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The Role of Mobile Computed Tomography in Mass Fatality Incidents

ABSTRACT: Mobile multi-detector computed tomography (MDCT) scanners are potentially available to temporary mortuaries and can be operational within 20 min of arrival. We describe, to our knowledge, the first use of mobile MDCT for a mass fatality incident. A mobile MDCT scanner attended the disaster mortuary after a five vehicle road traffic incident. Five out of six bodies were successfully imaged by MDCT in *c.* 15 min per body. Subsequent full radiological analysis took *c.* 1 h per case. The results were compared to the autopsy examinations. We discuss the advantages and disadvantages of imaging with mobile MDCT in relation to mass fatality work, illustrating the body pathway process, and its role in the identification of the pathology, personal effects, and health and safety hazards. We propose that the adoption of a single modality of mobile MDCT could replace the current use of multiple radiological sources within a mass fatality mortuary.

KEYWORDS: forensic science, forensic radiology, mobile, computed tomography, CT, mass fatality, disaster

Within a disaster mortuary, depending upon the nature of the incident be it an environmental, medical, industrial, vehicle, or terrorist-related, there may be up to three different radiological techniques used in the investigative process. The first would be fluoroscopy, which would be used at a screening stage prior to autopsy examination, the second is plain x-ray principally used for bone examination and the third is dental x-ray (1). Thus when designing 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 of the equipment and accurate image interpretation must be considered. It is thus important to establish what information can be obtained from various imaging techniques before designing imaging procedures for use in a mass fatality environment (2).

With the gradual development and adoption of computed tomography (CT) in autopsy practice throughout the world, we like others, have considered the use of this technology locally for mass fatality investigations (3–8). The increasing availability of mobile CT scanners, which can be operational within 20 min of arriving at a site, potentially makes the use of this technology available to a temporary mortuary or even to the scene itself.

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, we have identified no previous peer-reviewed paper or Internet-based report of the use of a mobile CT scanner at a disaster/temporary mortuary following a mass fatality vehicle incident (9–12). We present our experience of the use of mobile CT under such circumstances and put forward the proposal that mobile CT could be considered by those responsible for mass fatality planning as an alternative, if not replacement, to both fluoroscopy and plain x-ray within temporary mortuaries.

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Method

Incident

In early 2006, a five vehicle road traffic incident occurred on a two-lane road at 05:00 hours resulting in six fatalities. The incident involved a medium sized lorry (one fatality), three long heavy goods vehicles (no fatalities), and a minibus (five fatalities, two 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 chief 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.

Computed Tomography

At 13:35 hours 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 20:00 hours with the scanner set up and operational by 20:35 hours i.e. a time elapse of 8.5 h 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 lightspeed plus 4 channel multi-detector CT scanner with Advantage Windows workstation. It was operated by two CT radiographers with two morticians 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 nonmortuary 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.

Scanning Process

A total of 38 body bags—six adult size body bags and 32 bags containing body parts ranging from limbs to multiple fragments of human tissue greater than 5 cm^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 three body part bags were imaged by CT. Normally all body bags, no matter what size, should be imaged. All material was subject to autopsy examination the following day (day 2) with DNA samples taken from all pieces estimated at greater than 5 cm^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 process is summarized in Fig. 1.

The first body was taken straight from the funeral vehicle and placed onto the CT trolley and then onto the CT lift accompanied by a single mortician. 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 (Fig. 2). As the diameter of the scanner orifice was 700 mm the body bag was secured around the body using tape to ensure that it passed through without difficulty. The body bag was then scanned before being removed by two 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. For complete bodies the whole process can be achieved by an experienced team in *c.* 10–15 min. Body parts can be scanned individually or as multiple bags in one session at a faster rate.

Imaging

The imaging followed the normal Leicester forensic pathology CT protocol. Thus the imaging was undertaken to consider the following questions:

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

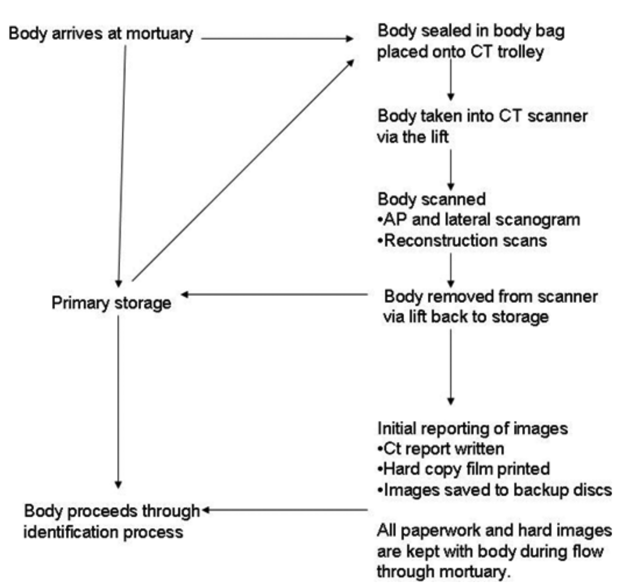

FIG. 1—*Flow diagram of the process of the use of a mobile CT scanner at a mass fatality incident.*

FIG. 2—*Both complete bodies and body fragments can be scanned without the necessity to open the body bags.*

In addition to these the following could also be considered:

- Dental identification—not specifically considered on this occasion (see Discussion).
- 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 nonanimate materials.

The body bags were first subject to head to toe "scanograms" which is a 2-D image of the body performed for all CT scans enabling localization to plan further imaging and has a similar format and appearance to a standard plain film x-ray. Imaging was performed using standard clinical settings and took *c.* 8 sec for the whole body scan. Although our normal practice is to ensure that the body is in a supine position with the head/face up at right angles to the scanner orifice, no positioning of the body occurred due to the novel circumstances under which these scans were performed. It is our normal practice, following review of the scout images, to rotate the body through 180° should the limit of the scanogram not include the full length of the body. Again due to the novel circumstances this was not undertaken on this occasion. To aid localization following the AP scanogram, a lateral scanogram was also undertaken as no movement of the body is required for this.

Whole body axial scans were then undertaken with scanning parameters 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, 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 0.625 to 10 mm. We chose a compromise of an intended reconstructed slice thickness of 2.5 mm but, due to tube heat loading factors and the novel environment, one scan was only performed and reconstructed to a 10 mm slice thickness. Full details of scan parameters are not included as standard parameters were used which vary from equipment to equipment. This is less likely to be an issue for future scans as we would normally intend to use a 16 channel multi-detector CT. For this platform the x-ray tube currents required to achieve suitable image quality at 1.25 mm slice thickness are unlikely to exceed tube loading limits. 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.

FIG. 3—*Anterior and lateral "scanograms" of a whole body generated with the mobile CT scanner illustrating bony trauma, foreign bodies, and location of personal property.*

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 (BM) and a trainee forensic pathologist (AJ). A typical report was performed by first reviewing scanograms (Fig. 3) and the axial CT images. 3-D reconstructions were then performed focusing on bone and soft tissue algorithms (Fig. 4). The radiological findings in all of the scanned cases were recorded using a newly designed forensic CT reporting form. 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 images were reviewed initially without reference to the post-mortem reports and the findings were documented ("blind

FIG. 4—*A 3D reconstruction of an amputated limb showing the degree of bony injury; Lateral "scanogram" and AP bone reconstruction (Voxar 3D; Barco, Kortrijk, Belgium). The aim of this image is to show the fracture pattern of the bones in a three-dimensional form. The artifacts such as the scanner bed can be extracted using different image settings. The metallic parts of the shoe were sculpted from the image using the Voxar software, as these are merely artifacts which obstruct the view of the underlying structures.*

review"). The final postmortem reports were then reviewed alongside the CT reports. A comparison was made and in cases of discrepancy, the CT images were revisited.

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 file. The initial data set is large and 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.

Although assessing all organ systems for potentially fatal injuries could be performed within minutes, full image review took *c.* 1 h per case due to the extensive injuries. It was possible to give accurate causes of death for all five of the whole bodies using the CT images. Large skin lacerations and significant soft tissue hematomas could be seen but superficial abrasions could not be reliably identified.

The musculoskeletal system was well represented in the CT images. In all but one case, every fracture demonstrated by autopsy was identifiable. The exception was a body reconstructed at 10 mm 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. These fractures included stable, posterior cervical vertebral, maxillary, nasal, and scapula fractures.

Imaging of the chest was able to identify a variety of traumatic sequelae (Fig. 5*a*). Pulmonary contusions were identified in all cases where present and it was possible to confirm the presence of pleural fluid collections and pneumothoraces. 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) (13).

The main area in which discrepancies were found was the mediastinum. At postmortem, three of the cases showed cardiac tears, two showed valvular damage and three showed aortic damage (tears or transactions), of which one had an associated esophageal tear. It was not possible to confidently diagnose these entities despite revisiting the images. Although aortic transection has been described previously in postmortem studies on CT in the case described the aorta was completely disassociated which was not a feature in this study (14). However, their presence could be inferred due to the presence of hemopericardia and hemothoraces. The aorta was also noted to have collapsed in three of the cases of aortic rupture/cardiac laceration which may prove to be a useful sign of death due to rapid exsanguination (15). There was therefore agreement in all cases where cardiovascular or lung trauma was a significant cause of death.

The abdomen and pelvis assessment of minor liver lacerations was compromised by the presence of intravascular air. Further more, image quality was also degraded by post-mortem gaseous distension of the bowel causing "streak" artifacts in the images. It

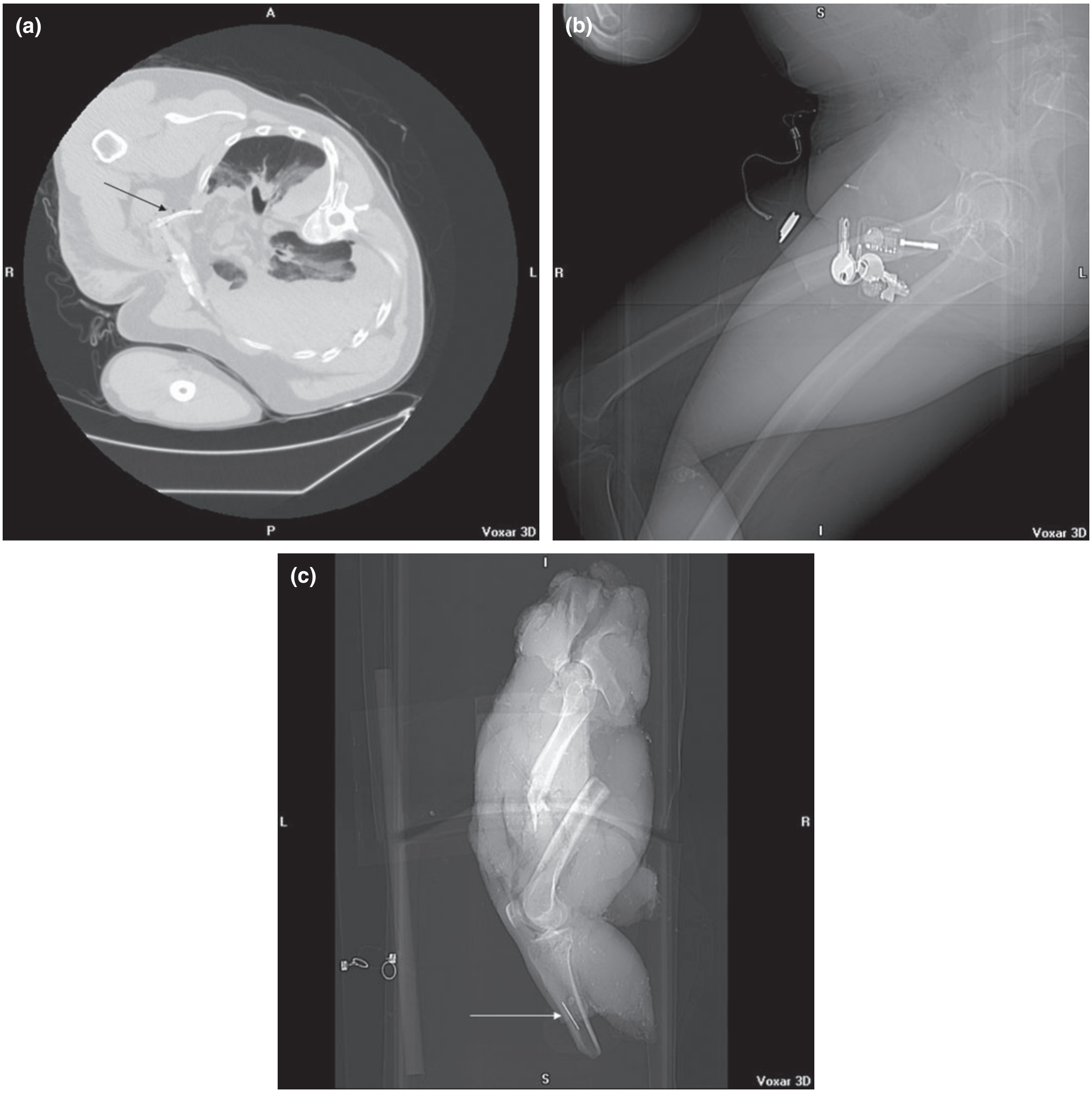

FIG. 5—*Examples of information generated from CT scanning of the victims of the mass fatality. (a) Axial scan showing chest trauma. This image illustrates that the heart has been lacerated by a broken rib with resulting hemothorax (arrow). (b) Location of personal possessions (c) Location of metal foreign object in soft tissue of traumatized lower limb (arrow).*

was possible to demonstrate large lacerations, generalized 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 200 mL on autopsy was not seen on the original report but detected around the spleen on review.

The CT images of the central nervous system, in three out of the five cases where the brain was intact, tended to yield more detailed information than the postmortem reports which did not include microscopic or formal forensic neuropathological examination. In all cases, due to the nature of the incident, the survival time was extremely short—hypothesized to be no more than a few minutes. The images showed subarachnoid hemorrhages reliably. In two cases, CT was able to demonstrate loss of grey-white matter differentiation and sulcal definition providing good evidence of life-threatening brain trauma causing edema and onset of increased intracranial pressure despite the short survival time and lack of gross macroscopic changes.

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 (Figs. 5*b* and 5*c*). 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.

Discussion

Over the last few years it has become increasingly recognized that radiology has an important role within the disaster mortuary environment (16–18). 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 x-ray within both routine and forensic autopsy practice with the gradual increase use of axial radiography. The data presented here suggest that CT may be adequate as the sole imaging investigation in this setting.

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 (19,20).

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 utilized 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.

In a disaster mortuary fluoroscopy may be used first to screen the bodies at the primary reception stage followed by further fluoroscopy or plain x-ray examinations during the disaster victim identification, autopsy or anthropological stages. These can be timely, rate-limiting procedures often requiring manual handling of both the bodies and the equipment to ensure adequate imaging. We have shown on this occasion that the single modality of CT can undertake both of these roles at a single time generating both soft tissue and bony images in AP, lateral, axial and three-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 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.

In this case, we were able to examine both whole and partial bodies. We identified the location of personal possessions and could even collect data related to articles of clothing for example the shoe tread pattern on the bottom of a boot. We identified debris both on and in the bodies, which could be of evidential value or pose a health and safety risk. CT correctly identified the potential causes of death in all patients. Fractures were well seen and could be reconstructed in detail in 3D. In many cases, CT showed additional information not easily obtainable by autopsy such as stable fractures and nonhemorrhagic brain injury.

One important issue raised by this review is the need for a robust, well-trialed protocol for CT scanning in such events to avoid data loss. The body scanned and reconstructed at 10 mm 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 small 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 at thinner slice thicknesses to aid 3-D reconstructions, and thicker slice thicknesses 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, 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 we have introduced a standard operating protocol for our mobile scanning as follows:

- A standardized 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.
- Bodies or body parts are then scanned at optimum resolution. In the case of this mass fatality scanning an intended reconstructed slice thickness of ≤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 preprocessing data should be stored until expert review has been performed.

Through this incident, we have been able to illustrate for the first time the use of mobile CT in mass fatality investigations. We share our experience from this incident and report our protocol for mobile scanning and reporting of images, which we have developed subsequent to this experience. We hypothesize that 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.

Having made this recommendation, we accept that we do not provide supporting evidence in this paper that mobile CT can be used for the acquisition of dental radiological images which may be required in mass fatality investigations, as this imaging was not undertaken on this occasion. It is however our and others experience that dental imaging of cadavers can be undertaken with MSCT (including mobile units) (6,8). Within clinical practice traditional 2D ortho pantomographs (OPG), root imaging, quantifiable axial views, diagnostic pathological investigations, and 3D mandibular reconstructions can all be undertaken with clinical imaging software such as DentaScan (GE Healthcare, Slough, U.K.) (21,22). Thus as more experience is gained in the use of such software for cadaver identification then mobile CT could become an all encompassing single radiological modality for mass fatality investigations.

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