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Contribution of postmortem multidetector CT scanning to identification of the deceased in a mass disaster: Experience gained from the 2009 Victorian bushfires☆

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ABSTRACT

CT scanning of the deceased is an established technique performed on all individuals admitted to VIFM over the last 5 years. It is used primarily to assist pathologists in determining cause and manner of death but is also invaluable for identification of unknown deceased individuals where traditional methods are not possible. Based on this experience, CT scanning was incorporated into phase 2 of the Institute's DVI process for the 2009 Victorian bushfires. All deceased individuals and fragmented remains admitted to the mortuary were CT scanned in their body bags using established protocols. Images were reviewed by 2 teams of 2 radiologists experienced in forensic imaging and the findings transcribed onto a data sheet constructed specifically for the DVI exercise. The contents of 255 body bags were examined in the 28 days following the fires. 164 missing persons were included in the DVI process with 163 deceased individuals eventually identified. CT contributed to this identification in 161 persons. In 2 cases, radiologists were unable to recognize commingled remains. CT was utilized in the initial triage of each bag's contents. If radiological evaluation determined that bodies were incomplete then this information was provided to search teams who revisited the scenes of death. CT was helpful in differentiation of human from non-human remains in 8 bags, recognition of human/animal commingling in 10 bags and human commingling in 6 bags. In 61% of cases gender was able to be determined on CT using a novel technique of genitalia detection and in all but 2 cases this was correct. Age range was able to be determined on CT in 94% with an accuracy of 76%. Specific identification features detected on CT included the presence of disease (14 disease entities in 13 cases), medical devices (26 devices in 19 cases) and 274 everyday metallic items associated with the remains of 135 individuals. CT scanning provided useful information prior to autopsy by flagging likely findings including the presence of non-human remains, at the time of autopsy by assisting in the localization of identifying features in heavily disfigured bodies, and after autopsy by retrospective review of images for clarification of issues that arose at the time of pathologist case review. In view of the success of CT scanning in this mass disaster, DVI administrators should explore the incorporation of CT services into their disaster plans.

1. Introduction

Mass disasters pose considerable difficulty for forensic investigators not least being the large number of deceased persons involved. The dramatic forces of heat, explosion, flood or building collapse that are usually associated with such disasters result in gross disruption to, or at least disfigurement of the involved individuals. The major focus of forensic investigation in such disasters is human identification. In order to deal with the difficulties of such a task, international protocols have been established to facilitate speedy and accurate identification of the deceased for both judicial and family purposes.

The International Criminal Police Organization (Interpol) Disaster Victim identification (DVI) guide or plan [1] is a widely accepted five phase process and although not specified, may be implemented if there are two or more fatalities in a particular incident. Phase 2 of that plan involves extensive examination of the remains using available scientific techniques including fingerprint, radiological, anthropological, odontological and genetic analysis.

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These procedures are supplemented by autopsy examination and where possible photographic recording. All information from this postmortem (PM) phase is entered onto pink Interpol PM forms. Traditionally plain radiographic examination of remains has been used in DVI phase 2 to assist in victim identification [2,3]. Increasingly forensic centers are utilizing multidetector computed tomography (MDCT) and magnetic resonance imaging (MRI) scanning of the deceased to assist pathologists in determining cause and manner of death [4,5]. CT scanning has also been reported to be of value in the identification of deceased persons in cases of charred bodies discovered following house fires [6,7] and on a larger scale, in a multi-motor vehicle accident, using a mobile CT scanner [8]. Other authors have suggested that CT scanning would be useful in the mass disaster scenario both for the evaluation of dentition [9,10] and for assistance in the completion of the Interpol PM forms incorporating items such as age, gender, height, medical devices and natural disease [11].

Subsequent to the 2002 Bali bombing in which 202 persons were killed including 88 Australians, the Victorian Institute of Forensic Medicine (VIFM) in Melbourne applied for a grant from the Victorian State Government to purchase and install a MDCT scanner into the mortuary. The primary aim of this installation was to assist in the identification of victims if such a disaster was to occur in Victoria. In April 2005, a CT scanner was installed into the mortuary and since that time all biological material submitted to the Institute has been scanned and images stored on a picture archive and communication system (PACS) server. To date well over 15,000 deceased persons have been studied with the CT images used predominately for assistance in determining cause and manner of death. CT has also been proven to be highly successful in the identification and reconciliation of grossly fragmented and scattered remains following a light plane crash in Victoria [12]. Based on that positive experience, VIFM has included CT scanning into the phase 2 component of its DVI process.

Victoria is a state of Australia, with a population of ~5.5 million [13]. February 7, 2009 (known locally as "Black Saturday") was a day of unprecedented extreme weather conditions including strong, northerly winds and a maximum temperature of 46.4 °C. Devastating bushfires engulfed wooded regions on the outskirts of the capital city Melbourne, resulting in the destruction of 2000 houses, the loss of whole towns and multiple fatalities. This paper describes the unique contribution of postmortem CT scanning to the complex process of victim identification at VIFM.

2. Materials and methods

On February 7, the DVI process of VIFM was activated. As part of that protocol, all deceased individuals or their remains were CT scanned as soon as practicable within their unopened body bags at the mortuary of VIFM. No attempt was made to alter the deceased's posture, manipulate contents into optimal position or remove any foreign material prior to scanning. CT images were initially assessed by radiologists to determine if there were any significant technical issues precluding analysis such as poor CT procedure. If such problems were encountered, bags were rescanned. Despite the common "pugilistic" attitude of many deceased persons exposed to extreme heat [14], only 2 body bags could not be scanned completely due to the contorted upper limbs restricting entry to the CT gantry. To facilitate scanning of one individual in such a position, anatomical dissection of the upper limbs was performed by a pathologist prior to repeat CT scanning thus allowing repositioning of the protruding limbs so that the study could be completed. All victims showed varying degrees of heat effect from minor skin loss to extreme burning with gross destruction of soft tissue and bone. In some cases only fragments of heavily burnt or "calcined" bone was available for assessment. All presumed human remains were scanned, no matter how small or admixed with building materials or debris.

2.1. Scanning protocol

Images were acquired using a 16 channel MDCT scanner (Aquilion16®, Toshiba Medical Systems, Minato-ku, Tokyo, Japan) installed inside the mortuary at VIFM. Scan data were stored on the Institute's PACS server (IMPAX®, Agfa HealthCare NV, Mortsel, Belgium). MDCT scanning protocols were similar to those used for routine cases admitted to the Institute. Scans were performed by mortuary technicians trained in CT technique and accredited by the relevant state authority (Radiation Safety Section of the Victorian Department of Health) to perform radiographic procedures. In most cases 2 scan runs were undertaken; the first using 0.5 mm collimation reconstructed into 2/1.6 mm overlapping axial slices from the sternal notch to the feet and a second from the top of the head to the sternal notch in 1/0.8 mm overlapping axial slices using both soft tissue and bone convolution kernels. When isolated remains or individual body parts were detected by technologists on the preliminary CT "scout" view of the bag contents, only 1/0.8 mm overlapping axial slices were reconstructed.

2.2. Workstations

Images were reviewed by 2 teams of 2 radiologists experienced in forensic imaging employing Vitrea®2 (Vital Images, Inc. Minnetonka, Minnesota, USA) and AquariusNet (TeraRecon Inc., San Mateo, CA, USA) thin client workstations. Multiplanar reformatted (MPR) images as well as three-dimensional (3D) surface shaded display (SSD) volume rendered reformats for bones and a 3D maximum intensity projection (MIP) algorithm with color coding of high density picture elements (pixels) were assessed. This later sequence (known as "blue metal") proved very useful for the assessment of metallic objects within the body bags. All findings detected on 3D images were confirmed on the MPR slices. To maximize the quality of image interrogation, CT scans were read by 2 radiologists sitting in tandem. Findings were transcribed onto a data sheet constructed specifically for the DVI exercise (Fig. 1). This sheet was appended to the routine phase 2 documentation and made available to all interested parties at the time of autopsy as well as police investigators. Approximately 30 min of analysis time was required to complete each data sheet.

2.3. Image interpretation

Initial radiological overview of the bags contents determined the stated condition of bodies. Each was assessed as being intact if all bones were present with or without overlying soft tissue (Fig. 2), severely burnt if the body was predominately intact but depleted of at least one bone with or without overlying soft tissue (Fig. 3), incomplete remains if no normal body compartment was present including bones and/or soft tissue (Fig. 4), or an individual body part. This is an adaptation of the Crow–Glassman scale used by forensic anthropologists as a means of visually describing burnt remains [15]. Subsequently images where more rigorously analyzed for identification features and the presence of commingling or non-human tissue.

2.3.1. Identification criteria

Interpretation of images for identification purposes was based primarily on radiological criteria rather than odontological or anthropological characteristics. Identification features on CT were considered to be either general, i.e. age and gender of the deceased person or specific for that individual. Radiologists attempted to detect and identify the 4 specific category items considered to be of value for investigators, i.e. teeth, medical devices (Fig. 5), disease processes and objects of everyday living that might be uniquely associated with the deceased (Fig. 6). The detection of teeth and/or dental work was recorded to inform dentists of their presence but no attempt was made to perform a complete dental analysis and interpretation of bones was limited to basic anatomical analysis and detection of bony pathology rather than full anthropological interpretation. Determination of age and gender was based on visualization of specific anatomical structures including epiphyses and disease processes rather than anthropological measurements although CT images were subsequently reviewed by anthropologists or odontologists in order to confirm specific autopsy findings.

2.3.2. Species and gender determination

Determination of species was based on CT assessment of bones, looking for human or animal anatomical characteristics (Fig. 7). A museum of dried animal skulls (cat, dog and fox) was made available to the radiologists and subsequently CT scanned. Three-dimensional reconstructed images of the CT data were compared with suspected animal remains on the workstations. If animal bones alone were identified (Fig. 8), findings were promptly referred to the mortuary director and the bag contents expeditiously viewed by an experienced anthropologist. On physical confirmation of the CT findings, those bags were immediately removed from the DVI process. If commingled animal and human remains were detected on CT scanning then the entire bag contents were processed using routine phase 2 procedures including autopsy.

Gender was itemized as male, female or "not able to be determined". The detection of internal and external genitalia on CT (Fig. 9) as well as less specific findings of brassiere underwire (Fig. 10), jewellery and watches, were used for determination of gender. Despite severe destruction of the body, genitalia could in many cases still be identified notably the crura of the penis and prostate, as well as breasts, vagina, labia, cervix and uterus. Gender was assigned as "definite" if internal and/or external genitalia were clearly seen, "probable" if genitalia were

VIFM CT DVI screening form

VIFM #: ______________________ **DVI #:** ______________________

Date: ______________________ **Reported by:** ______________________

CT Technical issues: ____

State of body (circle appropriate): Intact Severely burnt Remains Individual parts

Details ____

Type of remains (circle appropriate): Human Non-human Co-mingled not able to be determined

Details ____

Gender (circle appropriate): M F not able to be determined

Based on ____

Growths plates (circle appropriate): Y N not able to be determined

Location ____

Disease (circle appropriate):

Coronary artery calcification Y N not able to be determined

Systemic vascular calcification Y N not able to be determined

(if so where) ____

Osteoarthritis Y N not able to be determined

(if so where) ____

Other ____

Identification:

Teeth (details) ____

Medical devices (details) ____

Other ____

Summary (circle):

Gender: Male Female not able to be determined

Estimated age: <12 months 1-5y 5-13y 13-20y 20-40y 40-60y >60y don't know

ID features: Teeth Medical devices Other ______________________

Fig. 1. Data sheet completed by radiologists as part of their CT scan interpretation.

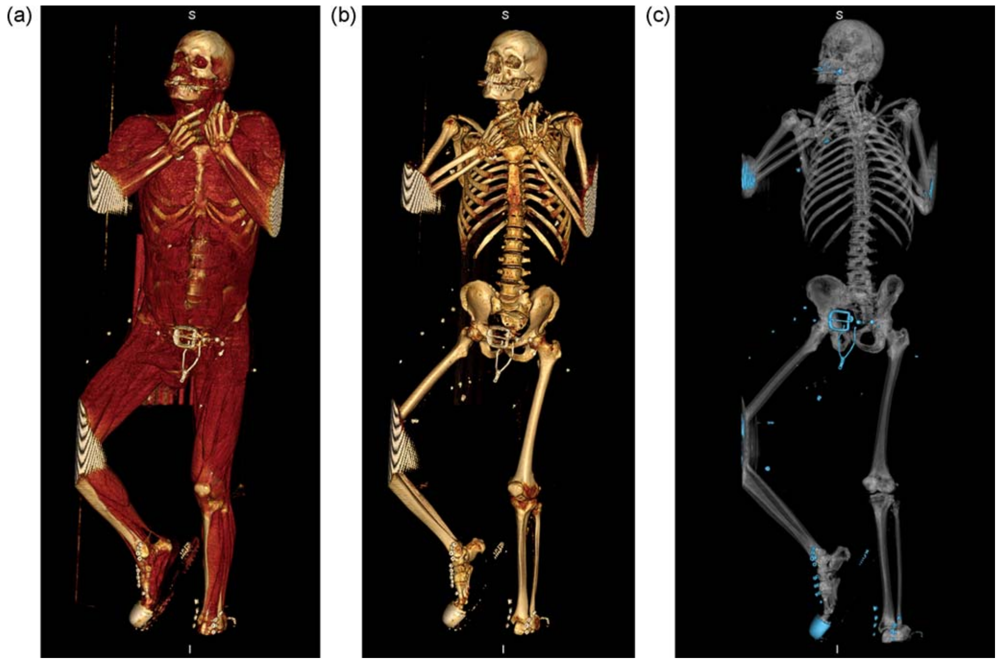

Fig. 2. 3D reconstructions using (a) SSD with soft tissue added, (b) SSD with digital soft tissue removal and (c) MIP with color-coded high density ("blue metal") pixels showing an intact deceased person adopting a typical pugilistic posture associated with extreme heat. Note metal associated with the teeth, apparel and footwear. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

partially destroyed by the effects of fire but still identifiable, or breasts alone were detected in women; and "possible" if there was only ancillary evidence of gender, e.g. bra underwire and/or jewellery for women and watches and/or pocket knives for men.

2.3.3. Age determination

CT aging was based on the presence and location of growth plates (physes) at the ends of long bones, presence or absence of primary and secondary dentition (Fig. 11), and signs of chronic disease such as atherosclerosis in the systemic circulation (particularly the presence of intimal calcification) and osteoarthritis in the spine (Fig. 12) and joints. Despite severe burning it was remarkable that major organs were often clearly identifiable with radiologically preserved internal structure, most notably the heart, lungs and liver. This proved very useful in age analysis especially for detection of coronary artery and aortic calcification as these were used as major indicators of advanced age. Categories of age chosen were by necessity broad as follows <12 months, 1–5 years, 5–13 years, 13–20 years, 20–40 years, 40–60 years, >60 years, and not able to be determined. For less than 20 years of age, aging was based on the presence of teeth and growth plates by reference to standard anatomical texts. The category of 20–40 years was based on the presence of growth plate fusion but no significant atherosclerosis or osteoarthritis. 40–60 years was listed if mild forms of either or both diseases were present and >60 was based on severe and widespread atherosclerotic change, osteoarthritis or both. Presence of joint prostheses (knee or hip) was used to confer an age of >60. One elderly woman was aged as such by the detection of a Gräfenberg ring in the uterus on CT confirmed at autopsy. This intrauterine contraceptive device has not been used in Australian clinical practice since the 1960s although a modified version was being inserted into mainland Chinese women until 1993 [16]. In some cases where only disrupted remains were detected, broader categories of age were used, e.g. isolated bone with fused epiphyses was categorized as >13–20 years, isolated bone with fused epiphyses showing minor osteophyte was classified as >20–40 and isolated bone with fused epiphyses and marked osteophyte >40–60 years.

Actual CT scanning times are short although total time needed for CT image acquisition is substantially longer as this necessarily includes time taken to place the deceased onto the scanner table and then removal to the refrigerator storage.

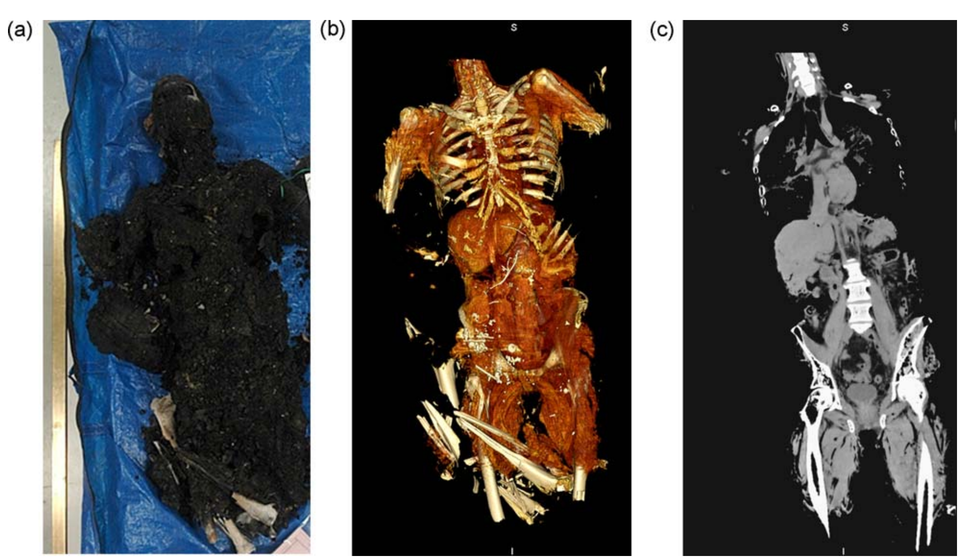

Fig. 3. (a) Admission photograph of a severely burnt deceased individual. (b) 3D SSD reconstruction of the deceased with soft tissues attached showing absence of peripheral upper and lower limbs but persistence of thoracic, abdominal and pelvic cavities and (c) corresponding coronal MPR demonstrating remarkable preservation of liver, heart and bladder despite loss of overlying thoracic and abdominal wall tissue.

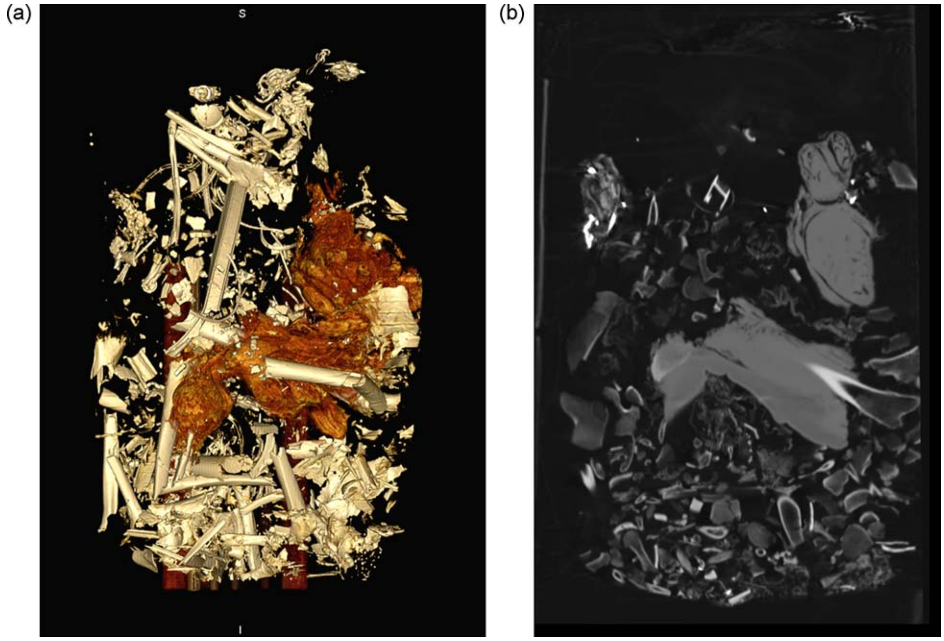

Fig. 4. (a) 3D SSD reconstruction of remains shows a collection of markedly fragmented bone. (b) Corresponding MPR image indicates residual muscle attached to bone together with visceral parts mixed with building materials.

Given the large data sets associated with post mortem imaging, computer reconstruction times are also protracted. At VIFM this whole process takes 30–45 min. Once acquired and reconstructed, images are immediately transferred to PACS and made available for analysis on departmental computers by all interested parties utilizing the AquariusNet thin-client server.

2.4. Documentation of findings

In most cases the CT images were analyzed and a report issued on the day prior to autopsy for review by the autopsy team. Findings were appended to the Interpol PM form. A radiologist was available for discussion with pathologists at the time of autopsy if there was an issue of concern regarding the CT report. In selected cases, a radiologist attended the autopsy in order to clarify points of anatomy or to help in the localization of foreign material. Images were available for review throughout the Institute including the mortuary on the AquariusNet thin client server. Forensic odontologists and anthropologists also had independent access to CT images using Vitrea®2 or AquariusNet workstations. This proved very useful during their detailed analysis after the autopsies especially at the time of data entry into the Plass Data DVI software (Plass Data Software A/S Holbaek, Denmark). CT images were also re-examined at the time of the pathologist's review of all phase 2 data, prior to the issuing of a final report for each deceased person.

From the outset a decision was taken in conjunction with the State Coroner that the primary aim of the pathological and ancillary examination of the deceased was victim identification. Limited dissection of the trachea was undertaken where possible for detection of soot in airways, and blood obtained for carbon monoxide and cyanide analysis. Tissue was also sampled for DNA analysis. If possible a limited laparotomy was performed to determine if the gallbladder and appendix were still present and internal genitalia detectable (for the purposes of identification). The "effects of fire" was determined to be the cause of death in most cases or unascertained if there were only tissue remains such as bones. If the CT scan suggested a cause of death other than the effects of fire then further limited autopsy was undertaken pertaining to that area. Forensic odontologists and anthropologists were also involved in determination of commingling and identity within the mortuary.

3. Results

3.1. Time scale

In the 4-week period following the fires, 288 body bags containing deceased persons or biological remains were admitted to VIFM, 284 CT scans performed and 255 CT reports issued. In 29 cases the remains were so small and severely fragmented that formal interpretation of CT images was not performed and autopsies alone were undertaken. Postmortem examination of the contents of 286 bags was performed in that time period. Ultimately there were 173 fire deaths although only 163 deceased persons were identified using the DVI process at VIFM. Nine deceased persons were identified by other means and the remains of 1 individual were not found.

In the majority of cases CT scanning was performed on the day of the deceased individual's admission to the VIFM and the autopsy completed the following day. In the 3 days immediately following the fires, 96 cases were admitted but only 79 CT scans performed due to limited scanning capacity necessitating the storage of 17 bags without immediate CT scanning and delayed autopsy. By the 6th day this "backlog" was overcome and all body bags admitted to that date ($n = 171$) were scanned (Fig. 13). Subsequent admissions were then scanned and reported with 24 h of admission, on the day prior to autopsy.

3.2. State of deceased

CT interpretation determined that bag contents were intact individuals in 29 (11%), severely burnt in 58 (23%), incomplete remains in 166 (65%), and individual parts in 2 (<1%). In 6 cases there was severe decomposition of the contents with marked gaseous putrefaction in 2 bags and insect infestation in 4 bags (Table 1).

The proportion of intact to disrupted bodies was in 2 distinct time phases. CT reports of the 127 body bags admitted in the first 4 days after the disaster indicate that a majority (73–58%) of the contents were complete (25–20%) or severely burnt (48–38%) and only 53 (42%) classified as remains with 1 individual part. In the following days, teams of police, pathologists, anthropologists and forensic dentists re-examined many of the scenes of death especially if autopsy or CT imaging had revealed incomplete anatomy. Consequently from day 5 to 28, the majority of the 128 CT reports was classed as isolated remains (113–88%), often small

Table 1
Number of decomposed deceased persons detected on CT.

Decomposition	Intact body	Severely burnt
Insect infestation	1	3
Putrefactive gas	2	0
Total	3	3

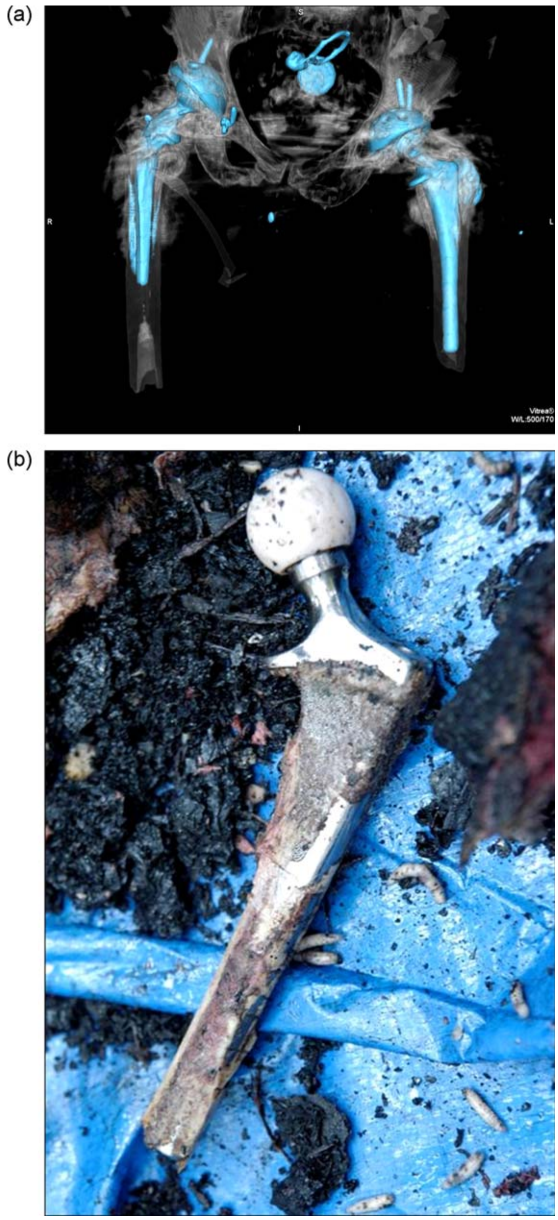

Fig. 5. (a) 3D color-coded high density pixel MIP ("blue metal") reconstruction shows bilateral total hip prostheses. (b) Explanted femoral stem of the left prosthesis at the time of autopsy. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

in size and predominately bone with only 4 (3%) being intact and 10 (8%) severely burnt. One individual part was found in this second phase (Table 2).

3.3. General and specific criteria of identification

Once an overview of the bag's contents was performed by the radiologist, images where then more rigorously analyzed for commingling and detection of any non-human tissues. In 8 (3%) cases, bones were clearly identified on CT as being solely of animal origin based on bone morphology. All 8 were confirmed to be of animal origin by direct anthropological examination of bag contents and as such immediately removed from the DVI process. In 10 bags (4%), CT suggested there were animal remains commingled with human tissue. For these cases the routine DVI process was continued. The subsequent autopsy confirmed commingled animal bones in all 10. Commingled deceased persons were also detected on CT in 6 body bags (2%). These findings were all confirmed on autopsy examination (Table 3). Two cases of commingling subsequently identified at autopsy were not recognized by CT.

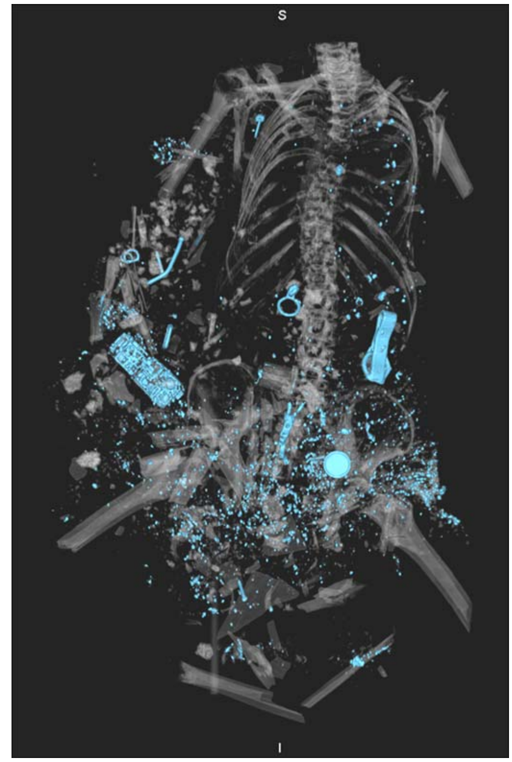

Fig. 6. 3D color-coded, high density pixel ("blue metal") MIP reconstruction showing multiple metallic objects associated with a severely burnt deceased person including watch, coin, ring, cell phone and building materials. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Of the 4 specific category items that could be of value to investigators, i.e. teeth for odontological assessment, medical devices, disease processes and objects of everyday living that might be uniquely associated with the deceased, a total of 196 bags (77%) prospectively contained one or more of these identifiable features on CT. These included 145 (57%) with teeth or dentures, 19 (8%) with 26 different medical devices (Table 4) and 13 (5%) with 14 CT findings associated with medical conditions (Table 5). Two hundred and seventy-five objects of everyday life (in 23 different categories) were detected in 135

Table 2
State of deceased persons determined by CT.

Day of DVI	Admissions (% of total)	Intact (% of time period)	Severely burnt (% of time period)	Remains (% of time period)	Individual part (% of time period)
1–4	127 (50)	25 (20)	48 (38)	53 (42)	1 (<1)
5–28	128 (50)	4 (3)	10 (8)	113 (88)	1 (<1)
Total	255	29 (11)	58 (23)	166 (65)	2 (<1)

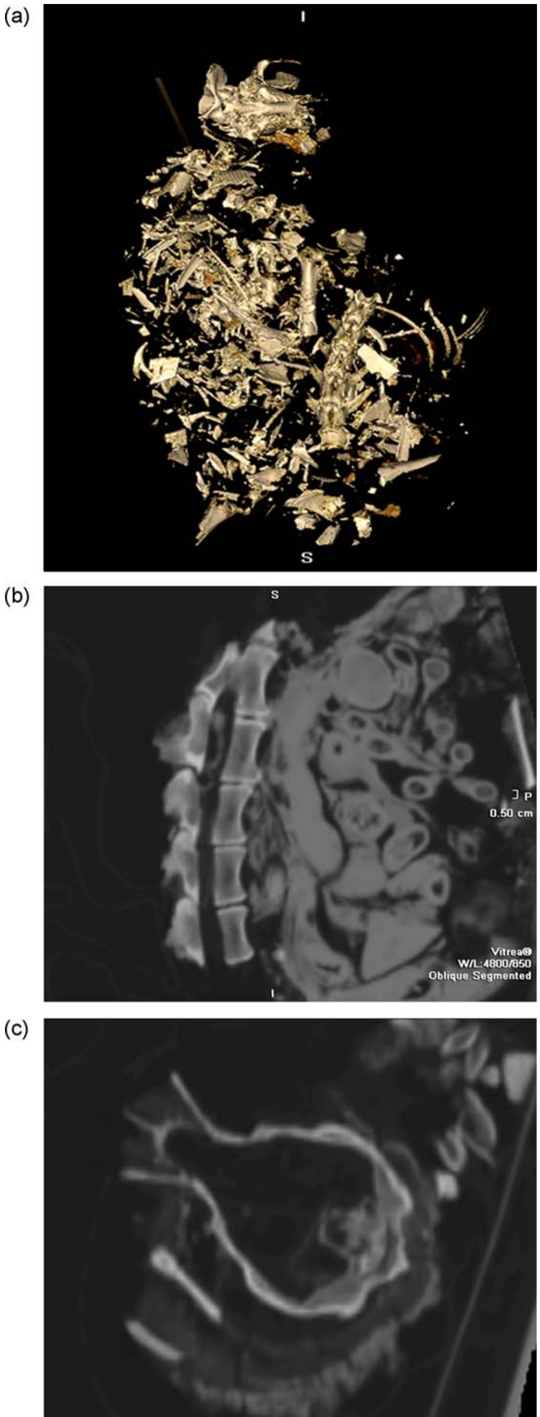

Fig. 7. (a) SSD 3D reconstruction of fragmented remains suggesting animal bones. (b) Confirmation on sagittal MPR of spine and (c) coronal MPR of skull with morphological appearances that are not human. Anthropological examination confirmed a large dog.

(53%) of the bags (Table 6). All 4 of these categories of identification were detected in 2 body bags, 3 categories in 11 bags, 2 in 72 bags and 1 alone in 111 (Table 7). Fifty-nine bags (23%) did not contain a specific identifying feature.

Of the 163 deceased persons ultimately identified by the DVI process, 161 (99%) were recognizable as human on CT. Two were not identified on CT due to unrecognized commingling with other deceased persons. The recognized deceased were classified as intact on CT in 29 (18%), severely burnt in 59 (37%) and remains or individual part in 73 (45%). Gender of these 161

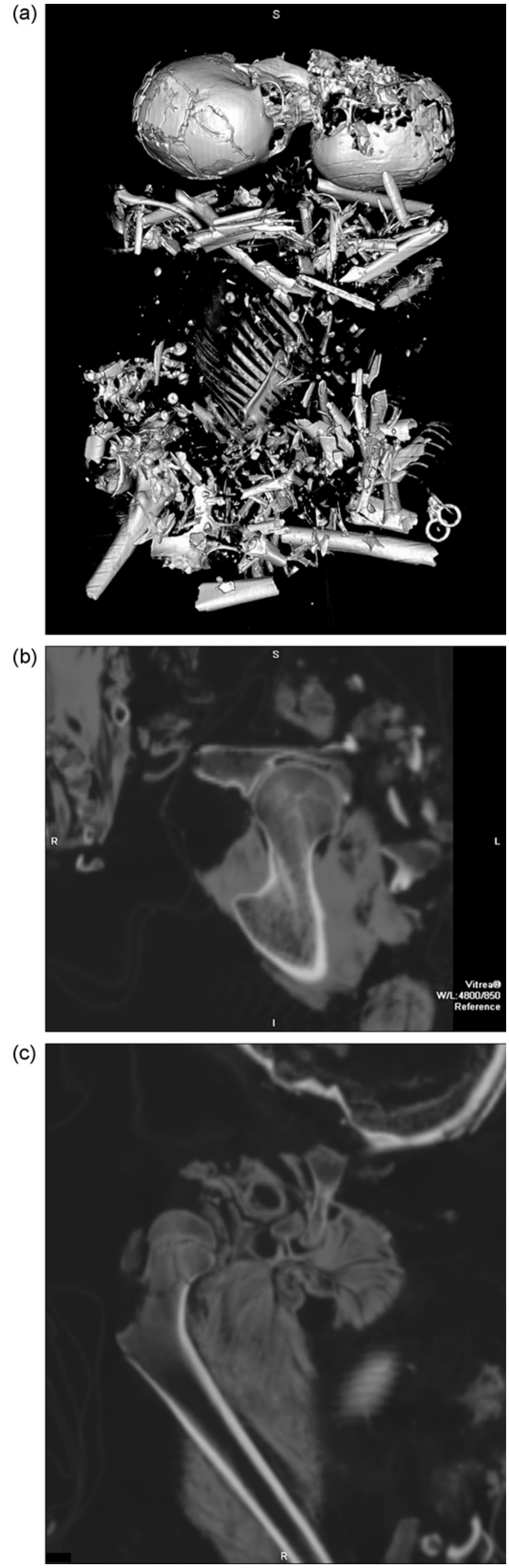

Fig. 8. (a) 3D SSD reconstruction of fragmented bones suggests human commingling with 2 skulls clearly seen but only one pelvis and 2 proximal femora. (b) Coronal MPR of one of these femora indicates a fused femoral capital epiphysis whereas (c) coronal MPR of the other proximal femur clearly outlines an unfused physis. Anthropological examination confirmed commingled adult and child.

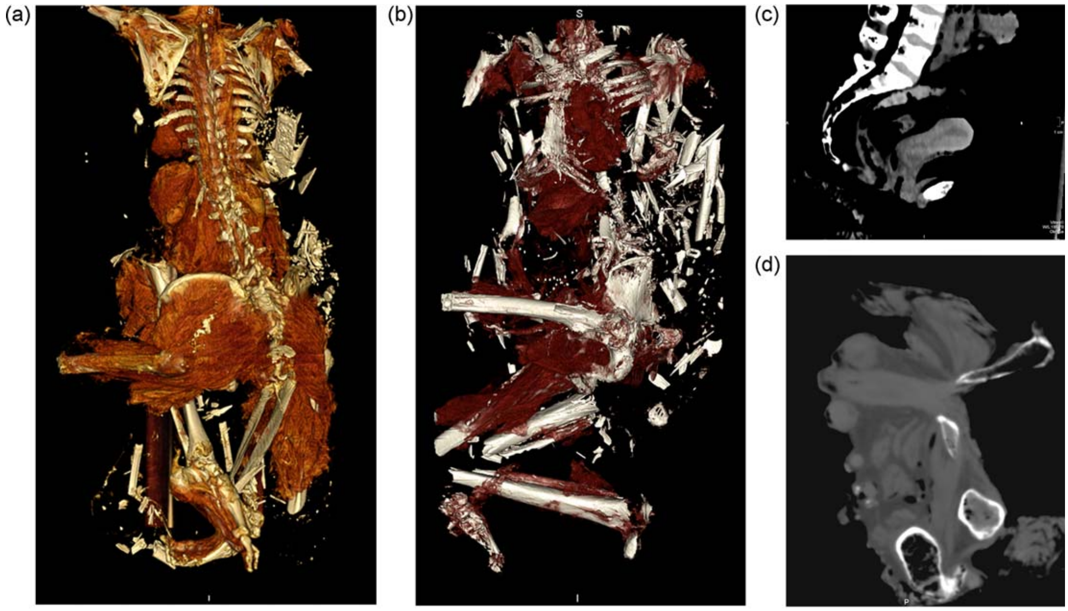

Fig. 9. (a) and (b) 3D SSD reconstructions show severely burnt individuals with (c) sagittal MPR of the pelvis clearly demonstrating the uterus and (d) axial MPR of the pubic symphysis showing the base of the penis and testicles on either side of the penile shaft.

Table 3
Commingling of bag contents determined by CT.

State	CT reported bags	CT recognized as commingled human	CT recognized as commingled human and animal	CT recognized as animal alone	Final identification possible	Commingled human unrecognized on CT
Intact	29	0	0	0	29	0
Severely burnt	58	1	0	0	59	1
Remains and individual parts	168	5	10	8	73	1
Total	255	6	10	8	161	2

individuals was ultimately determined to be female in 68 (42%) and male in 93 (58%). An attempt at gender determination was possible on CT in 98 of the 161 (61%) with 43 definite, probable or possible females on CT and 55 definite, probable or possible males (Table 8). 100% of the intact bodies, 75% of the severely burnt and 34% of the remains had gender determination performed using CT (Table 9). All 55 males were correctly identified on CT and all but 2 of the 43 females; 1 CT designated "possible female" and 1 "probable female" were actually male. The contents of this "possible female" bag included only bony remains and a purse with jewellery. The "probable female" was severely burnt and the reporting radiologists thought they could detect a severely disrupted uterus. In retrospect this structure was most likely the rectum. Of the isolated remains, females formed the greatest number of correct CT gender determinations due to the detection of brassiere underwire. This was the only indication of gender in all 12 correct determinations.

CT assessment of age was possible in 155 (94%) of the 161 cases. Of that 155, 118 (76%) were correctly aged with the most accurate age intervals being at the start of life, i.e. <1 year (1/1) and 1–5 years (4/4), and at the end of life, i.e. >40–60 years (9/9) and >60 years (12/12) due to the presence of well defined features of those ages (Table 10). The least accurate CT identified age ranges were 20–40 years (21/35 = 60%) and 40–60 years (23/

Table 4
Type and frequency of medical devices detected on CT.

Medical device on CT	Number of findings
Sternotomy wires	5
Pacemaker	1
Aortic valve prosthesis	1
Single knee prosthesis	1
Single hip prosthesis	3
Bilateral knee prostheses	1
Bilateral hip prostheses	2
Mesh hernia repair	1
Contraceptive device	3
Cholecystectomy clips	6
Cervical fusion device	1
Coronary artery stents	1
Total	26 in 19 deceased persons

Table 5
Type and frequency of medical conditions detected on CT.

Medical condition on CT	Number of findings
Calcification of ligamentum arteriosum	2
Cholelithiasis	3
Hiatus hernia	2
Lumbo-sacral fusion	1
Mal-united tibial fracture	1
Paget disease of pelvis	1
Pregnancy	1
Renal calculus	1
Scheuermann disease	1
Thymic hypertrophy	1
Total	14 conditions in 13 deceased persons

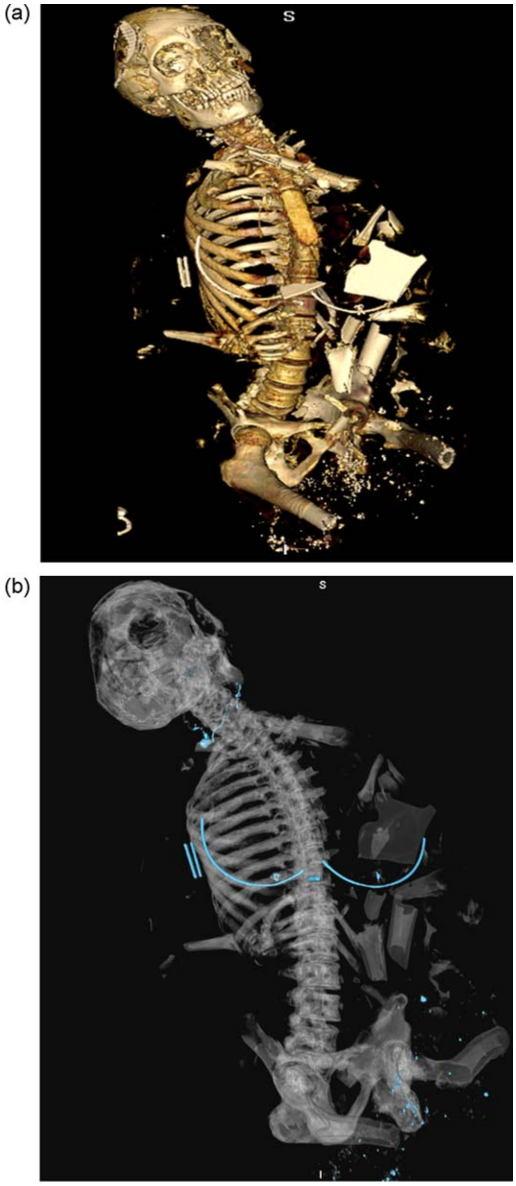

Fig. 10. (a) 3D SSD reconstruction of the skeleton showing a severely burnt deceased individual. (b) Color-coded 3D MIP ("blue metal") demonstrating typical appearances of brassiere underwire superimposed over the anterior chest indicating a possible female gender, confirmed as such by anthropologists. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

41 = 56%). In those that CT incorrectly determined the age, it tended to be an underestimation rather over, although not by many years (Table 11). If an extra 2 years was added onto either side of these age groups, e.g. 18–42 and 38–62 years, then correct age determination increased by 24 to 142/155 (92%).

3.4. Mechanism of death

Fractures were commonly identified on CT. In severely burnt deceased persons, the pattern of fracture and bone loss was typical of previously described thermal destruction including "cartoon hand" and loss of distal limbs [17]. Occasionally bone fragments were identified on CT demonstrating typical extreme heat associated concentric ring fractures. Many of the deceased were found inside houses that had been destroyed by fire. Where only fragmented remains were detected, bone disruption was pre-

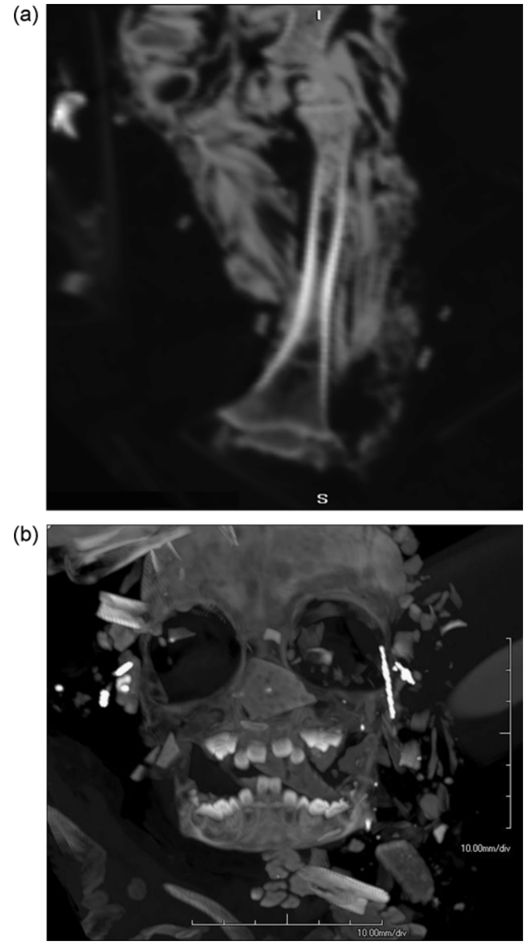

Fig. 11. (a) Coronal MPR of a femur shows unfused physes at the upper and lower ends. (b) Coronal MIP reconstruction of the skull delineating primary dentition consistent with a young child. Final identification procedures indicated a child of less than 12 months of age.

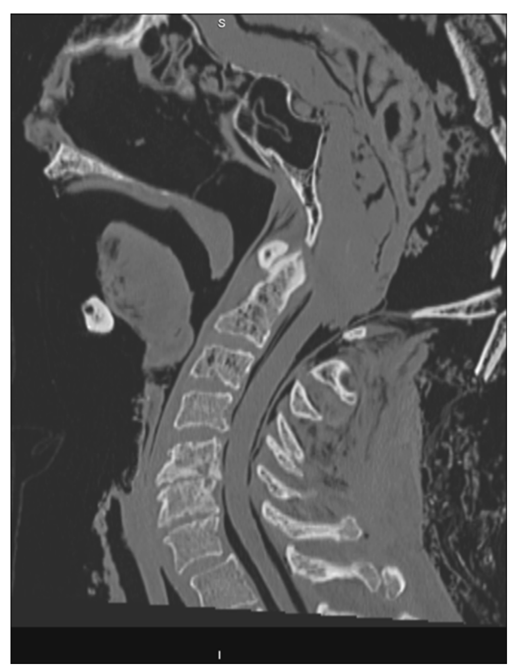

Fig. 12. Sagittal MPR of the cervical spine in a severely burnt individual displaying severe osteoarthritis at C5,6 and C6,7. An age of >60 years was assigned to the individual based on the CT findings and was confirmed on final analysis.

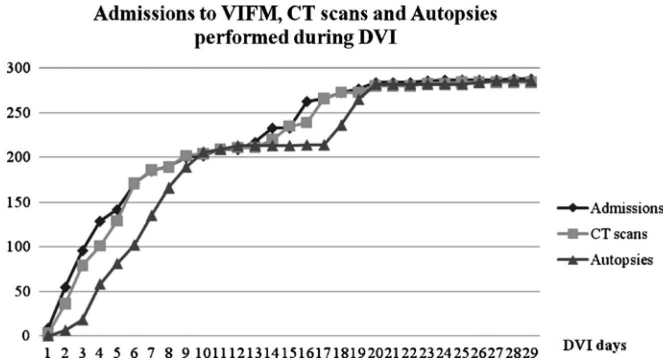

Fig. 13. Cumulative graph of admissions to VIFM, CT scans performed and autopsies completed during the first 28 days of the DVI process.

Table 6
Type and frequency of everyday objects detected on CT.

Object of everyday life on CT	Number of bags
Boot/shoe	32
Ring	31
Watch	30
Cell phone	27
Spectacles	23
Brassiere wire and/or clip	23
Key	22
Belt buckle	17
Neck chain	16
Bracelet	14
Ear ring	10
Electronic device (unspecified)	6
Hair clip	6
Pocket knife	3
Multifunction tool	3
USB drive	2
MP3 player	2
Umbilical ring	2
Animal lead clip	2
Cigarette lighter	1
Money clip	1
Name badge	1
Purse	1
Total	275 objects in 135 bags

sumed to be the result of burning and/or postmortem crushing by falling building materials.

In only one case was there the suggestion of bone injury that might have been a mechanism of death other than the effects of fire, i.e. C6,7 dislocation. This finding was relayed to the pathologist prior to autopsy and lead to a detailed anatomical dissection of the deceased's neck that otherwise would not have been performed. In his final analysis the pathologist indicated that in the absence of hemorrhage in the spinal canal and surrounding soft tissues of the neck, these changes at C6,7 were most likely artifactual [18] and related to removal of the deceased from the crime scene; a finding referred to by some as mortician's fracture. Subsequent toxicological analysis demonstrated a potentially toxic blood carboxyhemoglobin level.

Table 7
Frequency of specific identification classes detected on CT.

Classes of specific identification features on CT	Number of bags
1	111
2	72
3	11
4	2
Total	196

Table 8
Accuracy of gender as determined by CT.

Gender on CT	Number of deceased persons	Correct (%)
Female definite	23	23 (100)
Female probable	4	3 (75)
Female possible	16	15 (93.8)
Male definite	50	50 (100)
Male probable	4	4 (100)
Male possible	1	1 (100)
Total	98 of 161 identified on CT	96 (98)

Another common finding on CT was so-called "heat induced extra-dural hematoma". This artifact is well recognized by forensic pathologists in burns victims. It manifests as crumbly, red "brick-like" material in the cranial cavity at autopsy, and has distinctive CT findings [19]. As a result of the extreme heat most cases had associated loss of scalp tissue and delamination of the skull vault in exposed areas [20].

3.5. Retrospective review of CT images

During the course of the DVI process, antemortem medical information became available. From time to time radiologists received requests from investigators for retrospective analysis of CT scans based on that evidence. In 4 cases additional CT findings were made in the light of those reviews. In the first example, medical records obtained following autopsy indicated that the suspect deceased individual had 2 coronary artery stents in situ. Despite severe burning and putrefaction of the body, these delicate stents were retrospectively detected on MPR of the CT data, located in the circumflex coronary artery and dimensions calculated. The location and sizes matched the medical report exactly and a positive identification was possible. In the second case a pacemaker had been detected on initial CT but medical notes detailed an additional artificial cardiac valve. Extreme disruption to the body was evident on review but the valve was detected on CT in the appropriate cardiac chamber and determined to be a xenograft (porcine) valve (Fig. 14). Initial autopsy and CT examination had failed to detect the soft tissue (non-metallic) valve leaflets using the "blue metal" 3D color-coded, reconstruction algorithm. In the third case, medical notes indicated an old fractured forearm, yet to the concern of investigators, the CT report did not mention such a finding. This fracture was not visible even on retrospective review but the radiologist could report that only one arm was seen on the images as the deceased had adopted a pugilistic position and the previously injured limb was obscured by CT artifact. The last case was a fractured leg that had been detected on the initial CT examination but police evidence indicated previous surgical intervention with a metallic rod. The rod was no longer present (having been surgically removed); however, on retrospective review a channel was visible in the trabecular bone of the tibia. The dimensions of this channel were measured on CT, corresponding exactly to the size and shape of the rod as indicated in the deceased's clinical notes.

4. Discussion

CT is now an integral component of medico-legal death investigation at VIFM [4] and is regularly used to assist pathologists in identification of the deceased where traditional techniques of visual inspection, fingerprinting, dental and DNA analysis are not possible. The identification process entails establishment of a general biological profile by determining the deceased's age and gender, and if possible, eliciting more specific characteristics by the detection of unique biological or physical

Table 9
Accuracy of gender for each body state determined by CT.

CT body state	Actual gender (% of sub-total)	CT definite (% of actual)	CT probable (% of actual)	CT possible (% of actual)	CT determined (% of actual)	CT wrong (% of actual)
Intact	11 female (38)	10 (91)	1 (9)	0	11 (100)	0
	18 male (62)	18 (100)	0	0	18 (100)	0
Sub-total	29	28 (97)	1 (3)	0	29 (100)	0
Severely burnt	23 female (39)	11 (48)	1 (4)	3 (13)	15 (65)	1 – prob. (4)
	36 male (61)	26 (72)	2 (6)	1 (3)	29 (81)	0
Sub-total	59	37 (63)	3 (5)	4 (7)	44 (75)	1 (2)
Remains/part	34 female (47)	2 (6)	2 (6)	13 (38)	17 (50)	1 – poss. (3)
	39 male (53)	6 (15)	2 (5)	0	8 (21)	0
Sub-total	73	8 (11)	4 (100)	13 (100)	25 (34)	1 (1)
Total	161	73 (45)	8 (5)	17 (11)	98 (61)	2 (1)

features. Conventional radiographic techniques have been used for many years to assess the bony skeleton for these characteristics and to detect radio-opaque materials [21]. Plain X-rays are limited in the range of projections available although fluoroscopic screening has been employed to better determine the position of foreign bodies within the body. Conventional X-rays remain the mainstay of dental examination.

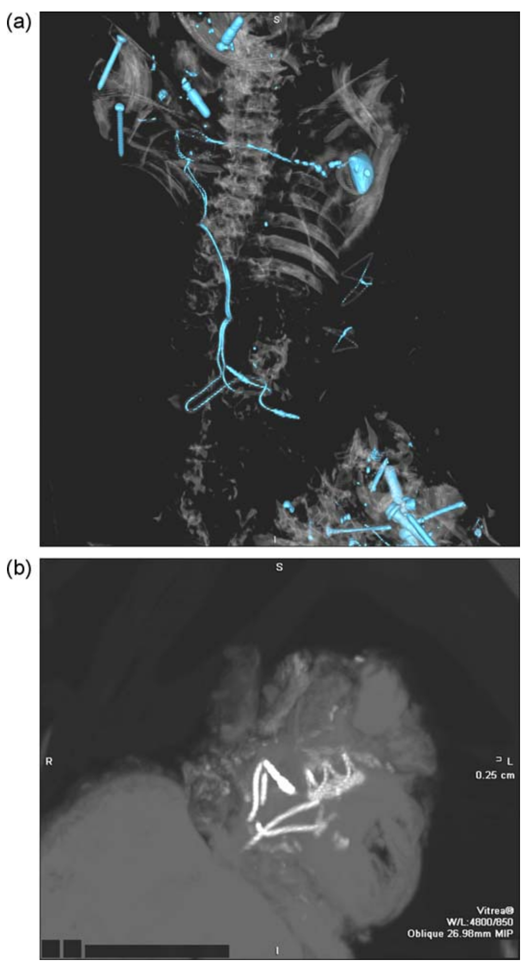

Fig. 14. (a) 3D color-coded high density pixel MIP reconstruction ("blue metal") of a severely burnt individual shows sternotomy wires and a pacemaker in the left anterior chest wall with 2 wires passing towards the position of the heart. (b) Oblique MPR shows the 2 pacing wires together with a device comprising 3 leaflets consistent with a tissue aortic valve. This was confirmed in the deceased's medical records. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Unlike the planar characteristics of radiographs, CT has the advantage of being a cross-sectional technique with intrinsically better contrast resolution allowing more accurate localization of many body parts and foreign materials. Bones are well seen on CT and even if heavily burnt or even calcined, still readily recognizable. Manipulation of CT data using 3D volume rendered software on a workstation allows soft tissue to be removed from the bone without the need for mechanical intervention; a process that has been labeled "digital cleansing" [12]. In many cases it is possible to differentiate human bones from those of animal origin and skeletal remains from admixed building materials on the basis of CT analysis.

Soft tissues in general are not conspicuous on radiographs, but are well visualized on CT. Using the technique of multiplanar reconstruction, organs and bones can be re-orientated irrespective of body position. These techniques can be used to great effect in the DVI process for detection of disease, delineation of features of older age including atherosclerosis and osteoarthritis, demonstration of epiphyses in long bones and presence of teeth or dental hardware

Table 10
Accuracy of age as determined by CT.

CT determination of age (years)	Number of deceased persons	Correct (% of correct CT)
<1	1	1 (100)
1–5	4	4 (100)
5–13	4	3 (75)
13–20	10	8 (80)
>13–20	26	25 (96)
20–40	35	21 (60)
>20–40	6	6 (100)
20–60	7	6 (86)
40–60	41	23 (56)
>40–60	9	9 (100)
>60	12	12 (100)
Total	155	118 (76)

Table 11
Analysis of incorrect age determination on CT.

Incorrect CT aging (years)	Number of deceased persons	Number that CT under-over estimated	Number of correct CT aging if further 4 years added (% of total)
5–13	1	0–1	0
13–20	2	0–2	1 (50)
>13–20	1	0–1	1 (100)
20–40	14	12–2	11 (79)
20–60	1	0–1	0
40–60	18	15–3	11 (61)
Total	37	37	24 (65%)

but most importantly for the display of internal and external genitalia. The detection of such organs provides a rapid, definitive means of gender assignation without need for comprehensive autopsy of heavily burnt remains. If genitalia are not present, the detection of metallic gender-associated accessories or clothing including brassiere underwire using the "blue metal" 3D display can provide circumstantial evidence allowing tentative assigning of gender. These same 3D color-coded techniques are useful for visualization of dental hardware as well as other metallic medical devices reducing the streak artifacts that are usually associated with such materials on CT [22]. Clearly the greatest value of CT scanning is early on in DVI process when retrieved bodies in general are more intact. Tiny, fragmented, bony remains are visible on CT but images are of insufficient quality for detailed analysis. They are best examined directly by anthropologists and/or dentists.

"Digital triage" is now incorporated into the phase 2 process of DVI at VIFM. Body bags are scanned prior to placement in refrigerator storage, contents interrogated by radiologists and findings relayed to relevant specialists. If technical issues are encountered then the mortuary manager can be informed and steps taken to correct the issues including if necessary rescanning of the remains following manipulation by a pathologist. If remains are found to be incomplete then relevant police officers can be informed so that search teams (if necessary equipped with cadaver dogs) can revisit scenes of death for further inspection. The finding of animal parts on CT leads to early anthropological intervention and corroboration of findings so that bags can be removed from the full DVI process. Radiological findings are incorporated into phase 2 documentation and made available for pathologists at the time of autopsy so that they can concentrate their efforts on confirming CT findings and retrieval of specific identifying physical characteristics. CT triage also provides an indication of non-biological contents. In this particular incident many homes were destroyed by fire and biological remains found admixed with building materials. This included asbestos impregnated debris. Staff involved in the autopsy process was forewarned of the potential risk allowing precautions to be instituted prior to autopsy.

CT streamlines the autopsy process. Although in mass disaster, identification rather than cause of death is usually the pathologist's focus, CT scanning may be able to exclude obvious trauma other than the effects of the disaster, and detect more sinister causes of death such as bullet wounds. Autopsy examination can be limited to the clarification of CT findings and minor dissection for the purposes of determining cause and manner of death. Ideally pathologists and other DVI participants should have access to CT images in the mortuary, most practically using "thin client" software. Radiologists should be available to attend the mortuary in order to clarify radiological findings or assist in the localization of dental or metallic objects such as rings or other jewellery. This proved to be a very useful technique given that bodies were often severely blackened and physical features obscured on visual inspection. It is an extension to the previously reported X-ray security screening system used successfully to locate both dental fragments and other foreign objects commingled with fragmented remains [23].

CT images provide a "snapshot" of the body bag contents at the time of admission to VIFM prior to any intervention. This is invaluable for retrospective review. In 4 cases, severe insect (maggot) infestation was detected on CT and confirmed at autopsy. As has previously been reported, routine refrigerator storage of the deceased at 4 °C need not necessarily impede the viability of insect larvae or indeed development of putrefactive gas [24,25]. Given a delay of 24–48 h between admission and autopsy, considerable soft tissue simply "disappeared" by the time pathologists had access to the remains at autopsy due to the effects of insect predation. CT was able to provide information on those anatomical structures that were no longer present. The autopsy process itself is also partly destructive and CT provides a permanent record of the deceased's anatomy prior to autopsy, available for retrospective review at any time.

Review of CT images can provide clarification and matching with antemortem findings including radiographs [26–28] where necessary, without the need to revisit the storage area. Bodies are therefore autopsied once and in most cases require no further intervention even if information is made available subsequent to autopsy. CT images can be re-evaluated in a procedure that has been given the moniker of "digital exhumation". As part of the DVI process at VIFM, all phase 2 findings including pathological, dental, anthropological and radiological were reviewed by the supervising pathologist prior to a final report being provided to the police responsible for the phase 4 (reconciliation) process. It was invaluable at the time of that review to have CT images of the deceased available prior to any intervention, to be used if necessary in the adjudication of apparent conflict in results. Unfortunately this review process is not always successful. In one case for example, CT images were reviewed as there was medical evidence indicating that the deceased person had a surgical metacarpal fixation device. Unfortunately due to the presence of associated building materials in the body bag, the device could not be separated radiologically from commingled metallic objects including domestic nails and screws.

The overwhelming impact of CT scanning is improved efficiency in all phases of DVI by the concentration of effort at each stage of the process. Crime scene experts directed to sites of interest if bodies are found to be incomplete, body bags removed from the DVI process if found to contain animal remains, pathologists focused in their autopsy procedures and investigators able to clarify antemortem findings by review of CT images rather than revisiting the body bags.

Other workers have highlighted this value of CT scanning in a mass disaster scenario but have adopted a different approach, i.e. the construction of an imaging facility adjacent to the site of the disaster using mobile CT scanners [29]. The method clearly has merit but requires considerable planning and resources. In the state of Victoria, forensic expertise and equipment are concentrated in a single location with deceased persons transported to this secure facility for comprehensive workup. The sheer volume of admissions to VIFM as part of the DVI has, however, highlighted deficiencies in this approach and also in the installed CT hardware. The routine work of the Institute in medico-legal death investigation continued during the DVI operation. CT scanning is part of that routine process and proceeded in synchrony with DVI such that the ability to scan all deceased persons was constrained especially given the limitations of computer reconstruction times. The CT scanner employed has a gantry bore of 72 cm and the contorted posture of some deceased persons made scanning impossible or suboptimal due to artifact. Radiologists with little if any anthropological or odontological knowledge were responsible for CT image interrogation. This limited their ability to assign gender and age, especially where genitalia were absent.

The minimal requirement for those involved in postmortem CT interpretation in a DVI is experience in forensic medicine and a thorough understanding of cross-sectional imaging. The interpreter must also understand the issues that are important to forensic practice notably cause and manner of death, as well as the processes of DVI. The optimum scenario is a team of specialists including radiologist, pathologist, dentist and anatomist viewing CT images in concert at a workstation prior to autopsy. This would be most useful for severely disrupted remains where standard radiological techniques have been shown in this study to be less reliable especially in determination of age and gender. The technique of anthropological evaluation of "virtual" skeletons on CT has for example been shown to be very successful at determining age and gender [30]. The same individuals who have viewed images and prepared the imaging report should then be able to participate in the autopsies of those individuals, having access to scan data at each mortuary station. This would provide a consistent, comprehensive approach to the autopsy, streamlining even further the phase 2 process.

A dedicated CT scanner with a wider bore (so-called bariatric CT in clinical practice) should reduce artifact derived from the contorted positions of the deceased and faster computer reconstruction times currently available on newer scanners, would further improve the efficiency of scanning. Dedicated coned beam CT would also be of use in assessment of the dentition especially in adults where metallic artifact from materials such as amalgam is problematic [31]. MRI was considered as a possible imaging modality but not performed in this DVI exercise because of concern regarding multiple metallic fragments commingled with remains causing artifact and possible harm to scan operators as well as reduced image quality due to heat effects producing desiccation of the bodies [32]. In general the main value of postmortem MRI is interrogation of organs rather than victim identification [33].

5. Conclusion

CT scanning of the deceased has proven to be an invaluable technique in a mass DVI event. Despite visual examination demonstrating remains that were often severely disrupted and blackened by the ravages of fire, CT scanning provided excellent assessment of body anatomy and localization of foreign materials. Its main advantage is that it affords a prompt, general overview of the deceased that in many cases allows for rapid identification of gender, age, disease processes, medical devices, commingling and discrimination of animal remains; information that is vital to the Interpol phase 2 DVI process. It is a permanent representation of the body early on in the DVI procedure and can be referred to before the autopsy to better inform pathologists and allow them to plan the autopsy, at the time of autopsy to clarify issues of anatomy or localization of foreign bodies, and after the autopsy if further interrogation of the body is necessary or specific issues require clarification ("digital exhumation"). CT scanning allowed information on the status of the deceased person to be passed rapidly to the phase 1 DVI search teams at the scene of death. If the body was not intact on CT (not always possible to determine on visual inspection alone due to the effects of burning) then further inspection of the crime scenes was undertaken to try and find the missing body parts. The fact that no human remains related to the bushfires have been submitted to VIFM in the subsequent 12 months, suggests that all discoverable remains were indeed found.

The experience gained with CT scanning in this catastrophe has reinforced our belief that it is now an integral part of the DVI process assisting all participants in identification of the deceased. To be properly prepared for a major disaster we believe that CT scanning should be included in formal DVI protocols. Its application will increase substantially as radiologists, pathologists, odontologists and anthropologists become more aware of and confident with the use of CT workstations to interpret the vast amount of imaging information available. The radiologist with specialist forensic interest and experience can become a vital member of the DVI team especially in Interpol phases 1 and 2 but also at the time of reconciliation, i.e. phase 4.

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