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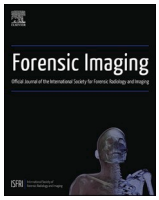

Forensic imaging in mass disasters: results of the use of post-mortem computed tomography in earthquake victims

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ABSTRACT

The use of Post-Mortem Computed Tomography (PMCT) has been proposed to investigate victims of mass fatalities. This study presents forensic investigations conducted on victims of a mass disaster.

In May 2012, an earthquake occurred in the province of Modena (Italy). On that occasion, 12 workers died and were found lifeless under the rubble of the industries in which they worked. All corpses were identified at the scene of the natural accident. The Prosecutor asked the forensic pathologist to perform only an external examination to identify the cause and manner of death. The forensic pathologist obtained permission to also perform PMCT to produce additional medico-legal evidence. The Prosecutor would request a judicial autopsy if the previous investigations had proved insufficient to define the cause and manner of death.

External examination revealed the presence of bone fractures, enabling localization of the injuries by anatomical region (skull, thorax, pelvis, upper extremities, lower extremities). PMCT was beneficial in identifying the exact nature and extent of skeletal injuries and direct (e.g., shattered organ) and indirect (e.g., hemoperitoneum without obvious organ laceration) evidence of organ injury. In two cases, PMCT findings were essential to perfecting the diagnosis of the cause of death.

Our experience supports the view that, in cases of major natural disasters, cause and manner of death may be determined with a reasonable degree of medical certainty thanks to circumstantial elements, external examination, and PMCT findings.

Introduction

Post-Mortem Computed Tomography (PMCT) has been increasingly used in mass fatality investigations as a complementary or alternative method to traditional autopsy. This forensic imaging technique can be used to identify foreign objects inside the body, to perform disaster victim identification (DVI), to define the cause of death, and to provide additional information for criminal investigations [1–4]. The computed tomography (CT) scanner can be mobile or stationary, so that it can be used at the scene of an accident, inside a mortuary or in a hospital [1–4].

Berran et al. examined victims of the earthquake that struck the Republic of Haiti on 12 January 2010 by performing PMCT [5]. They devised an algorithm that included PMCT results, digital X-rays and external examination in order to triage cases for non-invasive or complete autopsy: in 74 % of cases, internal autopsy proved unnecessary to define the cause and manner of death [5].

Therefore, the desirability of avoiding a full medico-legal autopsy should be considered, as the number of victims in mass fatalities disasters is unpredictable and exceeds the response capacity of the local Legal Medicine Institute [5,6].

Available literature on mortuary protocols in the aftermath of mass natural disasters remains limited. Indeed, the unique characteristics of each mass fatality make it difficult to define standards that enable to perform a shared assessment and to develop a single best practice [6].

The authors present here forensic investigations in the victims of a mass disaster through external examination followed by PMCT.

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Materials and methods

A cohort of 12 victims of the earthquake that struck the province of Modena (Italy) in May 2012 (10 males; age at death 24-65 years) was examined. All victims were employees of biomedical companies and were working at the time of the earthquake.

After the first tremor of magnitude 5.8, which occurred at 9 a.m. on 29 May 2012, work was interrupted and all industries were evacuated, so that all workers emerged unharmed. A few hours later, around 1 p.m. on 29 May 2012, 12 workers inspected the buildings to see if work could be resumed. Unfortunately, at that very moment, and more precisely at 12:55 p.m., a 5.5 magnitude tremor occurred, followed at 1 p.m. by a 5.0 magnitude tremor, which caused the buildings in which the victims were located to collapse. Following body recovery operations, the lifeless bodies of the 12 victims were found under the rubble of the industries that collapsed during the earthquake. Due to the urgent nature of the rescue operation, which prioritized the recovery of individuals who might still be alive, no detailed documentation was made regarding the exact positioning of the bodies or the composition of the rubble covering them. All bodies were identified by family members and colleagues on the scene.

The Prosecutor asked the forensic pathologist, who had 20 years of experience in forensic pathology, to perform only an external examination. The forensic pathologist asked the Prosecutor and obtained permission to also perform PMCT, so as to produce additional medico-legal evidence for the protection of the workers to better detail the fatal work injuries that occurred. The Prosecutor would request a judicial autopsy only if the previous investigations proved insufficient to define the cause and manner of death.

External examinations occurred in the Legal Medicine Institute of the University of Modena and Reggio Emilia, following the internal protocol.

Subsequently, the cadavers were transferred to the Radiology service of the University Hospital of Modena for PMCT scanning. The examinations were conducted using a 64-detector CT scanner (TC LightSpeed VCT 64; GE Healthcare, Milwaukee, WI, USA). First, two scans were acquired from head to toe, one in antero-posterior projection and one in latero-lateral projection. Then, an acquisition was made from the cranial vertex to the plantar plane, with layer thickness of 1.25 mm and interval of 1 mm, standard filter. A standard pitch of 1 was used, adjustable to 0.5 if necessary to improve reconstruction quality. The milliamp range 300-400 mA, with kilovoltage 120-140 kV was adopted. Bone filter reconstructions were performed using the acquired data. For each case, 3D surface reconstructions were performed using the Volume Rendering (VR) technique, and 2D images according to multiple planes were archived using the Picture Archiving and Communication System (PACS). Radiological images were reported by two radiologists with experience in the field of forensic radiology for 10 years.

Results

Our sample consisted of 12 victims of the earthquake that struck the province of Modena (Italy) in May 2012. The cohort included 10 blue-collar males and 2 secretary females, aged 24 to 65 years at the time of death, all of whom were received for external examination and PMCT at the Legal Medicine Service of the University of Modena and Reggio Emilia in May 2012. Results are reported in Table 1.

External examination revealed fractures to the skull in seven cases, to the thorax in nine cases, to the pelvis in six cases, to the right upper extremity in one case, to the left upper extremity in two cases, to the right lower extremity in one case, and to the left lower extremity in four cases. On external examination, fracture detection in our cohort was possible by: a] inspection, in cases where clear deformation of the anatomical profile or exposed fractures were observed; b] palpation, if this maneuver evoked abnormal yielding and preternatural mobility; c] percussion, to the neurocranial district. Multiple superficial injuries were observed in the body districts where fractures were described. In addition, an ecchymotic mask was documented in one case. External examination did not show findings suggestive of natural pathology in any case.

PMCT made it possible to confirm the presence of the fractures in the body districts identified on external examination, also allowing precise detailing of the affected bone segments [Fig. 1, Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9]. In two cases, PMCT also allowed documentation of a compound fracture of the *basicranium*, not suspected on external examination: in case 3, the fracture of the left sphenoid bone was found, while in case 11 the fracture of the right zygomatic arch was observed.

PMCT also made it possible to examine the internal organs, as reported in detail in Table 1.

In all cases, cause and manner of death were determined with a reasonable degree of medical certainty thanks to circumstantial elements, the external examination, and PMCT findings. Thus, according to the cause of death, five groups can be identified, classified as follows: cranio-encephalic injuries ($n = 2$); cranio-encephalic and thoraco-visceral injuries ($n = 1$); cranio-encephalic, thoraco-visceral and abdomino-pelvic injuries ($n = 4$); thoraco-visceral and abdomino-pelvic injuries ($n = 4$); mechanical asphyxia by chest compression ($n = 1$).

Discussion

A mass disaster is a crisis situation (e.g., a plane, ship, railroad, or highway accident, flood, earthquake) that exceeds a community's ability to recover, causing a number of casualties that requires a medico-legal investigation [7,8]. In the case of earthquakes, deaths generally occur as a result of building collapse [9]. The occurrence of an earthquake is typically an unforeseen event that can cause very serious damage to both people and property: Wyss et al. (2023) recently compiled a list of earthquake victims worldwide, covering the period from 856 B.C. to March 2022, estimating the total number of victims to be 8,336,526 [9].

In our cohort, consisting of 12 victims of the May 2012 Modena earthquake, external examination revealed the presence of bone fractures, enabling localization of the injuries by anatomical region (skull, thorax, pelvis, upper extremities, lower extremities). Fracture detection was possible by inspection, palpation or percussion, or a combination of these methods.

The external examination also found superficial traumatic injuries in all cases, observing in a single case (case 3) an 'ecchymotic mask' on the face. In addition, external examination did not show findings suggestive of natural pathology in any case.

PMCT took place after external examination. It is recognized that PMCT, after a detailed external examination and in cases where the crime scene investigation is accurate, can act as a triage between the external examination of the body and the decision to conduct an autopsy [10]. In our cases, PMCT confirmed the presence of skeletal fractures, better characterizing them. In two cases, PMCT also allowed documentation of a fracture that was not previously suspected because it was located in a site that was tough to examine on external examination (*basicranium*).

PMCT enabled the identification of internal organ injuries in all victims, complementing the findings of the external examination. In most cases (10 out of 12, approximately 83 %), external examination alone was sufficient to determine the cause of death. However, in two cases (Case 6 and Case 7), PMCT provided decisive evidence by revealing internal lesions that were not externally apparent, thus allowing a more accurate definition of the fatal injuries. Evidence of natural pathological conditions was found only in Case 2, where PMCT revealed bilateral diffuse pulmonary micronodules. However, in that case, the severity of the documented traumatic head injuries (skull crush with multiple displaced multifragmentary fractures involving the entire cranial theca, middle cranial fossa, sphenoid, and posterior cranial

Table 1
results. N.A. = not applicable (due to extensive body injury).

Nr.	Age [years], Sex and Occupational Activity	Body Mass Index [Kg/m^2]	Place of death	Principal external examination findings	Principal PMCT findings	Cause of death
1	44 y/o female secretary	34.3	Cavezzo, Modena (Italy)	to the head, lacerated wound in right parieto-temporal region, with exposure of the underlying bones, which appear fractured	to the head, right parieto-temporal fracture involving the sphenoid and posterior cranial fossa up to the occipital foramen; brain injury; compound fracture of the zygomatic arch and lateral wall of the right orbit	cranioencephalic injuries
2	33 y/o male blue-collar	23	Medolla, Modena (Italy)	to the head, marked deformation of the skull by crushing in the latero-lateral direction; multiple superficial lesions	- to the head, crushing of the skull with multiple multifragmentary dislocated fractures involving the entire cranial theca, middle cranial fossa, sphenoid, and posterior cranial fossa [Fig. 1]; brain injury - to the thorax, bilateral diffuse pulmonary micronodules	cranioencephalic injuries
3	36 y/o male blue-collar	20	Medolla, Modena (Italy)	- to the face, 'ecchymotic mask' - to the thorax, abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures; multiple superficial lesions	- to the head, compound fracture of the left sphenoid - to the thorax, fracture of the left clavicle; multiple bilateral rib fractures in the posterior region; multiple fractures of the dorsal vertebrae; fracture of the right scapula, bilateral pneumothorax, left lung contusion, left hemothorax - to the abdomen, spleen rupture, peri-splenic hematoma, pneumoperitoneum	mechanical asphyxia by chest compression
4	24 y/o male blue-collar	21.7	Medolla, Modena (Italy)	- to the thorax, abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures; multiple superficial lesions - to the pelvis, abnormal yielding and preternatural mobility on palpation, as for multiple fractures; multiple superficial lesions - sub-amputation of the left upper extremity; multiple superficial lesions	- to the neck, supraclavicular and right latero-cervical hematoma - to the thorax, multiple rib and dorsal vertebrae fractures [Fig. 2], bilateral hemothorax, bilateral pneumothorax - to the abdomen, perihepatic hematoma, right psoas hematoma - to the pelvis, right sacral wing fracture and left sacral wing fracture; right ischiopubic spine compound fracture and left ischiopubic spine compound fracture right pubic bone fracture - to the left upper extremity, compound fracture of humerus, radius and ulna	thoraco-visceral and abdominopelvic injuries
5	40 y/o male blue-collar	24.5	Medolla, Modena (Italy)	- to the thorax, abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures; multiple superficial lesions - extensive mangling of the pelvis; multiple superficial lesions - to the left upper extremity, preternatural mobility on palpation, as for humerus fracture; multiple superficial lesions	- to the thorax, multiple rib and vertebrae fractures [Fig. 3], bilateral pneumothorax - to the abdomen, pneumoperitoneum, right hepatic lobe contusion - to the pelvis, burst fracture involving all bones with multiple fragmentation, decomposition, and diastasis of bone fragments - to the left upper extremity, fracture of the humerus	thoraco-visceral and abdominopelvic injuries
6	45 y/o male blue-collar	26.8	San Felice sul Panaro, Modena (Italy)	to the head: at neurocranium, percussion suggestive for fractures; multiple superficial lesions; at splanchnocranium, abnormal yielding and preternatural mobility on palpation, as for multiple fractures; multiple superficial lesions	- to the head, multiple fractures of right frontal, parietal and temporal bone with partial dislocation of fragments; dislocated fracture of zygomatic bone, walls of maxillary sinus, and orbital cavity, malar bone, right sphenoidal bone; fracture of temporal bone and maxillary bone; brain injury - to the thorax, bilateral basal pulmonary contusion, left basal pneumothorax	cranioencephalic and thoraco-visceral injuries
7	29 y/o male blue-collar	N.A.	San Felice sul Panaro, Modena (Italy)	- to the head, cranial dislocation with avulsion of the encephalon; multiple superficial lesions - to the thorax, abnormal yielding and preternatural mobility on palpation, as in the case of thoracic breakthrough; multiple superficial lesions - to the left lower extremity, abnormal yielding and preternatural mobility on palpation, as for femur fracture; multiple superficial lesions	- to the head, cranial dislocation; avulsion of the encephalon - to the thorax, multiple rib and vertebral fractures, bilateral pneumothorax, right axillary hematoma - to the abdomen, peri-epatic and right hip hematoma, hemo-rachid - to the left lower extremity, femur fracture [Fig. 4]	cranioencephalic, thoraco-visceral and abdominopelvic injuries
8	56 y/o female secretary	20.5	Cavezzo, Modena (Italy)	- to the head: at neurocranium, percussion suggestive for fractures; multiple superficial lesions - to the thorax, abnormal yielding and preternatural mobility on palpation, as in	- to the head, dislocated fractures in the occipital region, in the left temporal region, and in the maxillary sinus; brain injury - to the neck, right latero-cervical hematoma - to the thorax, fracture of the sternum,	cranioencephalic, thoraco-visceral and abdominopelvic injuries

(*continued on next page*)

Table 1 (*continued*)

				the case of multiple fractures; multiple superficial lesions - to the pelvis, abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures; multiple superficial lesions	multiple rib fractures and dorsal vertebrae, bilateral pneumothorax - to the abdomen, diaphragm laceration, pneumo-peritoneum, hemo-rachid, abdominal wall laceration in right iliac fossa - to the pelvis, dislocated fractures of the sacrum, of the right acetabulum, and of the left iliopubic and ischiopubic branches [Fig. 5]	
9	61 y/o male blue-collar	24.9	San Felice sul Panaro, Modena (Italy)	- to the head: at neurocranium, percussion suggestive for fractures; multiple superficial lesions - to the thorax, abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures; multiple superficial lesions - to the pelvis, abnormal yielding and preternatural mobility on palpation, as for fractures; multiple superficial lesions	- to the head, multiple skull fractures [Fig. 6]; brain injury - to the thorax, multiple rib and dorsal vertebrae fractures, bilateral pneumothorax, bilateral hemothorax - to the abdomen, pneumoperitoneum, right parieto-colic hematoma - to the pelvis, diastasis of the pubic symphysis; compound fracture of the left acetabulum; compound fracture of the left ischiopubic branch	cranioencephalic, thoraco-visceral and abdominopelvic injuries
10	36 y/o male blue-collar	19.9	Mirandola, Modena (Italy)	- to the thorax, deformity of the anatomical profile as by flattening in the antero-posterior direction; abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures; multiple superficial lesions - to the pelvis, abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures; multiple superficial lesions - to the left lower extremity, preternatural mobility on palpation, as for fractures; multiple superficial lesions	- to the thorax, multiple rib and vertebrae fractures, bilateral pneumothorax, right hemothorax - to the pelvis, multiple fractures [Fig. 7] - to the left lower extremity, tibia fracture	thoraco-visceral and abdominopelvic injuries
11	65 y/o male blue-collar	27.7	Mirandola, Modena (Italy)	- to the thorax, marked deformity of the anatomical profile by flattening of the right thorax as by right thoracic breakthrough; multiple superficial lesions - to the pelvis, abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures - to the right upper extremity, preternatural mobility on palpation as for radius fracture; multiple superficial lesions - to the left lower extremity, preternatural mobility on palpation as for tibia fracture	- to the head, compound fracture of the right zygomatic arch -to the thorax, multiple ribs and dorsal vertebrae fractures [Fig. 8], bilateral pneumothorax - to the abdomen, lumbar soft tissue hematoma, hemo-rachid - to the pelvis, multiple fractures [Fig. 8] - to the right upper extremity, radius fracture - to the left lower extremity, fracture of tibia and fibula	thoraco-visceral and abdominopelvic injuries
12	39 y/o male blue-collar	N.A.	Mirandola, Modena (Italy)	- to the head: at neurocranium, percussion suggestive for fracture; avulsion of the encephalon; multiple superficial lesions; at splanchnocranium, abnormal yielding and preternatural mobility on palpation, as for multiple fractures; multiple superficial lesions - to the thorax, abnormal yielding and preternatural mobility on palpation, as in the case of multiple fractures; multiple superficial lesions - to the pelvis, abnormal yielding and preternatural mobility on palpation, as for fractures; multiple superficial lesions - to the right lower extremity, preternatural mobility on palpation as for fibula fracture; multiple superficial lesions - to the left lower extremity, preternatural mobility on palpation as for femur fractures; multiple superficial lesions	- to the head, crushing of the skull with multiple multifragmentary dislocated fractures involving the entire cranial theca [Fig. 9]; brain injury - to the thorax, multiple ribs and dorsal vertebrae fractures, bilateral pneumothorax, bilateral basal hemothorax - to the pelvis, multiple fractures, soft tissue laceration - to the right lower extremity, fibula and tibial malleolus fracture - to the left lower extremity, femur fracture	cranioencephalic, thoraco-visceral and abdominopelvic injuries

fossa) left no doubt as to a traumatic cause of death, excluding alternative natural causes. The results discussed so far confirmed also that, especially in trauma victims, PMCT is useful to identify injuries that are difficult to investigate on external examination and autopsy investigation [11–15].

Various systematic reviews have demonstrated that PMCT is particularly effective in detecting skeletal injuries, internal hemorrhages, organ lacerations, and gas embolism—findings that are central to determining the cause and mechanism of death in trauma cases [11,14]. Uthandi et al [12] concluded that PMCT provides a valuable diagnostic yield and can, in many cases, guide traditional autopsy, especially when cultural, religious, or logistical constraints limit invasive procedures. Additionally, Chatzaraki et al [10] emphasized PMCT's usefulness as a triage tool, helping to determine which cases require full autopsy. Ampanozi et al [13] further validated PMCT's diagnostic accuracy through a meta-analysis, confirming its strength in identifying traumatic pathologies with a high degree of reliability. Moreover, Kranioti et al [15] illustrated its application in complex forensic scenarios, such as

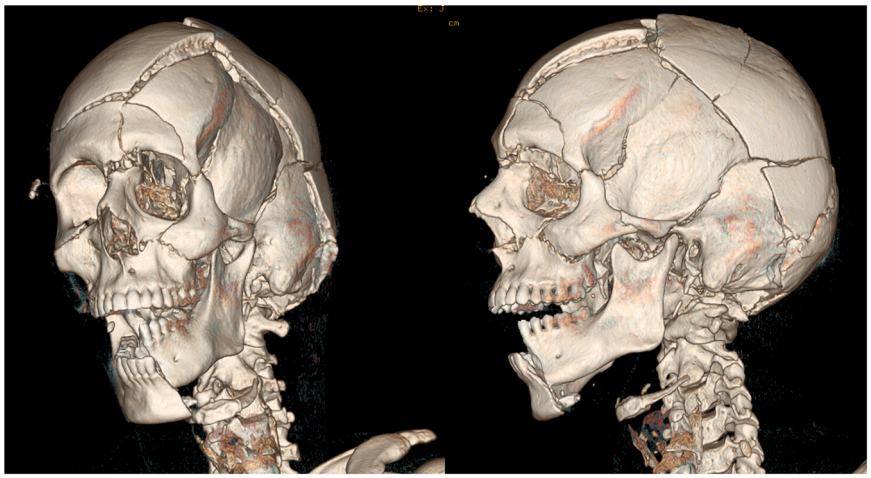

Fig. 1. case 2, PMCT – 3D surface reconstructions (volume rendering technique): to the skull, crushing of the skull with multiple multifragmentary dislocated fractures involving the entire cranial theca.

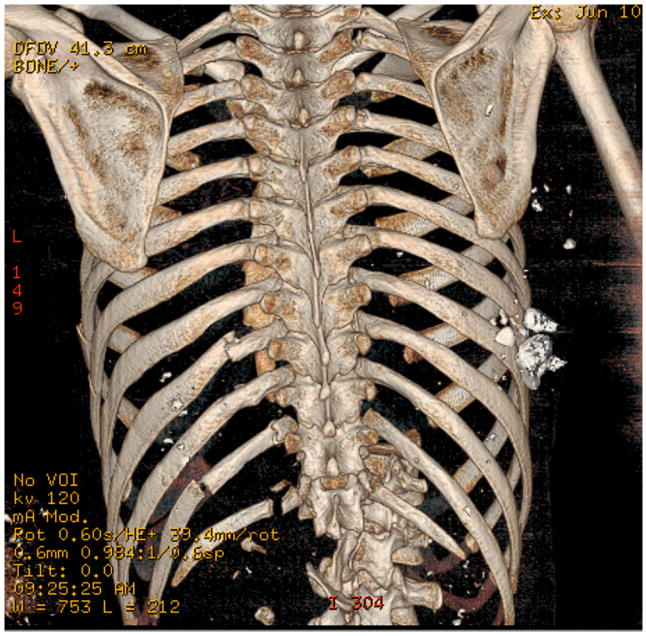

Fig. 2. case 4, PMCT – 3D surface reconstructions (volume rendering technique): to the thorax, multiple ribs and dorsal vertebrae fractures.

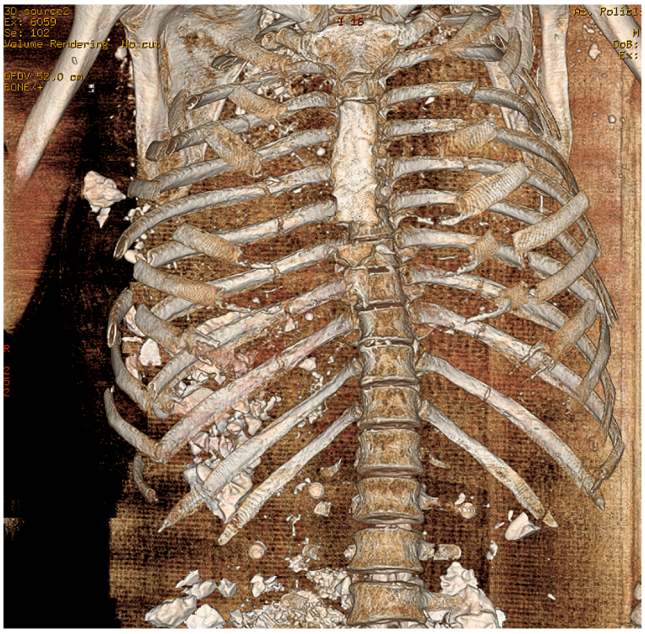

Fig. 3. case 5, PMCT – 3D surface reconstructions (volume rendering technique): to the thorax, multiple ribs and dorsal vertebrae fractures.

diagnosing fatal traumatic brain injuries in extensively burned remains. These findings highlight the growing relevance of PMCT in enhancing trauma assessments with greater precision and efficiency.

We determined cause and manner of death with a reasonable degree of medical certainty in all cases, confirming the usefulness of a non-invasive approach [5]. In eleven cases, the fractures, integumentary and internal organs injuries were of such severity and extent that the cause of death was attributed to fatal traumatic injuries to one or more body districts (cranio-encephalic, thoraco-visceral, abdomino-pelvic one). In one case (Case 3), traumatic injuries to the trunk were found at the posterior regions of the ribs, bilaterally, together with a fracture of the left clavicle and right scapula; this fracture pattern, in the absence of further fracture injuries (with the exception of the compound fracture of the left sphenoid) and in the presence of an 'ecchymotic mask' to the face, allowed the cause of death to be qualified as mechanical asphyxia by chest compression.

In the majority of cases (10 out of 12, approximately 83 %), external examination alone provided sufficient information to establish the cause of death. However, in two cases (Case 6 and Case 7), PMCT findings were essential in refining and confirming the diagnosis of the cause of death. In these instances, PMCT revealed injury patterns that were either not externally visible or not fully characterizable through external examination alone, thereby contributing significantly to the diagnostic process.

PMCT was beneficial in identifying the exact nature and extent of skeletal injuries and - within the limitations of non-contrast enhanced study [16–23,33] - direct (e.g., shattered organ) and indirect (e.g., hemoperitoneum without obvious organ laceration) evidence of organ injury.

In addition to its diagnostic utility, PMCT offered a valuable medico-legal advantage through the generation of three-dimensional surface reconstructions using the Volume Rendering (VR) technique [Fig. 1, Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9].. These 3D reconstructions can be particularly impactful in court proceedings, as they allow for intuitive and accessible visualization of injury patterns - even by individuals without specialized forensic training. In this way, PMCT

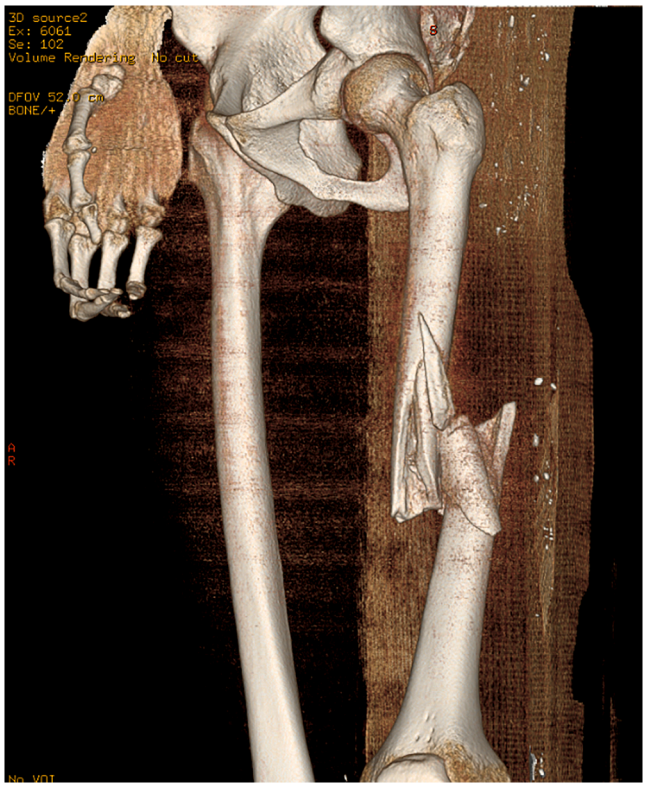

Fig. 4. case 7, PMCT – 3D surface reconstructions (volume rendering technique): to the left lower extremity, femur fracture.

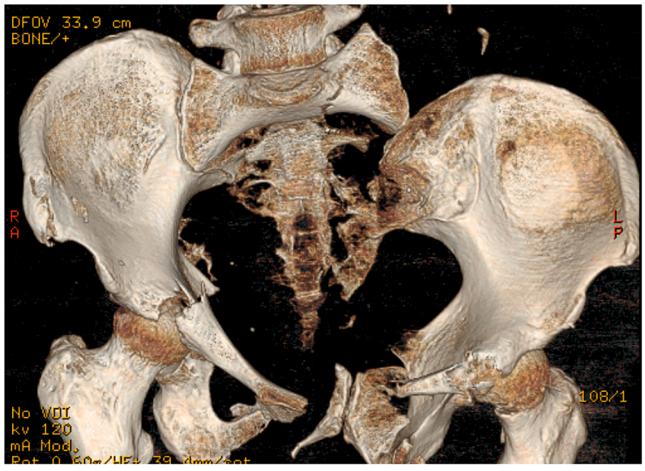

Fig. 5. case 8, PMCT – 3D surface reconstructions (volume rendering technique): to the pelvis, dislocated fractures of the sacrum, of the right acetabulum, and of the left iliopubic and ischiopubic branches.

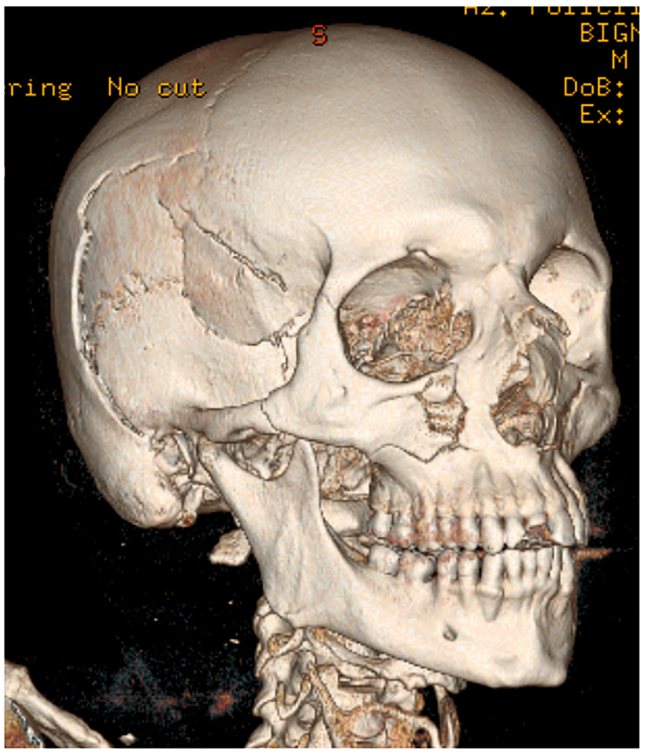

Fig. 6. case 9, PMCT – 3D surface reconstructions (volume rendering technique): to the skull, multiple skull fractures.

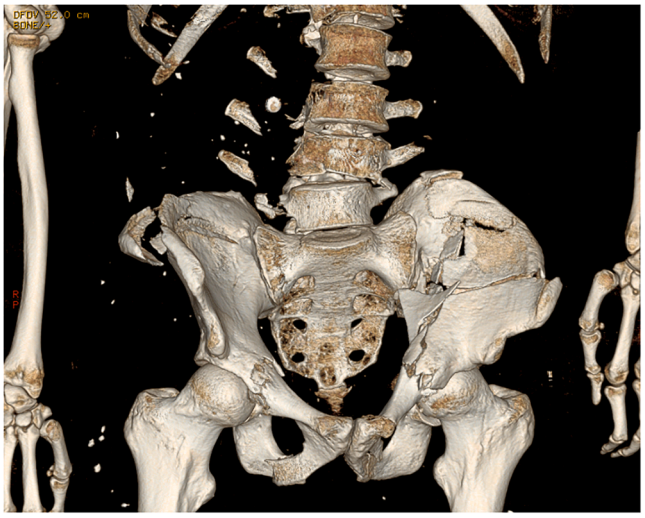

Fig. 7. case 10, PMCT – 3D surface reconstructions (volume rendering technique): to the pelvis, multiple fractures.

contributes not only to the accuracy of post-mortem analysis but also to the clear and effective communication of findings in judicial settings. This is especially significant in the context of mass disasters, where time/resources may limit the feasibility of full autopsies. In our cohort, PMCT also served this important purpose, acting as an additional tool for the rights of deceased workers by providing a non-invasive yet highly informative means of documenting fatal occupational injuries. The use of postmortem imaging in mass disasters has been reported and discussed in scientific literature in recent years [24–32]. However, it is difficult to identify a medico-legal operational protocol applicable to any mass disaster, since these are events with unique and unrepeatable characteristics, so the purposes of medico-legal investigation may differ (e.g., in cases where DVI is not necessary, as in the study presented here).

Conclusions

The present study reports the experience gained by the Institute of Forensic Medicine at the University of Modena and Reggio Emilia in 2012.

While external examination alone would have been sufficient to determine cause and manner of death in 83 % cases, PMCT allowed better characterization of the nature and extent of injuries, revealing organ injuries and additional fatal skeletal injuries in all cases.

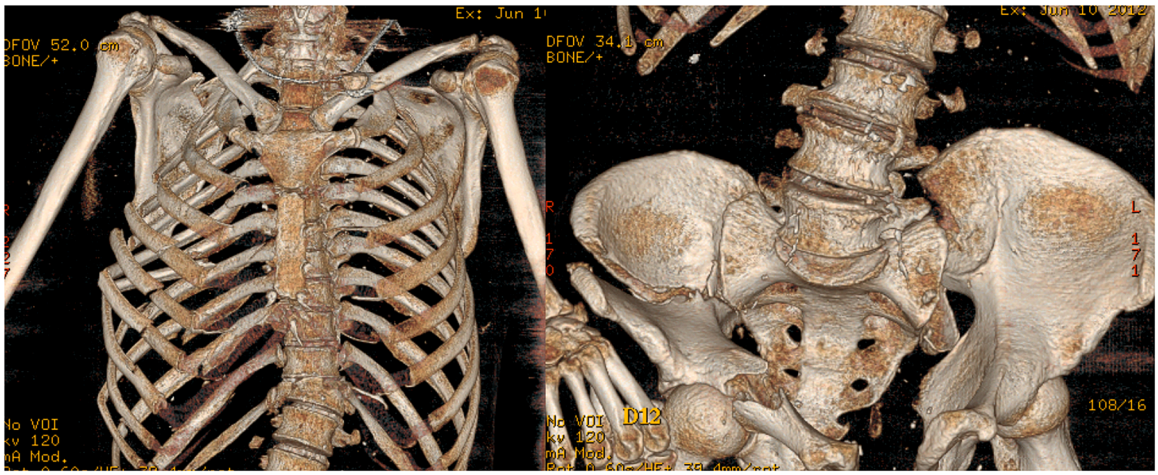

Fig. 8. case 4, PMCT – 3D surface reconstructions (volume rendering technique): on the left, thorax (multiple ribs and dorsal vertebrae fractures); on the right, pelvis (multiple fractures).

Fig. 9. case 12, PMCT – 3D surface reconstructions (volume rendering technique): to the skull, crushing of the skull with multiple multifragmentary dislocated fractures involving the entire cranial theca.

Our experience supports the view that, in cases of major natural disasters, cause and manner of death may be determined with a reasonable degree of medical certainty thanks to circumstantial elements, external examination, and PMCT findings.

CRediT authorship contribution statement

Anna Laura Santunione: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jessika Camatti:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Filippo Baldoni:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration. **Enrico Silingardi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Pietro Torricelli:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rossana Cecchi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] P. Hofman, A. Alminyah, M. Apostol, L.W.T. Boel, A. Brough, H. Bouwer, C. O'Donnell, H. Fujimoto, M. Iino, J. Kroll, C.T. Lee, D.S. Levey, Y. Makino, L. Oesterhelweg, B. Ong, D. Ranson, C. Robinson, G. Rutty, M.K.C. Singh, C. Villa, M. Viner, N. Woodford, T. Watkins, K. Wozniak, Use of post-mortem computed tomography in disaster victim identification. Updated positional statement of the members of the disaster victim identification working group of the international society of forensic radiology and imaging; July 2019, J. Forens. Radiol. Imag. (2019) 100346.

[2] A.L. Brough, B. Morgan, G.N. Rutty, Postmortem computed tomography (PMCT) and disaster victim identification, Radiol. Med. 120 (9) (2015 Sep) 866–873, https://doi.org/10.1007/s11547-015-0556-7.

[3] G.N. Rutty, M.J.P. Biggs, A. Brough, B. Morgan, P. Webster, A. Heathcote, J. Dolan, C. Robinson, Remote post-mortem radiology reporting in disaster victim identification: experience gained in the 2017 Grenfell Tower disaster, Int. J. Leg. Med. 134 (2) (2020 Mar) 637–643, https://doi.org/10.1007/s00414-019-02109-x.

[4] L. Filograna, G. Manenti, A. Micillo, F. Chirico, A. Carini, P.E. Gigliotti, R. Floris, A. Malizia, A. Oliva, Post-mortem imaging: a tool to improve post-mortem analysis and case management during terrorist attacks, Foren. Imag. 34 (2023) 200551, https://doi.org/10.1016/j.fri.2023.200551.

[5] P.J. Berran, E.L. Mazuchowski, A. Marzouk, H.T. Harcke, Observational case series: an algorithm incorporating multidetector computed tomography in the

medicolegal investigation of human remains after a natural disaster, J. Foren. Sci. 59 (4) (2014 Jul) 1121–1125, https://doi.org/10.1111/1556-4029.12422.
[6] M. Anderson, J. Leditschke, R. Bassed, S.M. Cordner, O.H. Drummer, Mortuary operations following mass fatality natural disasters: a review, Foren. Sci. Med. Pathol. 13 (1) (2017 Mar) 67–77, https://doi.org/10.1007/s12024-016-9836-3.
[7] R. Cecchi, E. Bottoni, S. Cappelletti, P.A. Fiore, M. Straccamore, G. Bolino, E. Marinelli, N.M. di Luca, F.S. Romolo, C. Ciallella, Mass disasters observed at the Sapienza University of Rome: a retrospective study between 1964 and, Rom. J. Leg. Med. (2005), 24]168-176 [2016].
[8] C. Cattaneo, D. De Angelis, M. Grandi, Mass disasters, in: A. Schmitt, E. Cunha, J. Pinheiro (Eds.), Forensic Anthropology and Medicine, Humana Press, 2006, https://doi.org/10.1007/978-1-59745-099-7_18.
[9] M. Wyss, M. Speiser, S. Tolis, Earthquake fatalities and potency, Nat Hazards. 119, 1091–1106 (2023). https://doi.org/10.1007/s11069-022-05627-x.
[10] V. Chatzaraki, J. Heimer, M. Thali, A. Dally, W. Schweitzer, Role of PMCT as a triage tool between external inspection and full autopsy – case series and review, J. Foren. Radiol. Imag. 15 (2018) 26–38, https://doi.org/10.1016/j.jofri.2018.10.002.
[11] M. Scholing, T.P. Saltzherr, P.H. Fung Kon Jin, K.J. Ponsen, J.B. Reitsma, J. S. Lameris, J.C. Goslings, The value of postmortem computed tomography as an alternative for autopsy in trauma victims: a systematic review, Eur. Radiol. 19 (10) (2009 Oct) 2333–2341, https://doi.org/10.1007/s00330-009-1440-4.
[12] D. Uthandi, A. Sabarudin, Z. Mohd, M.A.A. Rahman, M.K.A. Karim, Effectiveness of post-mortem computed tomography (PMCT) in comparison with conventional autopsy: a systematic review, Curr. Med. ImAging 16 (6) (2020) 669–676, https://doi.org/10.2174/1573405615666190821115426.
[13] G. Ampanozi, D. Halbheer, L.C. Ebert, M.J. Thali, U. Held, Postmortem imaging findings and cause of death determination compared with autopsy: a systematic review of diagnostic test accuracy and meta-analysis, Int. J. Leg. Med. 134 (1) (2020 Jan) 321–337, https://doi.org/10.1007/s00414-019-02140-y.
[14] H. Jalalzadeh, G.F. Giannakopoulos, F.H. Berger, J. Fronczek, F.R.W. van de Goot, U.J. Reijnders, W.P. Zuidema, Post-mortem imaging compared with autopsy in trauma victims–a systematic review, Foren. Sci. Int. 257 (2015 Dec) 29–48, https://doi.org/10.1016/j.forsciint.2015.07.026.
[15] E.F. Kranioti, D. Nathena, K. Spanakis, A. Karantanas, R. Bouhaidar, S. McLaughlin, M.J. Thali, G. Ampanozi, Unenhanced PMCT in the diagnosis of fatal traumatic brain injury in a charred body, J. Forensic Leg. Med. 77 (2021 Jan) 102093, https://doi.org/10.1016/j.jflm.2020.102093.
[16] F. Dedouit, M. Ducloyer, J. Elifritz, N.L. Adolphi, G.W. Yi-Li, S. Decker, J. Ford, Y. Kolev, M. M. Thali, The current state of forensic imaging - post mortem imaging, Int. J. Leg. Med. 139 (3) (2025 May) 1141–1159, https://doi.org/10.1007/s00414-025-03461-x.
[17] F. Dedouit, M. Ducloyer, J. Elifritz, N.L. Adolphi, G.W. Yi-Li, S. Decker, J. Ford, Y. Kolev, M. M. Thali, The current state of forensic imaging- clinical forensic imaging, Int. J. Leg. Med. (2025 Mar 18), https://doi.org/10.1007/s00414-025-03464-8.
[18] F. Dedouit, M. Ducloyer, J. Elifritz, N.L. Adolphi, G.W. Yi-Li, S. Decker, J. Ford, Y. Kolev, M. M. Thali, The current state of forensic imaging – perspectives, Int. J. Leg. Med. (2025 Mar 21), https://doi.org/10.1007/s00414-025-03466-6.
[19] F. Dedouit, M. Ducloyer, J. Elifritz, N.L. Adolphi, G.W. Yi-Li, S. Decker, J. Ford, Y. Kolev, M. Thali, The current state of forensic imaging - recommended radiological tools and international guidelines, Int. J. Leg. Med. (2025 Mar 25), https://doi.org/10.1007/s00414-025-03465-7.
[20] C. Jessika, S. Anna Laura, D. Stefano, G.B. Giuliano, B. Marco, B. Riccardo, R. Riccardo, S. Enrico, Diagnosing coronary thrombosis using multiphase post-mortem CT angiography (MPMCTA): a case study, Med. Sci. Law 61 (2021 Jan) 77–81, https://doi.org/10.1177/0025802420923175, 1_supplPMID: 33591864.
[21] J. Camatti, A.L. Santunione, S. Draisci, A. Drago, M.G. Amorico, G. Ligabue, E. Silingardi, P. Torricelli, R. Cecchi, Correlation between epicardial fat volume and postmortem radiological and autopsy findings in cases of sudden death: a pilot study, Forens. Imag. 40 (2025) 200620, https://doi.org/10.1016/j.fri.2024.200620.
[22] J. Camatti, A.L. Santunione, S. Draisci, A. Drago, M.G. Amorico, G. Ligabue, E. Silingardi, P. Torricelli, R. Cecchi, Predictive value of coronary artery calcium score on radiological and autoptic findings in cases of sudden death, Forensic imaging, Volume 39, 2024, 200610, ISSN 2666-2256, https://doi.org/10.1016/j.fri.2024.200610.
[23] A.L. Santunione, J. Camatti, G. Battinelli, L. Alemanno, G. Pizzuti, P. Torricelli, R. Cecchi, Application of multiphase post-mortem computed tomography angiography (MPMCTA) in a case of hemoptysis due to bronchopulmonary arterial fistula, Forensic Imaging. In press, 2025.
[24] L.W. de Jong, L. Legrand, T. Delabarde, G. Hmeydia, M. Edjlali, L. Hamza, J. Benzakoun, C. Oppenheim, B. Ludes, J.F. Meder, Experience with postmortem computed tomography in the forensic analysis of the November 2015 Paris attacks, Forensic Sci. Res. 5 (3) (2020 Nov 2) 242–247, https://doi.org/10.1080/20961790.2020.1802686.
[25] A. Oliva, S. Grassi, V.M. Grassi, V. Pinchi, R. Floris, G. Manenti, C. Colosimo, L. Filograna, V.L. Pascali, Postmortem CT and autopsy findings in nine victims of terrorist attack, Int. J. Leg. Med. 135 (2) (2021 Mar) 605–618, https://doi.org/10.1007/s00414-020-02492-w.
[26] C. Mondello, G. Baldino, A. Bottari, D. Sapienza, F. Perri, A. Argo, A. Asmundo, E. Ventura Spagnolo, The role of PMCT for the assessment of the cause of death in natural disaster (landslide and flood): a Sicilian experience, Int. J. Leg. Med. 136 (1) (2022 Jan) 237–244, https://doi.org/10.1007/s00414-021-02683-z.
[27] S.M. Cordner, N. Woodford, R. Bassed, Forensic aspects of the 2009 Victorian bushfires disaster, Forensic Sci. Int. 205 (2011) 2–7.
[28] C. O'Donnell, M. Iino, K. Mansharan K, J. Leditscke, N. Woodford, Contribution of postmortem multidetector CT scanning to identification of the deceased in a mass disaster: experience gained from the 2009 Victorian bushfires, Forensic Sci. Int. 205 (2011) 15–28.
[29] L.S. Khoo, A.H. Hasmi, S.A. Abdul Ghani Aziz, M.A. Ibrahim, M.S. Mahmood, MH17: the Malaysian experience, Malays. J. Pathol. 38 (2016) 1–10.
[30] M. Sidler, C. Jackowski, R. Dirnhofer, P. Vock, M. Thali, Use of multislice computed tomography in disaster victim identification—advantages and limitations, Forensic Sci. Int. 169 (2007) 2–3.
[31] A. Argo, S. Serraino, F. Midiri, G. Lo Re, S. Zerbo, A. Iovane, R. Lagalla, Postmortem imaging in mass disasters, in: G. Lo Re, A. Argo, M. Midiri, C. Cattaneo (Eds.) Radiology in Forensic Medicine, Springer, Cham. https://doi.org/10.1007/978-3-319-96737-0_22.
[32] A. Borowska-Solonynko, A. Dąbkowska, A. Moskała, G. Teresiński, K. Woźniak, Radiological examination of mass disaster victims – position statement of the forensic imaging examinations commission at the polish society of forensic medicine and criminology, Arch. Med. Sądowej Kryminol./Arch. Forensic Med. Criminol. (2018) 201–207, https://doi.org/10.5114/amsik.2018.83098.
[33] J. Camatti, B.G. Gangi, M.P. Bonasoni, G. Battinelli, L. Alemmano, G. Pizzuti, P. Torricelli, E. Silingardi, R. Cecchi, A.L. Santunione, Histological artifacts induced by the contrast agent in Multi-Phase Post-Mortem CT Angiography (MPMCTA), Part I - Normal Tissues, Forensic Sci. Med. Pathol. 15 (2025 Nov) doi, https://doi.org/10.1007/s12024-025-01117-1.