products of combustion.

In the remaining case, although the histology did not add significantly to the invasive procedure, the confirmation of aspirated blood within the lungs would have supported an otherwise equivocal CT finding.

6.5.2 Study Two: Responses from medico legal representatives

a. Report Acceptability

From the responses to the questions posed it was possible to ascertain whether or not the 'assessors' considered the non-invasive reports to be sufficiently complete.

Table 4 - Medico-legal acceptance of completeness of non invasive investigation

		Assessment of Completeness of the Case				
Case	**Nature**	**Judge**	**Coroner**	**Barrister**	**Solicitor**	**Police**
1	Burns	YES	NO	YES	YES	NO
2	RTC – Pedestrian	YES	YES	YES	YES	YES
3	RTC – train	YES	YES	YES	YES	YES
4	Stab wounds	NO	YES	NO	YES	NO
5	Fire death	YES	NO	NO	YES	YES
6	Asphyxia / hanging	YES	YES	DEPENDS ON LEVEL OF SUSPICION	YES	YES
7	Glass injury to neck	NO	NO	NO	YES	NO
8	Shotgun	YES	YES	NO	YES	YES

In case 1, the reported subdural haematoma on the CT was the main reason for rejection of this case as complete. Had this been recognised as a post-mortem artefact, all agencies would have accepted the case as complete and fit for purpose.

The main concerns raised in the fire related deaths involved the fact that fires may be used to dispose of bodies or hide murder. It was raised that even thorough external examination can fail to discover injuries such as stab wounds which may by masked by subsequent fire damage and for example coagulation of clothing. However, internal examination is likely to show more obvious injuries to the better preserved, solid organs. Equally, it was questioned as to whether discrete deep areas of bruising in the soft tissues such as grip marks, obscured by burning would be identified on CT scan. While this may not be directly related to the cause of death, soft tissue dissection may still be required if this is relevant to the police investigation.

Cases 2 and 3, transportation deaths were universally accepted as complete. The question was, however, raised again by one of the reviewers as to whether the CT scan could have accurately identified soft tissue injuries that might have been caused, for example, by a prior assault. Although neither of the cases was rejected on the basis of it, concerns were raised about the ability to exclude natural diseases that could contribute to the incidents. As such more invasive approaches may be required in drivers of vehicles compared to passengers. However, it must be recognised that the position of a deceased individual within a vehicle may not have been confirmed prior to the post-mortem examination.

Cases 4 and 7 involved inflicted sharp force trauma by a knife and by broken glass. More details were requested with regards to the exact injuries caused. For example: Which wound caused the most significant injury? What were the angles of the tracks? The inability to provide track depths and lack of evidence of tapering of the blade was considered unacceptable. It was felt that the absence of such information would leave too many questions unanswered and damage the success of criminal proceedings by introducing too much doubt. The depth in particular was considered highly relevant to the assessment of intent to kill or GBH.

The equivocal nature of the nasal fractures reported in the CT findings of case 4 was not considered acceptable. Arguably in this situation, the absence of external injuries was not specifically addressed by reporting pathologist but it could be ascertained from the report that there was no external evidence of ante-mortem blunt force trauma. The over reporting of nasal fractures may be have resulted from inexperience of the reporting registrar.

The equivocal skull fracture also raised in case 7 was not considered acceptable. In particular in this case there was evidence of a head injury and as such there was an almost unanimous agreement that full neuropathology would be essential to ascertain whether the head injury may have caused or contributed to death and to give additional information about the timing of the injury and the possibility of incapacitation.

Case 6 highlighted the dichotomy of post-mortem practice. All those considering the case to be non-suspicious felt the examination details were adequate but all provided the caveat that should further information come to light that raised the suspicion of foul play, the details would be inadequate and that direct layered dissection of the neck would be required. It was, interestingly suggested by one reviewer that internal examination of the neck may be the only area of the body that would need invasive examination.

In case 7 it was highlighted that the nature of any foreign body and its recovery is likely to be of evidential value

Case 8, the firearm case, was almost universally accepted as complete with only one concern raised regarding the potential ballistic value that might be gained by collection of a sample of the shotgun pellets or wadding to allow identification of the cartridge type.

b. Free text responses

14 Themes were identified and these were grouped into the following metathemes:

1) The viability of CT as an alternative to the invasive post-mortem

2) The Defence

3) Impact on relatives

4) Logistical considerations

5) Use of CT imagery

Metatheme 1: The viability of CT as an alternative to the invasive post-mortem

Theme a: The invasive post-mortem examination is the gold standard and so the credibility of the process could be questioned.

> "[The] need for a 2nd autopsy (invasive) after an inconclusive CT autopsy may be difficult in respect of time and credibility of process"

> "If you don't do an invasive PM, can you be sure you may not have missed something"

> "It is the question of whether the pathologist has deprived themselves of information by limiting the examination."

> "My concern is that potential evidence to provide the necessary scrutiny could be lost in a rare number of cases if invasive techniques are not used"

> "[I have] concern over whether a lurking feeling would exist along the lines of 'should we have had an invasive PM to cover all bases?'"

> "Unless the pathologist can say with confidence that an invasive technique would not have produced any more information I fear that use of non-invasive techniques will face inevitable criticism".

Theme b: Histology may be necessary.

> "In cases in which the deceased has a history of illness or disease, histology may be relevant."

Theme c: There is no legal requirement for an invasive examination

> "I cannot think of any legislation (statute or regulation) or principle of law which would restrict or prevent the adoption of the non-invasive approach. I see nothing in Part 33 of the criminal procedure rules which might impinge on this"

"In my area of practice (homicide) I am aware of no legislation or regulation which requires an invasive autopsy. It is necessary to establish that the actions of the defendant are 'a substantial cause' (not necessarily the sole or principle cause) of death.

Theme d: CT has the potential to replace the invasive examination.

"It does seem to me that computed tomography provides the same clues to the cause and manner of death as a traditional scalpel autopsy, the latter of which is time-consuming, expensive and, to many, a distressing procedure"

Theme e: Uncertainty is not easily accepted by the legal profession

"[The procedure] is not as precise with gaps"

"Where has the blood in the chest come from heart, lung, intercostal artery...?"

Theme f: The process needs to be accepted as a reliable and robust by the profession

"I am concerned about the extent to which this could properly be described as a 'novel' technique. The court will expect [the expert witness] to use the techniques that are generally accepted in [their] profession."

"All parties [in the criminal justice system] are under pressure to prevent unnecessary and distracting peripheral issues being argued in court....I cannot see any merit in an argument against such evidence being properly advanced subject to the scientific community agreeing to the general reliability of 'non-invasive' autopsy reports."

"[Whether the procedure provides the scrutiny required] depends on the reliability of the technique"

Metatheme 2: The Defence

Theme g: The CT approach could reduce the need for two invasive examinations

> "[The presence of reviewable images has the] potential to reduce 2nd Pms"

> "[It is] likely to prevent second post-mortem and the cost to the public purse that it entails."

Theme h: The defence would require an invasive procedure

> "[In some cases] the defence would almost certainly require a full post-mortem examination"

Theme i: The use of the non-invasive approach could be used by the defence to manipulate court proceedings

> "A defence pathologist (whether justified or not) could suggest that the lack of a traditional invasive autopsy reduces the value of the first pathologist's evidence"

> "A defence advocate could raise questions in cross-examination; Can you exclude the possibility that in the particular case an invasive technique could have produced other potentially relevant information?"

> "The jury might be led to conclude (rightly or wrongly) that the pathological findings were open to criticism and therefore carried less weight than they should have done."

> "[The absence of an invasive procedure], although unlikely, may lead to speculation about other cause(s) of death."

Metatheme 3: Impact on relatives

Theme j: A Non-invasive approach would be more acceptable to the family

> "It [non-invasive procedure] would be easier for the police to discuss with family"

> "It would be easier for the family to understand the nature of the procedure"

> "There would be a reduction in [emotional] trauma to the relatives of the deceased"

Theme K: The impact of an invasive procedure on the family can be over emphasised

> "In the vast majority of cases, the family will accept whatever procedures are necessary to establish the truth."

> "Relatives may feel marginally less distressed if there is a non-invasive autopsy, though this should not be overstated. Over the years I have met many such relatives and friends and have read many family impact statements. It is rare (though not unknown) for there to be any reference to the nature and extent of the autopsy. "

> "In cases of destructive deaths the need for non destructive examinations is more easily dismissed. "

Metatheme 4: Logistical considerations:

Theme l: Specialist centres may be required

> "If specialist centres are required for CT, this would require additional movement of bodies"

Theme m: It is perceived that a non invasive approach would provide quicker results.

> “[There is the] likelihood of quicker results and interpretation.”
>
> “Report available at a much earlier time”
>
> “Ensures a speedy return of deceased to family”

Metatheme 5: Use of CT imagery

Theme n: The use of CT images would enhance the presentation of findings

> “[The] CT images [are] useful”
>
> “The ‘new’ method seems to me to be more illustrative for jury purposes than a pathologist trying to explain the matter from the witness box!”
>
> “The images from the CT scan seem to me to be more useful than a normal PM report in seeking to explain to a jury how the deceased came to die and would render unnecessary the preparation of further diagrams, charts etc”
>
> “Presentation of the case would be easier and more effective”

6.6 Discussion

6.6.1 CT capabilities

This study has highlighted a number areas in which computed tomography cannot currently compete with the invasive post-mortem procedure. These included the reduced ability to demonstrate soft tissue bruising, cartilaginous injuries, parenchymal injuries, vascular injuries and medical intervention.

In many of the cases of deep bruising, these areas were underlying externally evident injuries but it is important to note that the presence of deep bruising may be used to determine severity of force applied and there are instances where deep bruising may be present in the absence of clear external injury. In pedestrian road traffic collisions, soft tissue dissection is recommended by some to enhance the ability to reconstruct events by demonstrating impact points. In the case of deaths due to fatal pressure on the neck, the presence or absence of deep bruising and the morphological features of any bruising present are crucial to the interpretation of the cause.

PMCT can demonstrate fractures in areas of the body that are difficult to demonstrate by the routine post-mortem techniques that would otherwise require additional disfiguring dissection. As mentioned in previous chapters, it can also show medical prosthesis which may be useful in identifying unknown individual.

However, a significant problem highlighted by the medico-legal representatives was the inability to determine defined wound tracks in the case of stab/penetrating injuries. The external findings, alone, may not tell the whole story particularly when a knife is partially withdrawn and pushed back in producing another track or when fire has concealed the external features.

The wound track information may be required to support or refute the descriptions of the incident in particular the positions of those involved. Probing of the wound remains a possibility but this would not provide the detail of a step-by-step dissection and false tracks can be produced. Comparing the severity of one wound with another may be particularly relevant when there is more than one assailant. The details of the track, including the depth may be used to link an assault with a particular weapon and may become critically important if the defendant raises the argument of a lack of intent to cause serious injury. The apparent inability to reliably identify cartilaginous injuries is, therefore, equally important as such features are use in the assessment of the force that has been required to produce the injury.

In firearm deaths, however, if no projectile remains within the body or the projectile is seen to be of limited evidential value, external examination, PMCT and toxicology may be able to address all of the investigative issues.

An important consideration in fire deaths is the potential inability of the PMCT to confirm whether the individual was alive during the fire. If the toxicological analysis had been inconclusive, the non-invasive approach may not have been able to provide evidence of life after the commencement of the fire as features such as heat damage and sooting cannot be demonstrated.

The presence and details of medical intervention can very important in medico legal death. It may be necessary to exclude the possibility that a medical intervention has contributed to or hastened death. In post-operative deaths in particular the efficacy of anastomoses and sutures may be in question. At present PMCT alone, is unable to assist in this matter.

6.6.2 Post-mortem computed tomography in the legal arena

The varying roles and agendas of different medico legal professionals mean that while CT examination might be able to meet the requirements of one, it might not satisfy all.

Involvement in this study fuelled great intrigue amongst the medico-legal representatives. The overall response to the proposed non-invasive was positive but all required that the non-invasive approach should be able to produce the same details as an invasive examination. Rather philosophical but poignant queries were raised by one of the responders:

> "Is the position that it is only when one has done a 'traditional"' PM that you can say – this wasn't necessary; I could have got everything I have got without using invasive techniques? Can you be sure in advance that non-invasive techniques in any one case will achieve the same results as a traditional PM."

Just as with the introduction of every new procedure into clinical medicine, the non-invasive approach needs to be shown to be scientifically robust if it is to be used as evidence in court.

When post hypnosis evidence was sought to be adduced, the Canadian Supreme Court laid down a series of tests in a case:

1) Can the technique be tested and has it been
2) Has it been subjected to peer review and publication
3) What is the known or potential rate of error
4) Has it been generally accepted

Within the medico-legal profession, despite the absence of any legal requirement for an invasive procedure, there remains a cultural belief that the current gold standard; that an invasive procedure, covers all bases.

Uncertainty and equivocal findings are not easily accepted by the legal profession. It has been argued that the absence of a 'full' invasive post-mortem may allow too much unquashable speculation.

The need for second post-mortem examinations otherwise known as defence post-mortems remains a controversial topic in the forensic pathology community. Before non-invasive examinations could become commonplace in suspicious cases there would need to be a blanket acceptance of the capabilities of radiology. Without this, it is possible that the defence team would still proceed with an invasive and arguably more accurate procedure, and any discrepancies could be exploited to the detriment of the prosecution's case.

6.7 CONCLUSION

The introduction of this new approach tomorrow would cause significant controversy within the medico legal community. A blanket application of the non invasive procedure to all cases could conceivably lead to missed homicide.

A step-wise approach could be undertaken whereby an initial CT scan is undertaken and following the results of this, a decision is made regarding the need for further invasive procedures. The invasive examination could equate to a standard post-mortem examination or be targeted to a specific body region. However, the very presence of the two options, invasive or non-invasive, is likely to be perceived as a two-tiered system and most senior investigating officers are likely to request that which they perceive to be the gold standard.

The ‘What if’ culture is the very basis of criminal proceedings; particularly defence cases and significant case information is often not available at the time of the examination.

Before the non-invasive approach can be accepted into routine practice, it must be shown to be scientifically robust and able to provide all the relevant information that can be achieved by an invasive examination.

While it is easy to be critical of a new approach, it must be remembered that even the most detailed of invasive post-mortem examinations may leave questions unanswered.

THE FUTURE

CHAPTER SEVEN: DISCUSSION

Over the last decade many journal articles, predominantly case reports, have championed computed tomography as a modern alternative to the traditional invasive post-mortem examination. Despite this many question still remained.

7.1 WHAT CAN POST-MORTEM COMPUTED TOMOGRAPHY ACHIEVE?

The potential for CT scanning to enhance areas of forensic pathological investigations is clear.

As a pre-screening tool, PMCT can demonstrate any potentially hazardous or forensically relevant foreign bodies present. It can also highlight features such as air embolism which could be easily overlooked and require specialist dissection techniques to demonstrate.

PMCT can be a very valuable tool for identification of the unknown body. It can provide vital information regarding unique skeletal features, odontological features, pathology and orthopaedic surgical interventions. As an all encompassing facility, it can revolutionise mass fatality investigation.

PMCT has proved to be an excellent tool in demonstrating skeletal trauma. It can demonstrate areas of skeletal trauma within relatively inaccessible areas of the body and reveal fracture patterns that assist in the reconstruction of the mechanism of injury. Without this radiological imaging visualising such features entails time consuming, and potentially disfiguring dissections.

Gross internal pathological findings, in particular large fluid collections such as blood collections are easily visualised as in clinical scenarios. Gross disruption of organs and indeed soft tissues may also be visualised.

CT is particularly helpful in the assessment of firearm deaths. CT can assist with the recovery of forensically relevant projectiles and jacket fragments providing more detailed three-dimensional information than plain film radiography. CT can also demonstrate fracture patterns which can assist in the differentiation of entrance and exit wounds.

In many cases, PMCT can provide the same, accurate cause of death as an invasive examination.

The use of PMCT also provides a permanent medico-legal record that may be revisited in the future by defence teams and prosecution teams alike.

PMCT scanning can also provide valuable images which can assist the court. The reconstructed three-dimensional images display anatomical landmarks and relations in a format which is much more familiar to the lay person.

7.2 What are the shortcomings of Post-mortem computed tomography?

PMCT surface reconstructions cannot compete with the naked eye external examination and therefore PMCT should not be interpreted without knowledge of the external examination findings.

Similarly, PMCT cannot provide sufficient detail regarding subcutaneous bruising which often requires extensive dissection to demonstrate at post-mortem examination.

Problems still remain with the exclusion of certain forms of natural disease. Whilst gross traumatic organ disruption may be identified, more subtle pathological changes may be overlooked. A statement of the absence of contributing natural disease can be equally as important as the details of inflicted injuries. Whilst queries still remain regarding the ability to exclude in particular cardiac disease, it is likely that the introduction of this technology will be resisted by the pathology and legal communities.

Legal professionals have become familiar with the information that an invasive post-mortem examination can provide such as directions and detailed measurements of wound tracks with subjective assessments of force required which are dependent on knowledge of the exact structures damaged. They will therefore expect any new procedure to achieve the same. At present these features cannot be reliably determined on all cases with internal examination by PMCT alone.

7.3 LOGISTICAL CONSIDERATIONS

7.3.1 Access

Post-mortem examinations are currently undertaken in a number of licensed facilities across the UK. Many of these are not associated with NHS trusts and may not have easy access to scanning facilities. PMCT examination in these areas may require additional movement of bodies to appropriate facilities. Alternatives would include the use of mobile CT scanners or the purchase of dedicated CT scanners. All of these options come at an increased cost to HM Coroner.

7.3.2 Financial Considerations

Currently, in addition to payment for the use of mortuary facilities which is heavily subsidised by the NHS, HM Coroners pay £96.80 for a standard post-mortem and £276.90 for a 'special' or forensic post-mortem by the pathologist. The police pay over £2000 for a forensic pathological examination.

It is unlikely that mortuary costs would be avoided by a non-invasive approach as body storage would still be required. A fee per scan would have to take into account the payment of on-call radiographers, and private practice reporting time of consultant radiologists. In addition to this there may be additional costs of initial CT scanner purchase (of the order or £700 000) with replacement within 5 years of prolonged use and annual maintenance (of the order of £70,000/year). A non-invasive approach may therefore not be the cheaper alternative that many expect in the UK.

7.4 What is the future of the Post-mortem examination practice?

It has been suggested that the post-mortem CT scanning could replace the invasive autopsy procedure. Before one can ask whether one form of examination can replace another one must first consider the aims and objectives of that examination.

7.4.1 What do we expect from the post-mortem examination?

In the National Confidential Enquiry into Patient Outcome and Death (NCEPOD) report of 2006, there were extensive discussions as to the purpose of a post-mortem undertaken under the jurisdiction of HM Coroner, with little consensus. The varying responses are included in Figure 7.1.

While there are there is such discrepancy in the perceived purpose of the autopsy examination it is difficult to put forward a case for replacement of the traditional examination by another procedure.

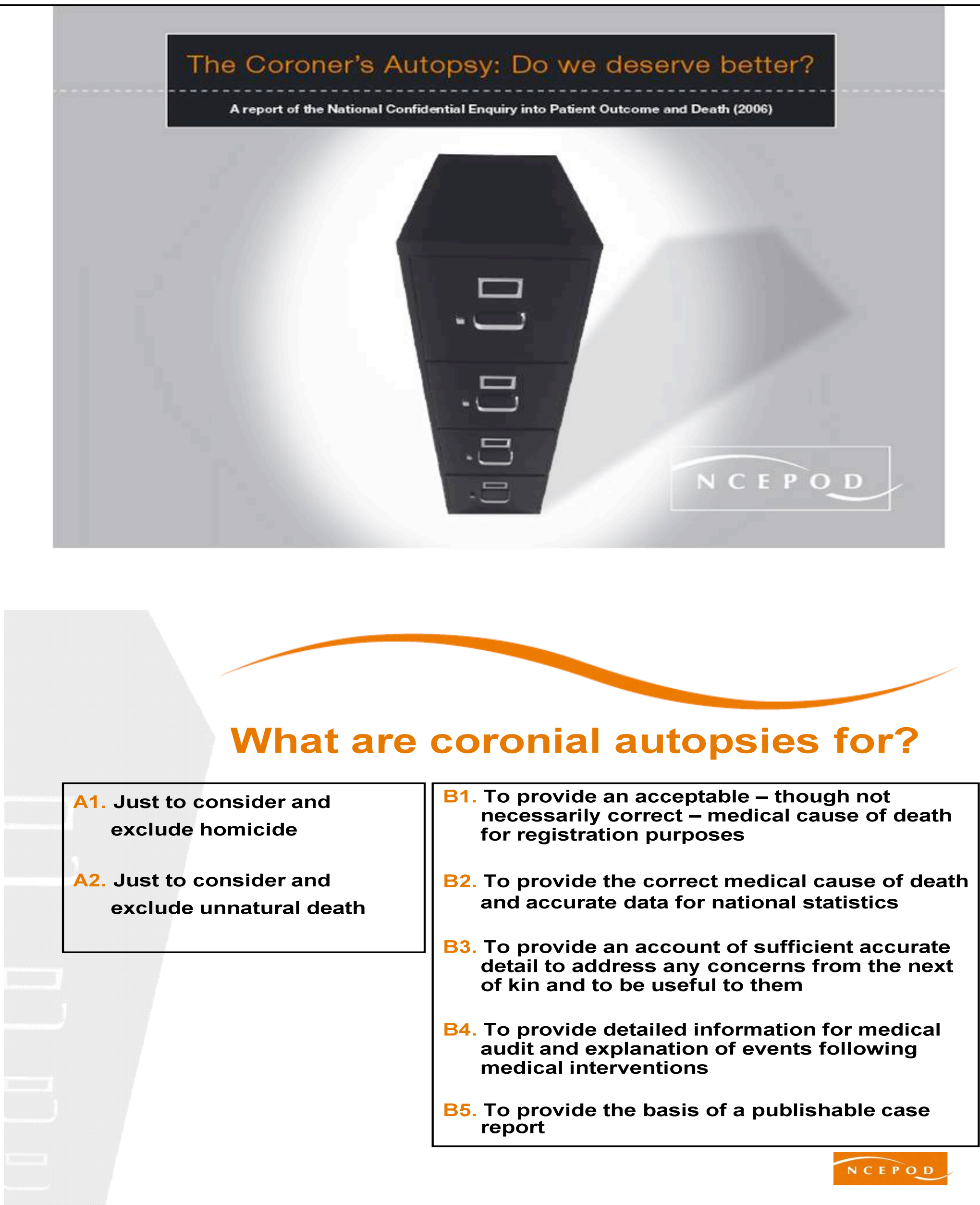


Figure 7.1 – Purposes of the coronial autopsy as per responses to NCEPOD enquiry. (http://www.ncepod.org.uk/2006.htm)

If the purpose is merely to provide a cause of death on the balance of probabilities, then arguably an external examination, CT scanning and toxicology sampling may be adequate in some cases, for example in the case of a witnessed road traffic collision where no criminal charges are applicable.

7.4.2 Who will become the expert witness?

The role of the expert witness has recently fallen under scrutiny [146]. Any comments regarding radiology, albeit post-mortem, are likely to be sought from radiologists rather than clinicians or pathologists. Radiologists may find themselves under increasing pressure to assess complex forensic cases involving both living and deceased. The forensic knowledge of the radiologist is particularly important. Without prior insight into aspects of forensic and legal medicine, important negatives may be omitted and subtle but forensically relevant injuries may be overlooked. This highlights the need for a degree of multidisciplinary reporting or dual training. Training is therefore an important area which needs development.

One of the primary concerns remaining is who do we consider to be an expert in this field; the pathologist or the radiologist? Until such time as forensic pathologists undergo specific forensic radiology training or radiologists undergo additional post-mortem and forensic training, it is likely that interpretation of the findings will require joint input.

7.5 CONCLUSION

Post-mortem computed tomography in its current form has a lot to offer the field of death investigation. Just like any new application of technology there is a steep learning curve and currently we are still on the ascent. Before post-mortem CT evidence can truly be accepted by the court, it must be shown to be a robust science but at present it remains a science in its infancy.

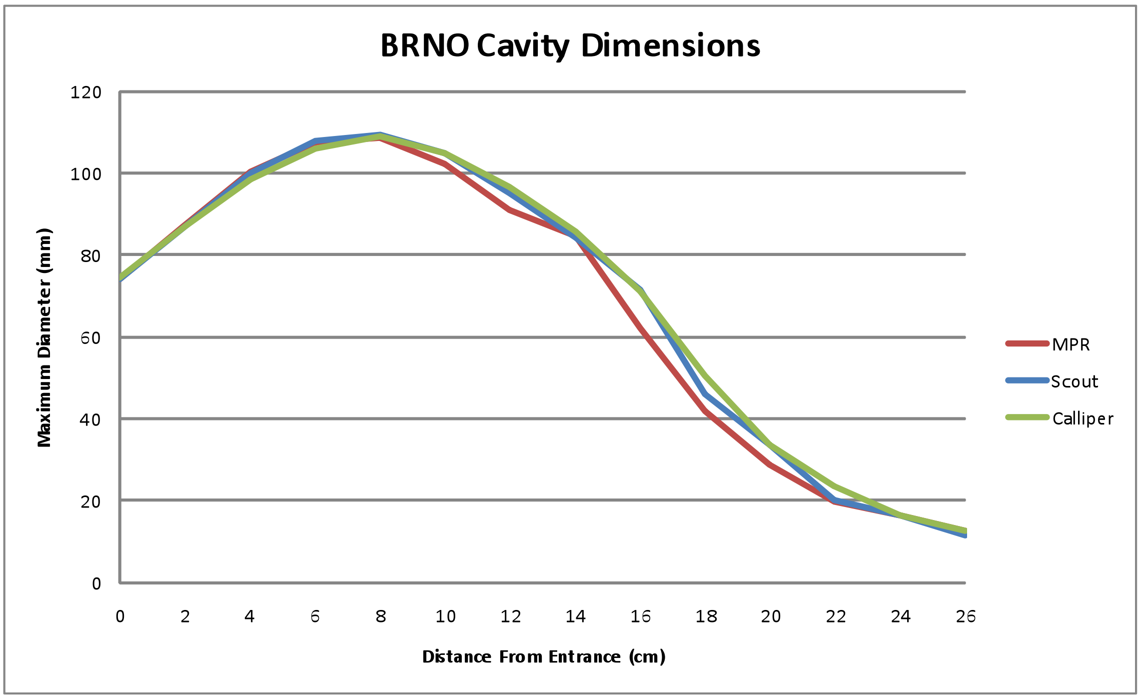
Difficulties in identifying some features such deep bruising, cartilaginous injuries and discerning parenchymal wound tracks may always limit its potential to replace the forensic post-mortem examination. There are certain situations in which a non-invasive approach to non-suspicious deaths, a so-called view and scan method may be appropriate. However one must be mindful of the limitations of the procedure to avoid missing homicides.

In order for its full potential to be realised, efforts now need to be focused on tackling the acknowledged short comings in particular the assessment of natural disease for example within the cardiovascular system.

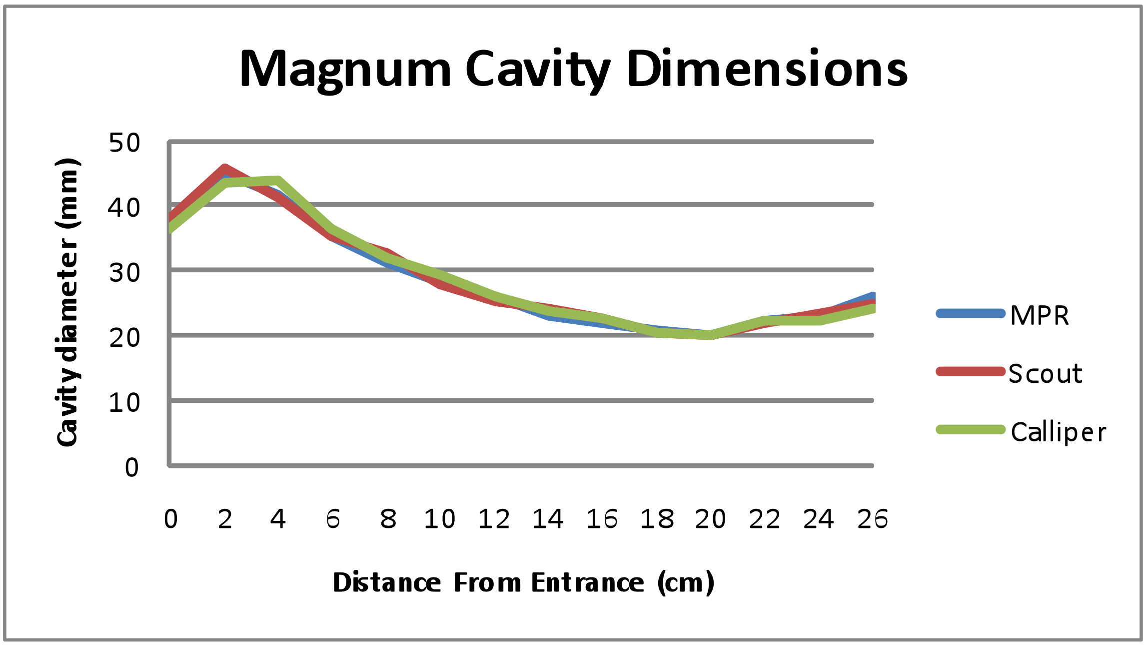
Whilst the current progress of research in this field cannot realistically support the complete replacement of the invasive post-mortem examination, one cannot ignore the ways in which this could be used to enhance current procedures. Those appraising this new mode of investigation must always remember that the current invasive techniques are not infallible. Even the most detailed invasive post-mortem examinations cannot always answer all of the questions posed by a case.

Appendices

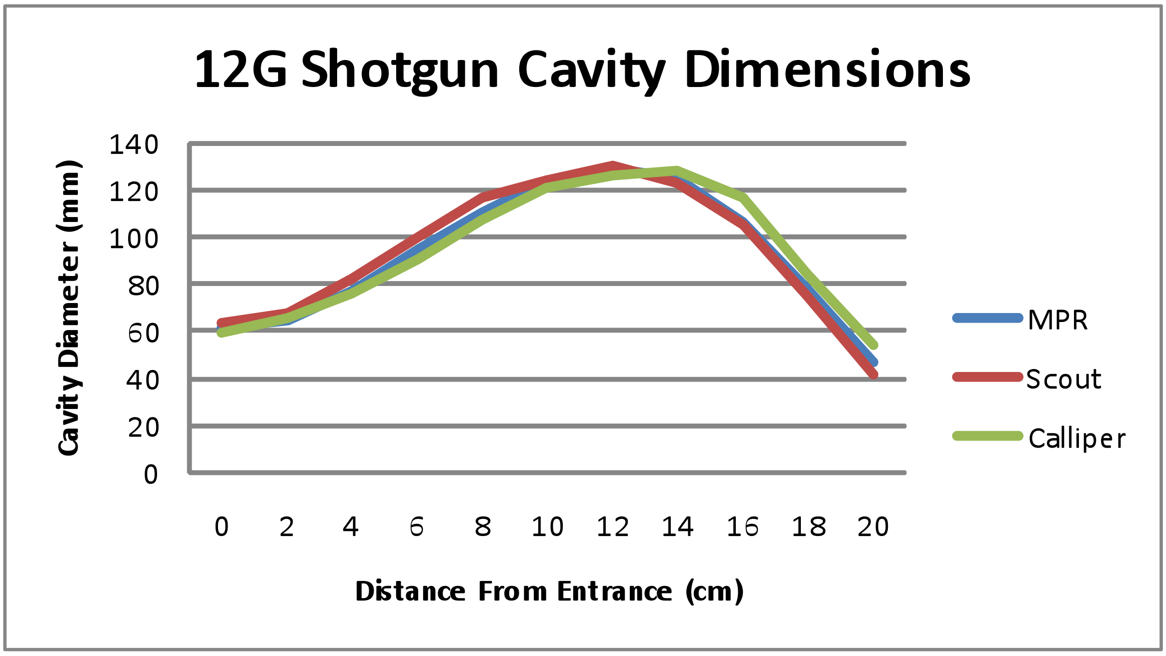
Appendix A - Terminal Ballistic Measurements



Distance from entrance (cm)	MPR CT Measurement (mm)	Scout CT Measurement (mm)	Calliper Measurement (mm)
0	74.2	74.1	74.63
2	87.2	86.9	86.92
4	100.5	99.9	98.49
6	107.5	107.9	106.00
8	108.7	109.5	108.96
10	102.1	105.0	104.76
12	91.1	95.2	96.45
14	84.8	84.4	85.90
16	62.2	71.4	71.15
18	41.8	46	50.38
20	28.6	33.6	33.60
22	19.6	20.0	23.45
24	16.5	16.5	16.30
26	12.5	11.5	12.83



Distance from entrance (cm)	MPR CT Measurement (mm)	Scout CT Measurement (mm)	Calliper Measurement (mm)
0	36.5	37.8	36.40
2	44.9	45.9	43.44
4	41.8	41.3	43.73
6	35.2	35.2	36.34
8	31.2	32.6	31.99
10	28.4	28.0	29.33
12	25.9	25.1	26.01
14	23.1	24.0	23.73
16	22.1	22.5	22.54
18	20.7	20.5	20.35
20	20.2	19.9	19.92
22	22.2	22.0	22.36
24	22.9	23.4	22.27
26	26.1	24.8	24.22



Distance from entrance (cm)	MPR CT Measurement (mm)	Scout CT Measurement (mm)	Calliper Measurement (mm)
0	61.5	63.6	59.61
2	64.4	67.4	65.89
4	77.2	82.2	75.82
6	94.9	100.3	90.95
8	110.2	116.2	107.74
10	123.5	123.5	120.70
12	129.5	130.7	125.67
14	124.7	123.2	128.52
16	106.2	104.9	117.16
18	78.0	74.9	83.89
20	46.7	42.1	54.39

Appendix B – Terminal Ballistic Measurements Analysis

Measurement (mm)	MPR CT	Calliper	Difference	% Absolute Difference
	74.2	74.6	0.4	0.6
	87.2	86.9	-0.3	0.3
	100.5	98.5	-2.0	2.0
	107.5	106.0	-1.5	1.4
	108.7	109.0	0.3	0.2
	102.1	104.8	2.7	2.5
	91.1	96.5	5.4	5.5
	84.8	85.9	1.1	1.3
	62.2	71.2	9.0	12.6
	41.8	50.4	8.6	17.0
	28.6	33.6	5.0	14.9
	19.6	23.5	3.9	16.4
	16.5	16.3	-0.2	1.2
	12.5	12.8	0.3	2.6
	36.5	36.4	-0.1	0.3
	44.9	43.4	-1.5	3.4
	41.8	43.7	1.9	4.4
	35.2	36.3	1.1	3.1
	31.2	32.0	0.8	2.5
	28.4	29.3	0.9	3.2
	25.9	26.0	0.1	0.4
	23.1	23.7	0.6	2.7
	22.1	22.5	0.4	2.0
	20.7	20.4	-0.3	1.7
	20.2	19.9	-0.3	1.4
	22.2	22.4	0.2	0.7
	22.9	22.3	-0.6	2.8
	26.1	24.2	-1.9	7.8
	61.5	59.6	-1.9	3.2
	64.4	65.9	1.5	2.3
	77.2	75.8	-1.4	1.8
	94.9	91.0	-4.0	4.3
	110.2	107.7	-2.5	2.3
	123.5	120.7	-2.8	2.3
	129.5	125.7	-3.8	3.0
	124.7	128.5	3.8	3.0
	106.2	117.2	11.0	9.4
	78.0	83.9	5.9	7.0
	46.7	54.4	7.7	14.1
Correlation Coefficient 'r' to MPR CT		0.995	0.38	-0.09
95% CI of 'r'		0.99 to 0.997	0.07 to 0.6	-0.4 to 0.2
Mean difference			1.2	
Paired 't' test			0.04	

Measurement (mm)	Scout CT	Calliper	Difference	% Absolute Difference
	74.1	74.6	0.5	0.7
	86.9	86.9	0.0	0.0
	99.9	98.5	-1.4	1.4
	107.9	106.0	-1.9	1.8
	109.5	109.0	-0.5	0.5
	105.0	104.8	-0.2	0.2
	95.2	96.5	1.3	1.3
	84.4	85.9	1.5	1.7
	71.4	71.2	-0.3	0.4
	46.0	50.4	4.4	8.7
	33.6	33.6	0.0	0.0
	20.0	23.5	3.5	14.7
	16.5	16.3	-0.2	1.2
	11.5	12.8	1.3	10.4
	37.8	36.4	-1.4	3.8
	45.9	43.4	-2.5	5.7
	41.3	43.7	2.4	5.6
	35.2	36.3	1.1	3.1
	32.6	32.0	-0.6	1.9
	28.0	29.3	1.3	4.5
	25.1	26.0	0.9	3.5
	24.0	23.7	-0.3	1.1
	22.5	22.5	0.0	0.2
	20.5	20.4	-0.1	0.7
	19.9	19.9	0.0	0.1
	22.0	22.4	0.4	1.6
	23.4	22.3	-1.1	5.1
	24.8	24.2	-0.6	2.4
	63.6	59.6	-4.0	6.7
	67.4	65.9	-1.5	2.3
	82.2	75.8	-6.4	8.4
	100.3	91.0	-9.3	10.3
	116.2	107.7	-8.5	7.9
	123.5	120.7	-2.8	2.3
	130.7	125.7	-5.0	4.0
	123.2	128.5	5.3	4.1
	104.9	117.2	12.3	10.5
	74.9	83.9	9.0	10.7
	42.1	54.4	12.3	22.6
Correlation Coefficient 'r' to scout measurement		0.993	0.43	0.002
95% CI of 'r'			0.13 to 0.7	-0.3 to 0.3
Mean difference			0.2	
Paired 't' test			0.75	

Measurement (mm)	MPR CT	Scout CT	Difference	% Absolute Difference
	74.2	74.1	-0.1	0.1
	87.2	86.9	-0.3	0.3
	100.5	99.9	-0.6	0.6
	107.5	107.9	0.4	0.4
	108.7	109.5	0.8	0.7
	102.1	105.0	2.9	2.8
	91.1	95.2	4.1	4.3
	84.8	84.4	-0.4	0.5
	62.2	71.4	9.2	12.9
	41.8	46.0	4.2	9.1
	28.6	33.6	5.0	14.9
	19.6	20.0	0.4	2.0
	16.5	16.5	0.0	0.0
	12.5	11.5	-1.0	8.7
	36.5	37.8	1.3	3.4
	44.9	45.9	1.0	2.2
	41.8	41.3	-0.5	1.2
	35.2	35.2	0.0	0.0
	31.2	32.6	1.4	4.3
	28.4	28.0	-0.4	1.4
	25.9	25.1	-0.8	3.2
	23.1	24.0	0.9	3.7
	22.1	22.5	0.4	1.8
	20.7	20.5	-0.2	1.0
	20.2	19.9	-0.3	1.5
	22.2	22.0	-0.2	0.9
	22.9	23.4	0.5	2.1
	26.1	24.8	-1.3	5.2
	61.5	63.6	2.1	3.3
	64.4	67.4	3.0	4.5
	77.2	82.2	5.0	6.1
	94.9	100.3	5.4	5.4
	110.2	116.2	6.0	5.2
	123.5	123.5	0.0	0.0
	129.5	130.7	1.2	0.9
	124.7	123.2	-1.5	1.2
	106.2	104.9	-1.3	1.2
	78.0	74.9	-3.1	4.1
	46.7	42.1	-4.6	10.9
Correlation Coefficient 'r'		0.998	0.25	-0.18
95% CI of 'r'			.-0.07 to 0.5	.-0.5 to 0.15
Mean difference			1.0	
Paired 't' test			0.02	

Measurement (mm)	MPR CT	Calliper	MPR CT %	Calliper %	Variance
	74.2	74.6	99.4	100	0.5
	87.2	86.9	100.3	100	0.1
	100.5	98.5	102.0	100	2.1
	107.5	106.0	101.4	100	1.0
	108.7	109.0	99.8	100	0.0
	102.1	104.8	97.5	100	3.2
	91.1	96.5	94.5	100	15.4
	84.8	85.9	98.7	100	0.8
	62.2	71.2	87.4	100	79.1
	41.8	50.4	83.0	100	145.0
	28.6	33.6	85.1	100	110.7
	19.6	23.5	83.6	100	134.8
	16.5	16.3	101.2	100	0.8
	12.5	12.8	97.4	100	3.3
	36.5	36.4	100.3	100	0.0
	44.9	43.4	103.4	100	5.6
	41.8	43.7	95.6	100	9.7
	35.2	36.3	96.9	100	4.9
	31.2	32.0	97.5	100	3.0
	28.4	29.3	96.8	100	5.0
	25.9	26.0	99.6	100	0.1
	23.1	23.7	97.3	100	3.5
	22.1	22.5	98.0	100	1.9
	20.7	20.4	101.7	100	1.5
	20.2	19.9	101.4	100	1.0
	22.2	22.4	99.3	100	0.3
	22.9	22.3	102.8	100	4.0
	26.1	24.2	107.8	100	30.1
	61.5	59.6	103.2	100	5.0
	64.4	65.9	97.7	100	2.6
	77.2	75.8	101.8	100	1.7
	94.9	91.0	104.3	100	9.4
	110.2	107.7	102.3	100	2.6
	123.5	120.7	102.3	100	2.7
	129.5	125.7	103.0	100	4.6
	124.7	128.5	97.0	100	4.4
	106.2	117.2	90.6	100	43.8
	78.0	83.9	93.0	100	24.6
	46.7	54.4	85.9	100	100.0
Within subject SD					4.4
Repeatability					12.3

Measurement (mm)	Scout CT	Calliper	Scout CT %	Calliper %	Variance
	74.1	74.6	99.3	100	0.3
	86.9	86.9	100.0	100	0.0
	99.9	98.5	101.4	100	1.0
	107.9	106.0	101.8	100	1.6
	109.5	109.0	100.5	100	0.1
	105.0	104.8	100.2	100	0.0
	95.2	96.5	98.7	100	0.8
	84.4	85.9	98.3	100	1.5
	71.4	71.2	100.4	100	0.1
	46.0	50.4	91.3	100	37.8
	33.6	33.6	100.0	100	0.0
	20.0	23.5	85.3	100	108.2
	16.5	16.3	101.2	100	0.8
	11.5	12.8	89.6	100	53.7
	37.8	36.4	103.8	100	7.4
	45.9	43.4	105.7	100	16.0
	41.3	43.7	94.4	100	15.4
	35.2	36.3	96.9	100	4.9
	32.6	32.0	101.9	100	1.8
	28.0	29.3	95.5	100	10.3
	25.1	26.0	96.5	100	6.1
	24.0	23.7	101.1	100	0.6
	22.5	22.5	99.8	100	0.0
	20.5	20.4	100.7	100	0.3
	19.9	19.9	99.9	100	0.0
	22.0	22.4	98.4	100	1.3
	23.4	22.3	105.1	100	12.9
	24.8	24.2	102.4	100	2.9
	63.6	59.6	106.7	100	22.4
	67.4	65.9	102.3	100	2.6
	82.2	75.8	108.4	100	35.4
	100.3	91.0	110.3	100	52.8
	116.2	107.7	107.9	100	30.8
	123.5	120.7	102.3	100	2.7
	130.7	125.7	104.0	100	8.0
	123.2	128.5	95.9	100	8.6
	104.9	117.2	89.5	100	54.8
	74.9	83.9	89.3	100	57.4
	42.1	54.4	77.4	100	255.3
Within subject SD					4.6
Repeatability					12.7

Measurement (mm)	MPR CT	Scout CT	MPR CT %	Scout CT %	Variance
	74.2	74.1	100.1	100	0.0
	87.2	86.9	100.3	100	0.1
	100.5	99.9	100.6	100	0.2
	107.5	107.9	99.6	100	0.1
	108.7	109.5	99.3	100	0.3
	102.1	105.0	97.2	100	3.8
	91.1	95.2	95.7	100	9.3
	84.8	84.4	100.5	100	0.1
	62.2	71.4	87.1	100	83.0
	41.8	46.0	90.9	100	41.7
	28.6	33.6	85.1	100	110.7
	19.6	20.0	98.0	100	2.0
	16.5	16.5	100.0	100	0.0
	12.5	11.5	108.7	100	37.8
	36.5	37.8	96.6	100	5.9
	44.9	45.9	97.8	100	2.4
	41.8	41.3	101.2	100	0.7
	35.2	35.2	100.0	100	0.0
	31.2	32.6	95.7	100	9.2
	28.4	28.0	101.4	100	1.0
	25.9	25.1	103.2	100	5.1
	23.1	24.0	96.3	100	7.0
	22.1	22.5	98.2	100	1.6
	20.7	20.5	101.0	100	0.5
	20.2	19.9	101.5	100	1.1
	22.2	22.0	100.9	100	0.4
	22.9	23.4	97.9	100	2.3
	26.1	24.8	105.2	100	13.7
	61.5	63.6	96.7	100	5.5
	64.4	67.4	95.5	100	9.9
	77.2	82.2	93.9	100	18.5
	94.9	100.3	94.6	100	14.5
	110.2	116.2	94.8	100	13.3
	123.5	123.5	100.0	100	0.0
	129.5	130.7	99.1	100	0.4
	124.7	123.2	101.2	100	0.7
	106.2	104.9	101.2	100	0.8
	78.0	74.9	104.1	100	8.6
	46.7	42.1	110.9	100	59.7

Within subject SD 3.5

Repeatability 9.6

Appendix C - Weapons used in Animal Study

Weapon	Ammunition
Bows/Crossbows	
Oakwood crossbow, draw weight 250lb	Peregrine take down bow, target point arrow
Barnet commando crossbow, draw weight 175lb	Laminated long bow, target point arrow
Peregrine take-down bow (Quicks), draw weight 45lb	Yew long bow, bullet head arrow
Oregon Yew long bow, draw weight 65lb	Oakwood crossbow, aluminum crossbow bolt
	Commando crossbow, aluminum crossbow bolt
Air weapons	
Break action .22" air rifle	.22 Prometheus air weapon
	.22 roundnose air weapon
	.22 Logun (first shot bounced off) air weapon
Shotguns	
12 gauge shotgun, (Baikal) (Over & Under)	12 gauge Number 6
Sawn-off 12 gauge shotgun	12 gauge Number 8
	12 gauge Hatton
	12 gauge, SG
	12 gauge, AAA
	12 gauge, BB
Hand guns and rifles	
FN FAL 7.62 x 51mm	Converted 8mm blank, 6mm steel ball bearing
AR15 .223" (armalite)	Forward venting blank firer with SG shot

SA80 5.56mm

Brno rifle .22 LR

AKM 7.62 x 51mm

H&K 33 7.62 x 51mm

FAMAS .223”

Glock 17, 9mmP

Converted Bruni ME8, 8mm blank

Smith & Wesson model 66, .357 magnum

Brocock revolver .22”

ME38 converted 8mm blank]

H&K 4, 7.65mm + 6.35mm

H&K P7, 9mmP

Starr pistol .22LR

Kimar model 85, 9mm blank

Converted Valtro 9mm blank

Converted 9mm blank with lead projectile 9mm

6.35 mm (S + B)

.22” short

.22LR roundnose

.22LR hollowpoint

7.65 mm (exited)

9mm (S + B) – head shot

9mm (S + B) (exited)

9mm hydroshock (exited)

9mm THV

9mm softpoint

9mm 2Z

9mmP military (exited)

SA80, SS109

AR15, Remington 223”

AKM, 7.62 x 39mm

FN FAL, 7.62 x 51mm

.38 Smith & Weston

.38 Special Smith & Weston

.357 Magnum (exited)

.357 Magnum lead (exited)

.357 Magnum hollowpoint

.38 special glazer safety slug

38 special shot shell

Other

Taser

Appendix D – Correlation of CT findings with Firearm Discharges

<u>Animal 1 – Canine</u>

Discharge	Firearm	Ammunition	Site Shot	Track and Damage Caused	Projectile	Comment
1	SA80	SS109	Left side of Head	Entrance to left frontal region of skull Left to right direction Brain cavitation up to 6cm in width Fractures to right facial bones, mandible and skull Exit not identified	Not identified	Exit wound obscured by hair. Exit wound would have been identified and correctly linked to the entrance if external examination details or photographs were made available to the radiologist.
2	SA80	SS109	Left Shoulder	Entrance to left shoulder Left to right direction Passing through Left scapula, posterior spine, right scapula Exit in region of right shoulder 6cm in diameter	Not identified	
3	AR15	Remington 223”	Left Shoulder	Skin wound identified to left upper chest Left towards midline Collapse of left lung No exit wound	Present within left lung	

Discharge	Firearm	Ammunition	Site Shot	Track and Damage Caused	Projectile	Comment
4	AKM	7.62 x 39mm	Left lower chest/Abdo	Skin wound to left chest No distinct track identified Exit wound not identified	Not identified	The large areas of cavitation caused by other discharges had obscured the wound track. Ballistics officer confirmed exit of the projectile. Exit wound obscured by hair. External examination details or photographs would have assisted
5	FN FAL	7.62 x 51mm	Left Hip	Two skin wounds identified. One to the left pelvic region. One over the left hip. Both left to right direction. Gross disruption of the bone of the femur and left pelvis with multiple free bone fragments in the pelvic region. No exits identified.	Not Identified	Following discussion with the ballistics officer it became apparent that the two shots were fired in quick succession into the same area thus there may not have been two distinct tracks Ballistics officer confirmed exit of projectile. Exit wounds obscured by hair. External examination details or photographs would have assisted.
6	FN FAL	7.62 x 51mm	Left Hip			

Animal 2 – Porcine

Discharge	Weapon	Projectile	Site of Shot	Details		Tip Shape/ Projectile	Comments
				Direction	**Position of tip/projectile**		
1	Peregrine take down bow	Target point arrow	Left shoulder	Entered anterolateral left chest Left to right direction, 30^{o} anterior to posterio, slightly downwards	Lodged in aorta		In the arrow cases, the ballistics officer was able to identify the arrow type based on the shapes drawn by the radiologist.
2	Laminated long bow	Target point arrow	Left upper chest	Entered left upper chest. Left to right direction 30^{o} anterior to posterior, horizontal	IVC / right atrium		
3	Yew long bow	Bullet head arrow	Left chest	Entered left mid chest Left to right direction, horizontal	Medial Liver		
4	Oakwood Crossbow	Aluminium crossbow bolt	Left chest	Left lower chest Left to right direction 45^{o} anterior to posterior, horizontal	Lodged in lumbar vertebra		
5	Commando crossbow	Aluminium crossbow bolt	Left Abdomen	Left abdomen Left to right V. slightly anterior to posterior, horizontal	Just anterior to right psoas muscle		

Discharge	**Weapon**	**Projectile**	**Site of Shot**	**Details**		**Tip Shape/ Projectile**	**Comments**
				Direction	**Position of tip/projectile**		
6	AKM	7.62 x 39mm S&B	Head	Entrance wound to vertex of skull The projectile had passed through foramen magnum fracturing C1 & C2, right larynx, passing through right lung and sternum	Present in the subcutaneous fat of the anterior right chest	8.9mm x 18mm metal projectile	Clear path due to absence of intersecting discharges. Clear entrance wound due to lack of hair.
7	12 g shotgun	SG shot	Upper right side	2cm entry wound right shoulder	47^{o} spread from entrance throughout soft tissue	9 pieces minimum diameter of 9mm	In the shotgun cases, the size and number of shot pieces were consistent with the ammunition used. Clear entrance wounds due to absence of hair.
8	12 g shotgun	AAA Shot	Mid right side	2cm entry wound right chest	35^{o} spread from entrance	31 pieces minimum diameter of 5.6mm	
9	12 g shotgun	BB shot	Lower right side	1.6cm entry wound right flank	50^{o} spread from entrance	>50 pieces Minimum diameter of 4mm	

Animal 3 – Porcine

Discharge	Weapon /Ammunition	Site	Entrance	Direction	Depth / cavity	Projectile	Damage	Comments
1	.22 Prometheus air weapon	Left posterior shoulder area	Left shoulder	Left to right	Just beneath skin	11mm	Superficial	
2	.22 roundnose air weapon		Small entrance left neck	Left to right, Anterior to posterior, 30^{o}, horizontal	5cm track	11mm	Soft tissue only	
3	.22 Logun air weapon		-	-	-	-	-	This projectile could not be accounted for. The ballistics officer indicated that he would not expect significant penetration and that it may have fallen from the body when it was moved.
4	Converted 8mm blank, 6mm steel ball bearing	Posterior left side	Not seen	Entrance & track not clear	3.4cm depth	7mm	-	The entrance wound could not be identified, possibly due to the small size of projectile
5	Forward venting blank firer with SG shot		Left chest 8.2mm	Left to right, slightly posterior to anterior, horizontal	Expansion to 14mm cavity after striking a rib	Fragments under skin on right over 17mm	Travels through peritoneum and liver fracturing right ribcage	
6	Converted 9mm blank with lead projectile 9mm		Left flank	-	-	18mm	Stopped by right rib	

Discharge	Weapon /Ammunition	Site	Entrance	Direction	Depth / cavity	Projectile	Damage	Comments
7	6.35mm (S&B)		Left pelvis	Left to right, Anterior to posterior, upwards	-	13mm	Embedded in left psoas	
8	.22 short		Left chest 5.5mm	Left to right, slightly down, slightly anterior to posterior	Traverses body (26cm) cavity up to 8mm in width	Exited	Travels through liver and fractures left ribcage. Exit measures 14mm Additional fracture to left ribcage not clearly associated with distinct track	These wound tracks coalesced so that it was not possible to differentiate the three tracks.
9	.22LR round nose							
10	.22LR hollow nose							
11	7.65mm	Left side	Left lower chest	Left to right	Traverses body	Exited	-	
12	9mm (S&B)		Anterior head	Anterior to posterior, downwards	-	?exited projectile present in anterior chest wall.	-	Path difficult to differentiate from discharge 17.
13	9mm (S&B)		Left flank	-	Traverses body	Debris in peritoneum ? exited		Initially believed to have exited but informed by ballistics officer that these forms of ammunition would fragment thus accounting for the debris seen.
14	9mm hydroshock		Left flank	-	Traverses body	Debris in peritoneum ? exited		

Discharge	Weapon /Ammunition	Site	Entrance	Direction	Depth / cavity	Projectile	Damage	Comments
15	9mm THV	Left hip area	Not identified	Left to right	-	15mm	#left femur with bullet in peritoneum/pelvis. Conical projectile	Unique shape of projectile clearly visible on CT images
16	9mm soft point		Not identified	Left to right	-	19mm frag	# left femur with bullet frags in perineum	
17	9mm 2Z	Base left side of neck	Left shoulder / base of neck	Left to right A-P Horizontal	-	Not definitely identified	Travels through left & right 1^{st} rib damaging lungs & great vessels. Track then unclear. It may deviate to PA course leaving projectile under skin anterior R chest but that may be associated with different wound track	This was a further example of how intersecting wound tracks complicate assessment.
18	9mmP military	Left upper limb	Left lateral chest 6mmm	Left to right Slightly down Straight	16mm cavity after 14cm	Not definitely identified	Travels straight through lung and heart and may exit or remain under skin of anterior right chest	This was a further example of how intersecting wound tracks complicate assessment.
19	Taser	Left shoulder	L Shoulder tip	N/A	<10mm	2x ?arrow tips	Superficial subcutaneous tissue only	

Animal 4 – Porcine

Discharge	Weapon / Ammunition	Site	Track & Damage	Projectile	Comments
1	.38 Smith & Weson	Left shoulder	Not identified.	Not identified	Believed to have been masked by shotgun ammunition of discharge 8. Further review revealed 1.5cm metal fragment in spine T1/T2
2	.38 Special Smith & Weson	Left chest	Enters posterolateral left chest Left to right direction Passes through posterior vertebral processes.	10mm metal projectile lodged in right flank	
3	.357 Magnum	Left chest	Enters posterolateral left chest Left to right direction Strikes anterior vertebra Exit not identified.	Not identified Exited	The ballistics officer confirmed that this projectile had exited the body despite the difficulty identifying an exit wound.
4	.357 Magnum lead	Left chest	Enters left chest – entrance wound 9mm diameter Left to right direction Traverses body fracturing right ribcage Marked widening of cavity 2cm in Discrete exit wound right chest, 2cm diameter.	Exited	
5	.357 Mangum hollow point	Left chest/abdomen	Very small entrance lower left chest with superficial 23mm cavity beneath skin in association with projectile.	13mm x 24mm metal fragment in subcutaneous tissue	

Discharge	Weapon / Ammunition	Site	Track & Damage	Projectile	Comments
6	.38 special glazer safety slug	Left Abdomen	Entrance to left abdomen, 9mm in diameter. Widens immediately in association with shot pieces.	>30 pieces of shot each approx 3mm in a discrete group travelling less than 10cm.	
7	.38 special shot shell	Left pelvis	Entrance to left pelvic region, 9mm in diameter.	As for 6 but less penetration.	
8	12 g Number 6 shot	Left front leg	3cm entrance to base left neck cavitates widely after 2cm causing gross disruption.	>100 shot Spread = 76^{o}	
9	12 g Number 8 shot	Left hip area	Enters left hip area.	>100 pieces of shot spread over 10cm diameter.	
10	12 g Hatton	Anterolateral left Abdomen	Enters anterolateral left abdomen	Multiple variable sizes of shot Large opacity in right subcutaneous area ?mass of >100 shot.	
11	.38 Special Smith & Weson	Forehead	Entrance in top of skull passing through left larynx.	? Small bullet in left anterior neck or lost in shot.	

Human Cases

Case	Entrance	Direction	Damage caused	Projectile(s)	Exit	Comments
1	14mm right petrous temporal bone Internal beveling	Right to left and slightly upwards	Extensive fracturing to the cranial vault, skull base and upper facial bones. There was resulting pneumocephaly and blood in the ventricular system	Absent Bone fragments seen traversing the track	20mm right temporo-parietal region External bevelling	Able to show beveling and degree of intra-cerebral damage
2	Right occipto-parietal area	From back – front & right to left	Depressed fracture of occiput just to the left of the midline. Fractured left parietoccipital region. Fractured base of occiput. Fractured base of skull through left jugular foramen. Haematoma to soft tissues of right face and posterior scalp Air in anterior cranial vault Subdural & subarachnoid haemorrhage Posterior contusions	Main focus of pellets present in the right occipitoparietal region Small number of pellets present to the right facial soft tissues One pellet present inside left petrous bone ?? pellet in region of right jugular foramen	N/A	

Case	Entrance	Direction	Damage caused	Projectile(s)	Exit	Comments
3	Differential = left face or palate	Unclear	Large defect to bones of left face Evidence of natural disease: Bilateral pleural effusions cavitating lesions throughout both lungs suggestive of metastatic tumour.	Numerous (20+) pellets throughout the cranial vault predominantly on the right	N/A	The determination of entrance wound would have been greatly assisted by access to external findings/photographs. An occipital tumour described at post-mortem was not identified despite review.

Appendix E – ACPO forms

☐ Number of VPF15's attached

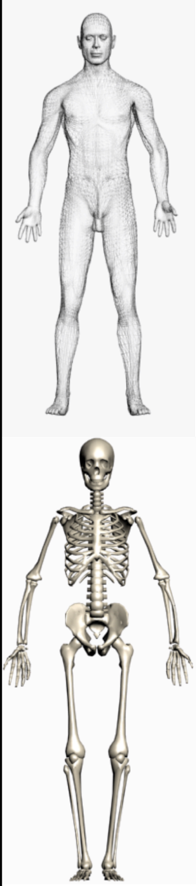
LABEL

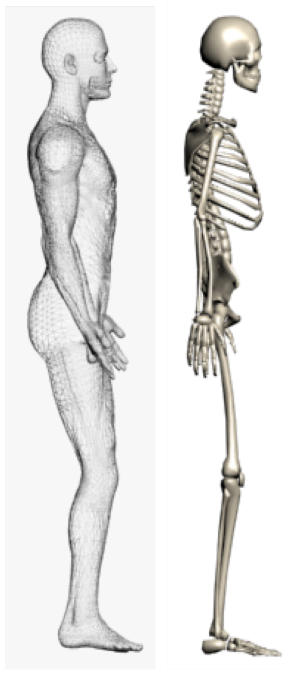
VICTIM PROFILE FORM **
COMPUTED TOMOGRAPHY FINDINGS – Whole Body

Male/ Female/unknown *(delete as appropriate)*

BODY NUMBER							**A or B**

Radiographer________________





Legend
- ■ Missing body Parts
- ▒ Fractures
- ◉ Projectiles
- △ Sharps

Comments *(include details of hazardous objects/sharps and personal effects where appropriate)*

____

Films printed Yes ☐ No ☐

If yes, films released to ______________________

Images archived to CD Yes ☐ No ☐

Images sent digitally to ______________________

Dental scan done Yes ☐ No ☐

Operator completing this page *(signature)*______________________________

Name *(in capitals)* ______________________ ***GMC No:***______________________

Time completed ______________________ **Date completed** ______________________

☐	Number of VPF15's attached

LABEL

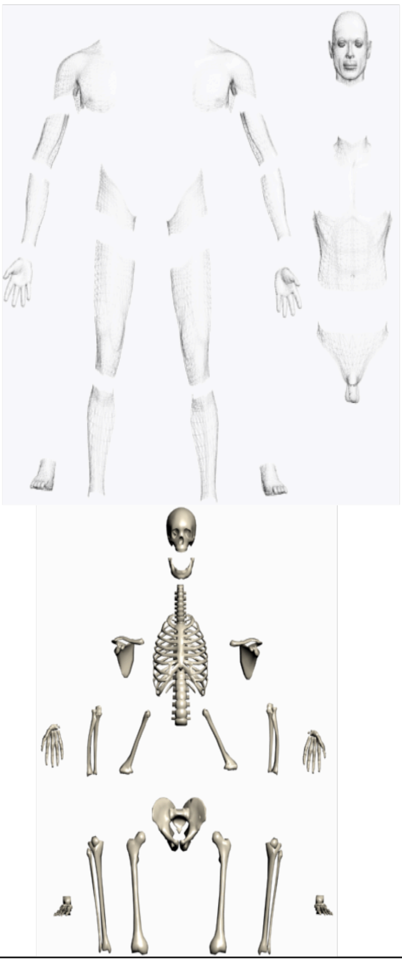
VICTIM PROFILE FORM **
COMPUTED TOMOGRAPHY FINDINGS – Body Parts

Male/ Female/unknown *(delete as appropriate)*

Page _____ of ______

BODY NUMBER							A or B

Radiographer ____________________



Legend

Missing body parts

Fractures

Projectiles

Sharps

Comments *(include details of hazardous objects/ sharps and personal effects where appropriate)*

Films printed Yes ☐ No ☐

If yes, films released to ____________________

Images archived to CD Yes ☐ No ☐

Images sent digitally to ____________________

Dental scan done Yes ☐ No ☐

Operator completing this page *(signature)*____________________

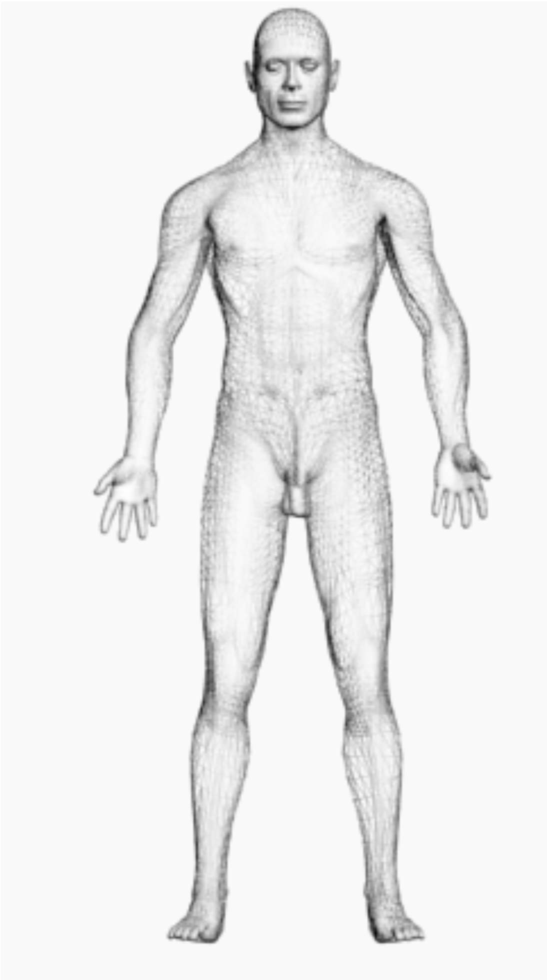
Name *(in capitals)* ____________________ ***GMC No:*** ____________________

Time completed ____________________ **Date completed** ____________________

Appendix F – PMCT Reporting form

FORENSIC CT REPORTING FORM

GENERAL



Gender Female / Male
Femur length
……………………………………………………....................
Humerus length ……………………………………………………....................
Subcutaneous fat
Congestion / Oedema Present / Absent
Details ……………………………………………………....................
…......................……………………………………………………………………….....
....
Surgical Emphysema Present / Absent
Details……………………………………………………………...….......................
………………………………………………………………………………………….................
....

Fat thickness / Flank

……………………………………………………..............................

Skull thickness

Frontal:………………………………………………………………………………

Temporal:…………………………………………………………………………..

Occipital………………………………………………………………………………

MUSCULO-SKELETAL SYSTEM

	Intact (Yes or No)	Details
Spine		
Skull		
Facial Bones		

Axial Skeleton Inc sternum		
Appendicular Skeleton		

PROJECTILES / FOREIGN BODIES

Number			
Details	1	2	3
Size			
Site / position			
Entrance and exit			
Direction of travel			
Details of Damage caused			

NECK AND CHEST

Pleural Cavities
Adhesions Present / Absent
Details ……………………………………………………..
Effusions Present / Absent
If present, Size ……………………………………………………..
CT No ……………………………………………………..
Diaphragmatic Integrity Intact / Breached
Hyoid bone integrity ……………………………………………………..
Laryngeal cartilages & pharynx……………………………………………………..
……………………………………………………..
Cervical muscles haematoma present / absent
Carotid arteries haematoma present / absent

Major Airways Open / crushed
Contents Clear / Fluid / Foreign body
Details ………………………………………………….
Lungs
Natural Disease Present / Absent
Details ………………………………………………….
Contusion Present / Absent
Details ………………………………………………….
Other comments ………………………………………………….

CARDIOVASCULAR SYSTEM

Pericardial Fluid Present / Absent
Details ………………………………………………….
Heart size / Ventricular thickness ………………………………………………….
Coronary arteries - calcium scale ………………………………………………….
Aorta Open / collapsed
Maximum diameter - Thoracic ………………………………………………….
- Abdominal ………………………………………………….
Integrity ………………………………………………….
Calcification ………………………………………………….
Vena cava - Diameter ………………………………………………….

ABDOMEN AND PELVIS

Peritoneal Cavity Dry / Fluid present
If present, size ………………………………………………….
Tongue ………………………………………………….
Oesophagus ………………………………………………….
Stomach ………………………………………………….
Contents ………………………………………………….
Small Intestines ………………………………………………….
Appendix ………………………………………………….
Large intestines ………………………………………………….
Rectum ………………………………………………….
Anus ………………………………………………….
Liver ………………………………………………….
Gall bladder ………………………………………………….
Common bile duct ………………………………………………….
Pancreas ………………………………………………....
Spleen ………………………………………………….
Lymph nodes ………………………………………………….
Kidneys ………………………………………………….
Bladder ………………………………………………….
Prostate / Uterus ………………………………………………….
Testes / Ovaries ………………………………………………….

ENDOCRINE

Thyroid …………………………………………………
Adrenals …………………………………………………
Pituitary & Pituitary fossa …………………………………………………

CNS

Intracranial vessels calcification ………………………………………………….
Meninges Haematoma present / absent
Details ……………………………………………........
Brain ………………………………………………….
Middle ears ………………………………………………….
Spinal Cord
Spinal canal integrity ………………………………………………….
Cord integrity ………………………………………………….

PERSONAL EFFECTS

…………………………………………………………………………………………………
…………………………………………………………………………………………………
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…………………………………………………………………………………………………
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SUMMARY

Natural Disease Present
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………

Other Observations
…………………………………………………………………………………………………
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Predicted Cause of Death From CT findings
Ia
Ib

II

Appendix G – Mass Fatalities: Correlation of CT and PM Findings

Body / Body Part	CT & PM Agreement	Found on CT but not PM	Found on PM but not CT (despite review)	Found on PM and on CT review
Leg 1	Compound fracture, Major skin lacerations Foreign bodies in wound	None	None	N/A
Leg 2	Compound fracture foreign body within wound	None	None	
Body 1	Gender Surgical emphysema Some skin lacerations Pleural effusions		Abrasions Atrial tear (only collapse seen) Oesophageal tear Bleeding in region of coronary Artery	Tracheal tear (step-like area) Some Skin lacerations Clavicle fracture T2 and C4 fractures (re-reviewed at 2.5mm)
Body 2	Gender One skull fracture Mandible fracture Trimalleolar fracture Rib fracture Sternal fracture Pleural effusions Subarachnoid Haemorrhage. Pulmonary contusions	Cerebellar contusions Sulci indistinct (raised ICP) Cerebral oedema Scapular fracture	Bilateral Laryngeal cartilage # Abrasions	Pen (foreign body) Tear to ventricle causing Haemothorax Hyoid fracture One skull fracture Sternal fracture Trauma to thyroid

Body / Body Part	CT & PM Agreement	Found on CT but not PM	Found on PM but not CT (despite review)	Found on PM and on CT review
Body 3	Gender Pulmonary contusions Blood in airways Subarachnoid Haemorrhage	Maxillary and nasal fractures Right temporal fracture Left Parietal oedema and evidence of raised intracranial pressure	Rib fracture (non displaced) Splenic trauma (believed due to bowel artefact) Aortic transection (In CT aorta noted to be collapsed with fluid in mediastinum. Tear not seen) Pulmonary valve trauma not seen. Abrasions Left wrist # (outside area scanned) Liver lacerations	Midline mandibular fracture 200ml of Blood (found in the region of the spleen on review of images)
Body 4	Gender Surgical emphysema Skull # Spinal # Facial # SAH Pulmonary contusions Splenic and renal trauma Pelvic trauma haematoma thigh & flank	C2/3 # Hyoid fracture Air in cranial cavity and Blood in the ventricles.	Abrasions Bleeding around atria Degloving injury (not adequately scanned)	Laryngeal # recorded as supra-glottic trauma
Body 5	Gender Thyroid trauma All #s identified Laryngeal cartilage Disruptionliver, splenic & renal trauma	Pleural effusions not mentioned at PM Bullae in lung Posterior stable C spine #s Pubic rami # & Acetabular # Small pneumothoraces	Pulmonary valve trauma not seen Diaphragm tears (ragged but intact on CT) Cardiac laceration Small renal laceration	Penile laceration

Appendix H – Non-invasive PM Report Evaluation Form

NON-INVASIVE POST-MORTEM REPORT EVALUATION

Case Number (circle) 1 2 3 4 5 6 7

Your Role (tick):

- Coroner ☐
- Judge ☐
- Police ☐
- Crown Prosecution Service ☐
- Barrister ☐
- Solicitor ☐

1. Some procedures have been omitted as they would necessitate opening of the body for example histological sampling and stomach content sampling. Has the absence of this information affected the value of ***this*** case?

Yes ☐ No ☐

If yes, please give reasons:

2. Are there any essential pieces of information that you deem to be missing from the report in its current format?

Yes ☐ No ☐

If yes, please give reasons:

3. Are you aware of any common legal practices or legislation that would restrict or prevent the adoption of this non-invasive approach into routine practice?

Yes ☐ No ☐

If yes, please give details:

4. Would the report in this format allow you to perform your role within the medico-legal system?

Yes ☐ No ☐ Not applicable ☐

If No, please give details:

5. To summarise, if this non-invasive approach was introduced tomorrow what advantages and disadvantages do you envisage?

<u>Advantages</u>	<u>Disadvantages</u>

Please use the box overleaf if you need additional space or have any further comments.

Your input is greatly appreciated and you may identify important issues that have not yet been considered by colleagues in other professions.

Appendix I – Forensic Cases: Correlation of CT and PM Findings

Case	Detailed on CT but not PM	Detailed on PM but not CT
1	Blood in sudural/subarachnoid space	Sooting in trachea Burning of epiglottis and vocal cords Bruising to anterior neck muscles
2	Facial #s?? Pneumothoraces not described Additional pelvic # #s to right tibia/fibula and left humerus, radius and ulnar Presence of L shoulder hemiarthroplasty	Deep bruising to neck Lung lacerations Liver cirrhosis Testicular bruising Diffuse scalp bruising Transverse vertebral # t6/7
3	Increased details regarding pelvic # # L5 transverse process	Areas of bruising to epicardium Transverse # through disc of C6/7 Lung lacerations. Sutured lacerations to liver and mesentry Cirrhosis Multiple areas of deep soft tissue bruising Sternal fracture
4	Segmented appearance of nasal bones suggesting # but not soft tissue swelling Free intra peritoneal air suggesting puncture	Determination of individual wound tracks with details of depth, direction and specific injuries attributed to each wound. Defects to the costal cartilages in association with stab wounds. Deep bruising to scalp.
5	Depressed # in frontal bone	Soot in trachea, smaller airways & stomach. Heat damage to larynx and epiglottis
6	Blood in subdural space/ subarachnoid space.	# of thyroid cartilage with surrounding haemorrhage. Deep bruising to posterior and anterior neck muscles Deep scalp bruises
7	Free air within cranium suggestive of skull fracture	Transection of L carotid artery and partial cut to vagus nerve. Depth and direction of penetrating injury. Incised injury to oesophagus Definitive nature of foreign body
8	Small amount parafalcine haemorrhage	Pericardial sutures Distinct pathways of shot pieces Penetrating injury to the aorta, pericardium, heart, IVC, liver

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